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# Influence of foveal load on the functional visual field

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The functional visual field defined in terms of a discrimination task of a target presented peripherally among ambiguous background patterns was investigated for various foveal loads which were to be recognized at the central retina. Foveal loads were numbers, letters, place names, traffic signs, and other figures to simulate commonplace situations for foveal information processing, and grouped into three in order of recognition difficulty based on daily experience. Boundaries of the functional visual field were obtained for simple fixation and for certain foveal loads. Comparison of these boundaries clearly showed shrinkage of the functional visual field size with the foveal loads of greater recognition difficulty.

By way of background rationale, one should expect the central retina, particularly the fovea, to play the most important role in visual information processing, since it mediates the best visual acuity achievable throughout the retina (Jones & Higgins, 1947; Mandelbaum & Sloan, 1947). Eye movements, in turn, help the visual system by orienting the fovea to the center of the visual task (Yarbus, 1967). While this is true, we also depend heavily upon peripheral vision for target detection, pattern recognition, and so on, so that the importance of investigating its characteristics should not be overlooked. Salient characteristics of the latter are acuity (see references cited above) and detection threshold (Sloan, 1949; Stiles & Crawford, 1937). However, these data state only the lower limit of peripheral response capability, because in these experiments subjects merely fixated centrally while attempting to detect peripheral stimuli. This kind of situation rarely occurs in daily life, since the central retina is never unstimulated. The influence of the central task upon peripheral vision is, therefore, a basic issue, for which different investigations have reported conflicting experimental results.

Leibowitz and his coworkers (Abernethy & Leibowitz, 1971; Leibowitz & Appelle, 1969) observed elevated peripheral thresholds for subjects while performing a central task of following an extinguishing fixation point. Gasson and Peters (1965) reported shrinkage of the peripheral visual field for light detection while concentrating upon a velocity control test at the fovea. A similar decrease in peripheral perception was found by Webster and Haslerud (1964) during a task of counting fixation points presented foveally at various occurrence rates. These experiments are even harder to integrate because of other factors which were not common to all studies, such as giving the subjects incentives (Bahrick, Fitts, & Rankin, 1952), and introducing various physical stressors, such as heat and/or humidity (Bursill, 1958; Leibowitz et al., 1972), underwater pressure (Weltman & Egstrom, 1971), and alcohol (Moskowitz & Sharma, 1974). In all cases, peripheral visual responding decreased (see also a review work by Easterbrook, 1959). The term functional visual field (Sanders, 1970) is apropos here, implying that peripheral performance depends not only on retinal sensitivity but also on the nature of the perceptual task.

It is important to mention that all of the above studies employed a rather simple peripheral stimulus, namely a mere spot of light. In commonplace viewing, however, we rarely encounter such simple detection situations, but rather are required to discriminate targets from noise-constituting backgrounds encompassing a wide range of the visual field.

The functional visual field, then, should be studied using a discrimination task. Such fields, however, vary greatly with respect to shape difference between target and background noise, density of background noise, etc. Indeed, many authors have emphasized the influence of such factors on the functional visual field in their investigations. For example, Mackworth (1965) compared detectability of a certain letter presented peripherally when it was given alone or juxtaposed by other letters. The detection was much harder in the latter condition, implying the reduction of the functional visual field was due to the noise-constituting background. A similar result was obtained by Bouma (1970). Chaikin, Corbin, and Volkman (1962) presented 80 circles and 1 triangle arranged in a 9 by 9 matrix, and determined the outer limit of the functional visual field for discriminating the triangle. The influence of shape difference between target and background noise on the functional visual field limits was investigated extensively by Engel (1971, 1974). Targets were presented along numerous meridians so that the peripheral field boundary could be obtained. He showed that the field became extremely small with decrease in shape difference.

None of the above tasks, however, involved foveal tasks beyond mere fixation. Therefore, although they simulated a more realistic situation with regard to target discrimination at the periphery, they did not do so for the central task situation. In terms of Woodworth and Schlosberg (1954), they were more concerned with external determiners than with internal determiners.

The aim of the present experiment was to combine those two features in an investigation of peripheral visual performance, using a target presented against background noise along several meridians from the fovea, such that the functional visual field boundary was obtained. At the same time, a central visual task was presented at the fovea (hereinafter called the foveal load), to determine its influence on peripheral response. This task is considered to be a useful analogue of common central-peripheral viewing situations.

## METHOD

### Apparatus and Procedure

The apparatus was a modified three-channel tachistoscope (see Figure 1). The subject viewed a rear screen monocularly at a distance of 50 cm. A chin rest and a forehead supporter were used. A dim square fixation frame (each side = 2° visual angle) appeared at the center of the screen, which was provided by a fixation light source, FS, via a half-mirror, HM. The target to be detected was projected onto the rear screen with a slide projector, P1, through density filters, F, and a beam splitter, BS. The slides could be shifted vertically and horizontally, and could be rotated by the experimenter to deliver targets at any desired position on the screen. The background field was provided with a second slide projector, P2, through density filters and a beam splitter which combined the P1 and P2 images. The slide positions of P2 were also adjustable, as in P1. The experimenter could observe the stimulus pattern on a monitor screen, R, while recording the subject's responses during an experimental session.

A third projector, P3, provided the foveal load inside the fixation frame. The slide holder of P3 could be moved horizontally and vertically, allowing the experimenter to choose desired foveal loads, all of which were printed on slides.

Photographic shutters, SH, mounted in front of each projector, provided an exposure duration of 250 msec to minimize saccadic eye movements during stimulation. The subject, when ready, pressed a button to operate the three shutters simultaneously.

The target was a bright star (see Figure 2, left) subtending about 1° of visual angle on the rear screen at a luminance of 1.8 cd/m².

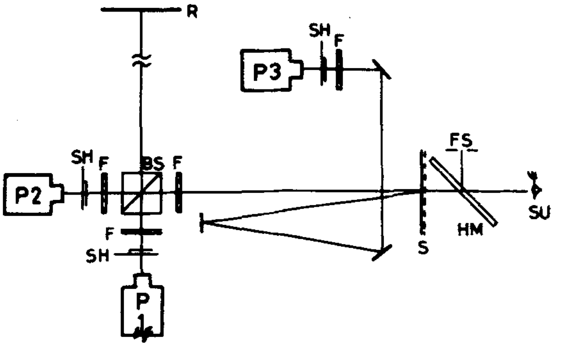


**Figure 1. Schematic diagram of the apparatus.**

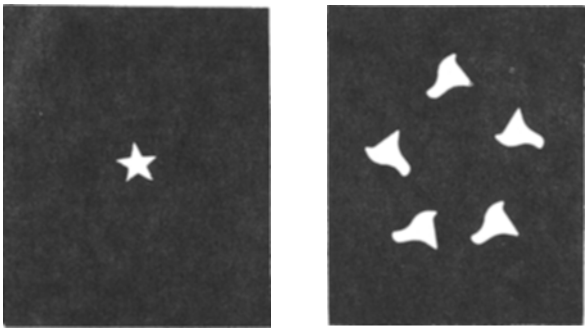

**Figure 2. Example of target (left) and background patterns (right).**


**Figure 3. Some examples of foveal loads. Left, L(1); center, L(2); right, L(3).**

The background patterns (see Figure 2, right) were distorted triangles of the same shape, following Attneave (1957), subtending about 1° of visual angle at a luminance of 1.8 cd/m². Their positions of occurrence were randomly distributed throughout a circular field subtending 30° of visual angle with a luminance of 0.01 cd/m². The density of the patterns was 0.08 units/deg², which comprised a total of about 60 patterns. Shapes of targets and background patterns and their density were determined by trial and error, such that the outer limit of the functional visual field did not exceed the display field of 30° diam. Preliminary testing indicated that a rectangular target was too easy to detect and that the outer field limit was not obtainable with the apparatus. On the other hand, an equilateral triangle was too difficult to discriminate and represented too small a functional visual field. A square target was also very difficult to detect.

Four kinds of foveal loads were used, and are denoted as L(i), where i = 0, 1, 2, or 3. Load L(0) had no figure at all, and thus corresponded to Chaikin et al. (1962) and Engel (1971). Examples of L(1), L(2), and L(3) are shown in Figure 3. They were grouped in order of recognition difficulty based on daily experience. L(1) is a simple load composed of two English lowercase letters randomly arranged (Figure 3, left). Being Japanese, the subjects had no basis to attach specific meanings to any alphabet pairs they recognized. L(2) stimuli were groups of three lowercase letters, three numbers, single handwritten Japanese characters, or simple traffic signals (Figure 3, center). L(3) loads (Figure 3, right) were combinations of three lowercase letters and numbers, two uppercase letters, and three numbers arranged in two lines, two Japanese characters representing place names such as Tokyo, or complicated nonsense figures, all handwritten.

Foveal loads all subtended less than 2° of visual angle so as to be enclosable entirely within the fixation frame, and had a luminance of about 2.2 cd/m².

The subject first fixated the center of the fixation frame and, when ready, pressed the shutter button, producing the display (such as in Figure 4). He then reported what was in the fixation frame, and the location of target, using 16 preordained descriptors, such as


**Figure 4. A segment of the visual display. Foveal load is L(1). Target is seen at the upper left.**

"up," "up and a little right," "upper right," "right and a little up," "right," and so on. Distance of the target from the center was not specified. For the example in Figure 4, a correct response would be "pq and upper left." Failure to report either one was counted as an incorrect response. The subjects were trained to report the foveal load first so as to be able to concentrate on the central task. This resulted in virtually no response when the subject reported only about the target without reporting about the foveal load. The subject was not informed about the scoring method and received no feedback to correct errors.

By presenting the target at various positions in the display field, the outer limit or edge of the functional visual field could be determined for a certain condition of the foveal load. The target's positions were presented in random succession, and the location of background patterns was varied for every target.

Two fields were measured within each session, one for L(0) and the other for a selected L(i), the presentations being randomized, to avoid sequence effects due to sessions. The subject was told before each L(0) exposure that there would be no foveal load, and before L(1)s to expect two English lowercase letters to avoid his sudden recognition of the load composition in the middle of an experimental session. For other conditions, he was informed only that there would be some foveal load. No foveal load was used more than once for the same subject.

**Subjects**

Eight students, all undergraduates or graduates, except one, whose age was a little over 40 (M.I.), were employed as subjects, and were divided into untrained and trained groups. The former had no previous experience with this experiment, whereas the latter had served in and knew the aim of the experiment. All subjects had visual acuity of better than 1.0, except subject N.S., who had 0.7.

Saccadic eye movements were checked during trials by means of an EOG. Only data without such movements were retained.

## RESULTS

An example of the data format obtained is given in Figure 5, for trained subject K.S. in the L(0) condition. The fixation frame is shown by a square at the center; circles represent correct responses and crosses incorrect responses. There are three possible incorrect responses by our definition; foveal load was not detected, or target was not detected, or neither one was detected. Since the first response was practically never given as stated above, the incorrect responses shown by crosses are for the latter two responses, although they were not differentiated in data collection.

Numbers and positions of the target presentation were determined by the experimenter in the course of the experiment in order to obtain a clear boundary contour of the functional visual field. That is, if a correct response was given at a certain position, another stimulus was presented towards a more peripheral direction at some time later, the opposite being the case for an incorrect response. Thus, positions of transition from correct to incorrect responses were determined for all directions. The number of target presentations therefore varied according to the size and the shape of the functional visual field.

These transitions are shown in Figure 5 by the dotted line drawn between circles and crosses. Transition from circles to crosses is quite abrupt, and there appears to be no appreciable mixing-up of those opposite responses; therefore, we consider this line to define the outer limit of the functional visual field. Visual fields were obtained in this manner for all subjects.

Characteristics of the functional visual fields for L(0) are summarized in Table 1, in which H and V denote maximum horizontal and vertical widths of the field in units of arc visual angle. $r_{HV}$ is a ratio of H to V. H and V values may be divided into two parts, respectively, namely the left and right sides relative to the fixation point, and the upper and lower sides. Ratios $r_{LR}$ and $r_{UD}$ were calculated from those

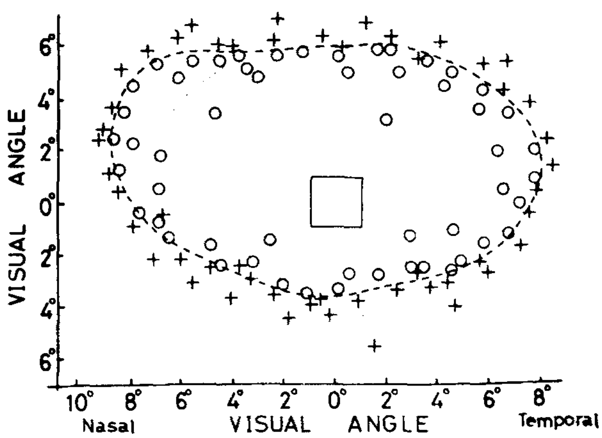


**Figure 5. An outer limit of the functional visual field obtained for the condition L(0). A square at (0°, 0°) indicates the fixation frame. Circles represent correct responses, and crosses represent incorrect responses. A dotted line was drawn between crosses and circles by visual inspection. Subject: K.S.**

**Table 1**
**Summary of the Functional Visual Fields for the L(0) Condition**

| Subjects | | H(deg) | V(deg) | $r_{HV}$ | $r_{LR}$ | $r_{UD}$ |
|---|---|---|---|---|---|---|
| | M.I. | 18.1 | 11.4 | 1.59 | 1.47 | 1.28 |
| Tr | H.I. | 23.5 | 18.9 | 1.24 | 1.08 | .90 |
| | K.S. | 15.7 | 9.6 | 1.63 | 1.13 | 1.22 |
| | N.T. | 17.4 | 12.9 | 1.35 | 1.19 | .88 |
| | H.S. | 18.4 | 14.5 | 1.27 | 1.13 | 1.06 |
| Untr | N.S. | 8.6 | 6.7 | 1.29 | 1.27 | 1.09 |
| | T.W. | 19.1 | 15.8 | 1.21 | 1.39 | .97 |
| | M.H. | 22.6 | 16.1 | 1.40 | .95 | .95 |
| Mean | | 17.9 | 13.2 | 1.37 | 1.20 | 1.02 |

values. When a subject provided more than one visual field, mean values were obtained.

In Table 1, it can be seen that both H and V differ widely among subjects. In fact, having a wide functional visual field is not necessarily attributable only to trained subjects (untrained subject M.H. had a larger visual field than K.S., who had extensive practice). Since the present experimental method did not produce the same level of performance or a common internal criterion in all subjects, a wider functional visual field cannot be construed to be superior peripheral target discrimination.

The mean values of H and $\bar{V}$ are about 18° and 13°, respectively, indicating an elliptical shape of the functional visual field with a longer axis in the horizontal direction. These characteristics are clearly shown by $r_{HV}$ values, which are all greater than unity.

The mean value of $r_{LR}$ is 1.20, suggesting that the functional visual field is a little extended toward the left. However, the generality of this conclusion is not certain, since some subjects showed smaller values than unity. Although such left-right differences are interesting, the present data cannot support a detailed analysis (see Bouma, 1973; Bryden & Rainey, 1963).

Some raw data for the L(i) condition are shown in Figure 6, trained subjects shown on the left, and untrained subjects on the right. The top figures (a, b) are for L(1), the middle (c,d) for L(2), and the bottom (e, f) for L(3). The solid curve in each figure denotes the outer limit of the functional visual field obtained from L(0), which corresponds to the dotted curve of Figure 5. Data for L(0) and L(i) in all figures were collected within the same session, as stated before.

The top figures indicate that the raw data for L(1) are distributed evenly around the solid curves; i.e., there was no influence of foveal load. This implies that simple loads, such as two alphabet letters, are so easy to read that they do not affect information processing at the periphery. On the other hand, for L(3), most of the circles and crosses are inside the solid curves, showing that the functional visual field shrinks noticeably when difficult foveal loads are imposed. The situation for L(2) is a little more complicated, since the influence of foveal load apparently occurs only for untrained subjects (Figure 6d). After a subject had completed some training, he seemed to gain an ability to keep his visual field unaffected to a certain extent.

The influences of foveal load on functional visual field size by the three conditions discussed above are summarized in Table 2. $R_1$ denotes a ratio of the functional visual field area for L(1) to that for L(0). Ratios $R_2$ and $R_3$ are similarly defined for conditions L(2) and L(3). For trained subjects, $R_1$ and $R_2$ are near unity and the influence of the foveal loads appears only at $R_3$. For untrained subjects, $R_2$ is already much smaller than unity and no further reduction seems to take place in $R_3$.

Table 2 contains another ratio, $R_{-1}$. This was similarly obtained as above, but for the condition L(-1), which corresponds to Engel's visibility area. For this condition, trained subject K.S. was asked to pay selective attention in a specific direction at every peripheral target presentation, while fixating the fixation frame; no foveal load was given. Eye movement was restricted, as before. Raw data for the condition are plotted in Figure 7, with arrows indicating directions of selective attention. Figure 7a

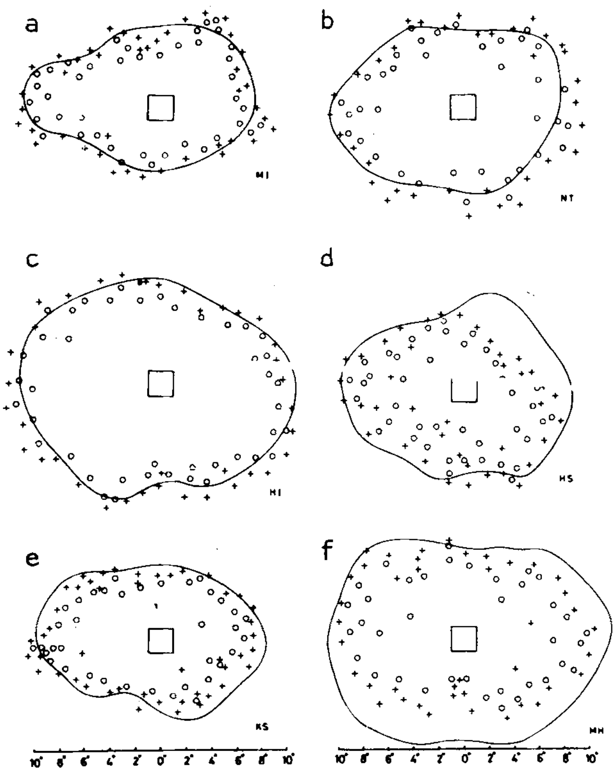


**Figure 6. Functional visual fields obtained for the L(i) conditions. The top results are for L(1), the middle for L(2), and the bottom for L(3). Results at the left are from trained subjects and at the right from untrained subjects. Solid curves are for the L(0) condition.**

**Table 2**
**Ratios to Show the Decrease of the Functional Visual Field Size for L(i) Condition Compared to that for L(O) Condition**

| Subjects | | $R_{-1}$ | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|---|
| | M.I. | | .96 | | |
| Tr | H.I. | | | .97 | .79 |
| | K.S. | 1.6 | .98 | .97 | .74 |
| | N.T. | | .98 | .64 | |
| | H.S. | | | .69 | |
| Untr | N.S. | | | .40 | .47 |
| | T.W. | | | | .67 |
| | M.H. | | | | .64 |

*Note–Most subjects participated only in one or two conditions to save time as well as to avoid training effect.*

shows data for target presentations during attention upward. The solid curve is for L(0) and was determined in the same session. It is clear that selective attention widened the functional visual field towards its direction, as shown also by Engel (1971). Assuming that such expansion will occur for all directions in similar fashion, we estimated the area of the functional visual field for L(-1) and calculated a ratio $R_{-1}$, which turned out to be about 1.6, as shown in Table 2.

## DISCUSSION

The present results have several practical applications. First, there are many occasions when we must view objects at the fovea and in the periphery simultaneously. The area available for the latter task is neither fixed nor unlimited, and furthermore, changes dynamically depending on foveal stimulus information; in effect, the greater the resolution difficulty of central figures, the greater the resulting shrinkage of the functional visual field. This finding of shrinkage is not new, as cited above. However, the present investigation had the advantage of using commonplace foveal and peripheral stimuli of daily occurrence (recognition of figures or letters), and also the peripheral boundary of the functional visual field was specifically determined.

The grouping of the foveal loads into four, namely L(0), L(1), ... L(3), was recognized as a dubious approach. However, the results in Figure 6 show relatively clear outer edges, which indicates that the grouping was appropriate. There are, however, some incorrect responses at close locations to the fovea, such as the two points on the right in Figure 6f. These and other similar ones are mostly responses wherein subjects could detect neither the foveal load nor the peripheral target. In these cases, we cannot completely rule out the possibility that subjects gave up and did not respond to the peripheral target simply because they could not recognize the foveal load at all. However, although subjects were encouraged to respond to the central load as much as possible as the first priority, they were never told to ignore the peripheral target as such. Further, they knew nothing about the scoring methods employed. Therefore, we conclude that subjects were so hard put to recognize the foveal load in only 250 msec that they were unable to attend to the peripheral target. Obviously a study of foveal load grouping according to difficulty of detection should be made.

As noted in Figure 6 and in Table 2, shrinkage of the functional visual field is less obvious with trained subjects, indicating that they learned to shift their attention towards the periphery without sacrificing detectability at the fovea as the experiment proceeded. This training effect was also noted by Engel (1971), who states that the functional visual field became larger during training. We think that this is similar to the feedback effect shown by Abernethy and Leibowitz (1971). In practice, such a training effect may occur in special cases, such as pilots learning to read instruments. On the other hand, the performance of the naive subjects may be analogous to such daily experiences as traffic signal detection while driving a car, in which the driver encounters continuously incoming new information.

We employed only one combination of the

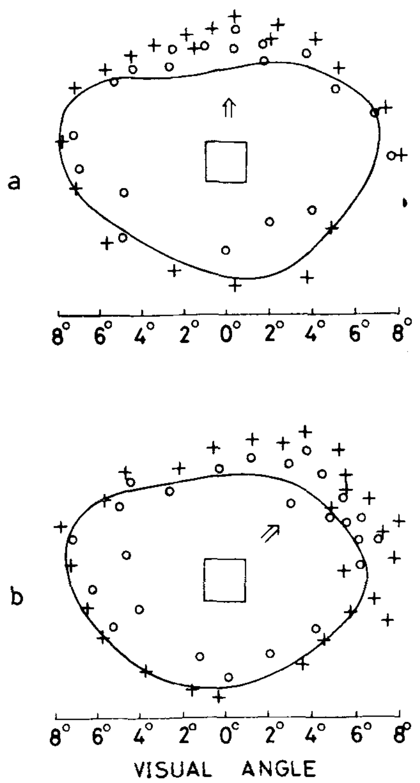


**Figure 7. Functional visual fields obtained with the selective attention of which directions are indicated by arrows. Solid curves are for the L(0) condition. Subject: K.S.**

peripheral target and the background pattern, namely a star and distorted triangles. This shape difference and other conditions, such as the duration of the display presentation, will alter the size of the functional visual field. In this line, Leibowitz and Appelle (1969) showed that the amount of increase of the increment threshold due to the central task differed according to peripheral stimulus position, and was particularly small at the extreme periphery. This, then, suggests that the shrinkage characteristics shown by $R_i$ in Table 2 depend on the shape difference among other conditions that determine the outer limit of the functional visual field for L(0).

As a final point, the area of the functional visual field varied greatly among subjects, and also changed for a particular subject when the data were collected on different occasions. This prevented us from defining quantitatively the outer limit of the functional visual field itself and limited the analysis to consideration of the ratio $R_i$. It is difficult to imagine that underlying physiological characteristics are so different among subjects and vary so much from time to time within an individual to produce such variation. We think, rather, that the fluctuation of the area is due mostly to differences in attitudes of subjects towards their own tasks, some being very conservative in responding to stimuli and the opposite being the case with others. It is needed, therefore, to find a technique to motivate each subject equally for the task of detecting stimuli in further investigation.

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