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"Enhancing the perception of form in peripheral vision"

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These are preliminary lecture notes, intended only for distribution to participants.

Enhancing the perception of form in peripheral vision

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Enhancing the perception of form in peripheral vision

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Abstract. Experiments are reported which show that the tachistoscopic presentation of a figure at the point of fixation makes salient the same figure where it occurs elsewhere in the visual field during the same flash. This induced saliency operates in all directions from the axis of gaze. If the eccentric figure is alone on a blank field the phenomenon is termed 'eccentric enhancement'. The induced saliency of figures that are laterally masked within horizontal strings of figures that lie off the fixation point is termed 'demasking'.

1 Introduction

Away from the axis of gaze a form loses clarity as its angle to the axis increases. Eccentrically seen, a form is clearest against some featureless background, grows less clear as other forms lie in its neighbourhood, and becomes unrecognizable when they are of comparable size and fairly close to it. This indistinction of a form in a texture of other forms is termed 'lateral masking' (eg Bouma 1970; Townsend et al 1971). An example of lateral masking appears in the top row of figure 1. If you fix your gaze on X with either eye, or with both, the isolated N is clear but not overly distinct, the N in TENET, however, is quite unreadable. The effect does not depend on the distance of your eye from the page.

The shape of a letter, its topology, boldness, contrast, distance from neighbours, and similarity with neighbours all affect how well it is masked (Bouma 1970; Bjork and Murray 1977; Eriksen and Eriksen 1974; Mackworth 1965; for a recent short review see Wilford and Chambers 1983). For example, an O in place of N (figure 1) is much less strongly masked than other interior letters, and the far terminal letter is less masked than the near one (Banks et al 1979; Bouma 1973).

N X TENET

O X TEOET

TENET X TENET

TENET X **TENET**

Figure 1. Demonstration of lateral masking. At each line fix your gaze on the center X and compare what is seen peripherally on the left and the right. A detailed description is given in the text. The black dots in the third line on the right occupy the same area as the lines on the opposite side.

It is not easy to say what information is lost in masking. The middle letter of a string gives the impression as being of the same textural nature as its neighbours, but its form is vague. The optical resolution as measured with lines or dots is more than adequate to distinguish the letter. But resolution is not the issue, as can be seen by comparing the two Ns in the top line of figure 1 (the distances of the Ns to the X are equal).

A microtexture formed by breaking up letter strokes into dots or by imposing wiggles strongly increases the masking, as in the last two lines of figure 1. In peripheral vision we do not abstract form from an aggregate of elements as easily as we do with direct gaze.

If lateral masking is the result of an operation occurring early in the physiological process that underlies vision (eg interaction between receptive fields in the primary visual cortex), then the information lost should not be retrievable by processing that occurs 'deeper' in the brain. Our experiments suggest, however, that this is not the case. If a string of letters or signs lies peripheral to a fixation point and is presented in a flash, the letters or signs lose clarity. But if a copy of one of the letters or signs, identical in all respects, including orientation, is suddenly flashed at the fixation point at the same time, that letter or sign stands out transiently against its neighbours in the string. This does not occur when the letter or sign flashed is unlike the ones in the string. Although this transient sympathetic appearance of the eccentric letter was vivid enough to us, we designed a set of experiments to test whether naive observers would see the same thing.

These studies demonstrate enhancement of a single letter in the peripheral field (experiment 1) and enhancement of a letter or sign embedded in a peripheral string (experiments 2 and 3). An additional experiment tested for higher-order functions in the effect (experiment 4) and showed the contribution to be negligible.

In the course of the studies it became clear to us that these types of interactions, which aided form perception in the eccentric visual field, could be tentatively separated into two parts which are not necessarily intrinsically different. When other visual elements in the periphery are absent we call the interaction 'eccentric enhancement', and when the figure is embedded in other visual elements, 'demasking'. The distinction is made clear by experiments 5, 6, and 7. A case in which such interactions are weak or absent is given by experiment 8.

The reason for pursuing this effect is that it presents itself in common experience, eg as in hunting for a word on a page or a face in a crowd. Expectation aids the hunting, particularly when a similarity exists between the momentary object of gaze and the object sought. Such experience is fallible, anecdotal, and, therefore, suspect. Nevertheless, others have pursued the idea (Egeth and Blecker 1971).

2 Methods

2.1 *Apparatus*

Black and white test images were made on standard 3.25 in × 4 in slides. They were projected from the rear through two large standard projectors onto a diffusing screen 30 cm × 16 cm. Two Uniblitz (Model 225-L) electronic shutters occluded each projection lens and could be opened and closed completely and reliably within 5 ms. A time sequence controlled the shutters.

The observer sat facing the screen, 1 m away from it. The screen was moderately illuminated by soft room light (5 cd m^{-2}). The images cast on the screen were quite bright (150 cd m^{-2}) for the open shutter times (the effect we studied remained unchanged when we used a three-way tachistoscope, which kept the level of adaptation to illumination constant). The images were all high contrast, about 10:1.

2.2 *Stimuli*

Boldfaced uppercase black letters (Helvetica-medium) or other visual signs like △,⅂, or Ɔ, were laid in different arrangements on blank slides. At a distance of 1 m away from the screen the letters or signs, when projected on the screen, had a uniform height of 35 min visual angle and were at most 30 min wide. The width of the lines composing the letters and signs was uniformly 3.6 min. If the stimuli consisted of a string of letters or signs the spaces between their boundaries were 20 min wide. A tiny black dot was permanently mounted on the front of the screen as a fixation point.

In experiment 1 each display (stimulus) consisted of two letters, one 8 deg to the right of the fixation point and the other at the fixation point. They were either alike or unlike. Both letters in each display were taken from a group of letters assigned for the particular experiment. For each presentation of a pair of letters which were alike there was another in which the pair was unlike. The letters at the periphery were identical for both pairs, and only the letters at the fixation point were different.

In all the other experiments the display consisted of a string of three letters or signs that we call 'elements'. The middle element in the string was at 8 deg eccentricity to the right. Another element lay either at the fixation point or near to it, depending on the experiment. In experiment 7 the 8 deg eccentricity was vertical. The element at the fixation point was either like one of the elements in the string or unlike any of them. The displays were divided into groups of four. Each group of four had identical triads of elements in the peripheral string, but were different one from the other by the element at the fixation point—the 'inducer'. Three displays had each of the elements in the peripheral string separately offered as inducer, and one display had an inducer unlike any elements in the string. Each experiment was done with only letters or only signs.

Preliminary tests showed that the resolution of the stimuli at the periphery was good if the image was viewed with an exposure long enough (see also Bouma 1970) to permit good seeing but short enough to preclude a directed eye-movement within the presentation.

2.3 *Procedure*

At 1 m from the screen a comfortably seated naive subject looked with both eyes at the fixation point (a small dot on the blank screen) in a moderately lit room to which the subject had adapted after a few minutes. The instructions were to report what was seen on the screen during the brief exposure of the stimulus. We did not explain the purpose of the experiment prior to testing.

Shortly after the subject's gaze was fixed a test slide was projected on the screen for a time t_1 which did not exceed 150 ms. During so short a time no directed eye-movement occurs. The test image was followed after a short adjustable interval, $t_2 < 150$ ms, by a prolonged (2 s) 'erasing' image. This meant that display time, ie exposure time, as well as afterimage time, was $t_1 + t_2$. We used the additional interval t_2 to give display times longer than 150 ms for subjects who needed it, without risking directed eye-movements. For all subjects t_1 and t_2 were about equal as long as t_1 was not less than 30 ms. The erasing image consisted of a grid of diagonal, horizontal, and vertical black lines on a white background that blocked rumination on the afterimage of the test slide. Other grids and arrays that we tested were equivalent in the 'erasing' effect.

Before each experiment began the duration of t_1 and t_2 was determined for each subject individually. In the experiment with single letters at the periphery the procedure was as follows. Single letters only were first presented at 2 deg 40 min to the right of the fixation point with arbitrary test times t_1 and arbitrary intervals t_2. After a search the test times t_1 and t_2 were adjusted to values at which the subject reported 80–90% of the letters correctly. Thereafter the values of t_1 and t_2 were held constant during the experiment.

For the test itself the eccentric letters were moved to 8 deg to the right from the fixation point. At this eccentricity the correct identification of the letters at the periphery dropped to 40% or less for most subjects, as predicted by the Aubert–Foerster

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law (1857).[1] This law states that the visual recognition of a single letter varies directly with the angular distance from the centre of fixation when presented with a flash of constant duration. In this way we kept the subject from saturating either with correct or with incorrect reports, so that a measure of better and worse identification could be made reliably.

The setting of t_1 and t_2 was done in similar fashion for the experiments in which the peripheral stimulus consisted of three elements in a string.

The displays were randomly presented. After each exposure of a string the subject reported which elements were seen on the screen and their relative position, ie which element appeared at the fixation point, as well as those that appeared in the periphery, and in what order. Identification was regarded as correct only when the letters or signs, and their position, were reported in correct order. The subjects were free to choose the order of report in each display. They all reported the one at the fixation point first and then the eccentric order.

The subject's gaze on the fixation point was observed by the experimenter directly. When the gaze wandered off the fixation point during a test the response was not counted and the stimulus was repeated on a later occasion. Usually, when the gaze was well off the fixation point the subject showed error in identifying the element flashed at the fixation point. This gave an additional, if limited, verification of the direction of gaze, and in our judgment it was sufficient, although crude.

All the subjects had normal or trivially corrected vision. One subject, who participated in all the experiments, had been blind in one eye for many years. Not all subjects participated in all the experiments.

Evaluation of the data was made by averaging the scores of correctly identified elements. In experiment 1, where single letters were presented at the periphery, averages of correctly identified letters at the periphery were made for two separate groups. The averages were later compared. One set consisted of all correctly identified letters which were presented with an identical inducer, and the other set consisted of all correctly identified letters with an unlike inducer.

We have used several statistical tests for bias in answers (eg if a subject answered only the inducer as the letter in the periphery) and found bias to be so marginal as not to warrant further treatment.

The four displays in each group were (only the elements in the strings are considered):

$$\mathrm{F}_i^{\mathrm{d}},\quad \mathrm{M}_i^{\mathrm{d}},\quad \mathrm{T}_i^{\mathrm{d}};$$
$$\mathrm{F}_i^{\mathrm{f}},\quad \mathrm{M}_i^{\mathrm{f}},\quad \mathrm{T}_i^{\mathrm{f}};$$
$$\mathrm{F}_i^{\mathrm{m}},\quad \mathrm{M}_i^{\mathrm{m}},\quad \mathrm{T}_i^{\mathrm{m}};$$
$$\mathrm{F}_i^{\mathrm{t}},\quad \mathrm{M}_i^{\mathrm{t}},\quad \mathrm{T}_i^{\mathrm{t}}.$$

There were n sets of these displays and the subscript refers to which set was used, ie $i = 1 \dots n$, where F, M, and T stand for first, middle, and terminal elements in a string. The configurational notations are: d, unlike inducer; f, inducer like the first element; m, inducer like the middle element; and t, inducer like the terminal element. The number of groups was n. The averages of correctly identified elements of each configuration and position were separate, eg

$$\overline{\mathrm{F}}^{\mathrm{d}} = \frac{1}{n}\sum_{i=1}^{n}\mathrm{F}_i^{\mathrm{d}} \qquad \text{or} \qquad \overline{\mathrm{M}}^{\mathrm{m}} = \frac{1}{n}\sum_{i=1}^{n}\mathrm{M}_i^{\mathrm{m}} .$$

(1) A small group of subjects showed high detection (about 70%) at this eccentricity. They were all known to be dyslexic or had had prolonged dyslexic episodes in the past. Such subjects seem to violate the Aubert–Foerster law in this range. We defer our other results on them to a later paper.

The data were treated with the standard statistical procedure for distribution (analysis of variance, ANOVA) and for significance of separation (t-test). All effects to be reported were significant at the 5% level, at least. Each element in the periphery had an equal frequency of occurrence in the course of the experiment.

3 Results

3.1 *Experiment 1: Eccentric enhancement of single letters*

The display in these experiments consisted of a single letter at the fixation point and another letter at 8 deg eccentricity to the right (figure 2, Ia and Ib). In each display the two letters were either alike or unlike. The letters were taken from a group of ten letters. All together there were twenty different displays. They were randomly ordered in presentation. The subjects were asked to identify the two letters in each display. Each subject had forty trials.

The results are given in figure 3 as averages from six subjects. D signifies the inducer when it is unlike the peripheral letter signified by M. The results show a significant enhancement of correct identification when letters were alike, in agreement with previous findings (Eriksen and Lappin 1965; Kinchla 1974; Mackworth 1965). We termed this interaction 'eccentric enhancement'.

Different letters have different recognizability. We offset this effect by using the same element at the periphery, once with an identical inducer and once with an unlike inducer.

The way we collected the data enabled us to make comparisons of average enhancement for each letter separately and then to compare the results between letters. This comparison did not show significant differences between nine of the ten letters used.

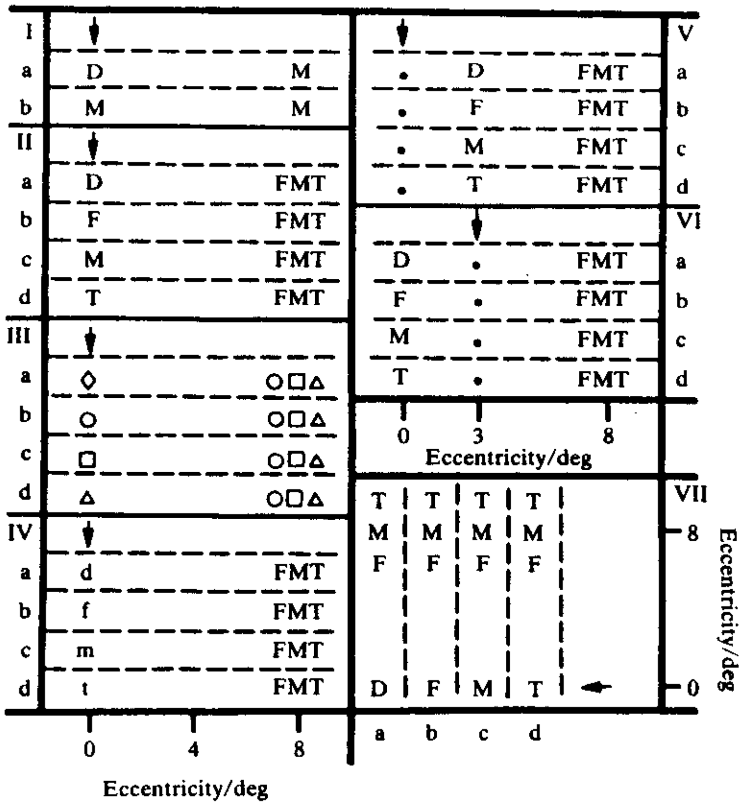

Figure 2. The various elements and arrangements used in the experiments. The Roman numerals indicate the experiment number in which the particular set of displays was used. The arrow shows the point of fixation. D represents a letter at the fixation point if it differs from any in the string. F, M, and T are the first, middle, and terminal letters of the sting at the periphery. They can be subscripted in each experiment for the set of letters used.

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All were eccentrically enhanced except for the letter I, which was not enhanced (see also Andrissen and Bouma 1976).

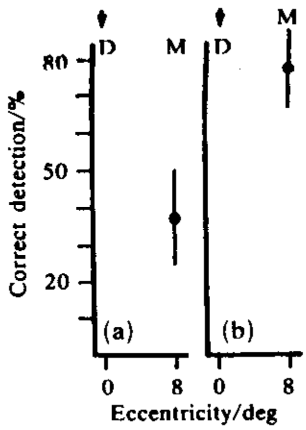

Figure 3. Eccentric enhancement of single letters from the first group of subjects used (experiment 1). (a) Unlike letters were presented simultaneously at the fixation point (0 deg) and at 8 deg eccentricity. (b) Like letters were presented at these locations. Averages of correct identifications are given by the solid dots, standard deviations by the vertical bars. The resulting difference between the averages is significant ($p < 0.001$).

3.2 *Eccentric enhancement and demasking*

3.2.1 *Experiment 2: Uppercase letters in strings of three.* The elements were chosen from a pool of seven uppercase letters: Y, N, I, O, E,, V, and C. These were presented in displays where three different letters lay in the periphery in a fixed order, and the inducer was either one of that triad or not. The combination of the triad had no meaning. In figure 2, IIa-d, the markers F, M, and T stand for first, middle, and terminal letters of the triad, and D for the inducer unlike any of them. There were fifteen such triads used, giving sixty displays. Eight subjects were tested.

The score for correct identification of the letter at the periphery was averaged for each configuration as described. The results in figure 4 show significant enhancement of identification of a letter in the periphery when a letter like it appeared simultaneously at the fixation point. In this experiment the letters in the string were laterally masked by each other. In spite of this masking, enhancement was significant. We termed the

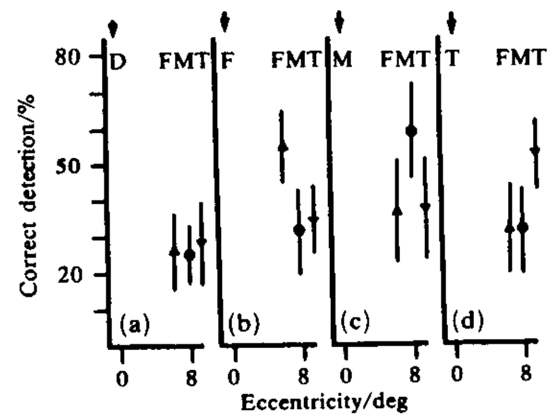

Figure 4. Eccentric enhancement and demasking for letter strings whose middle letter is 8 deg from the fixation point (experiment 2). The average results of correct identification when the letter at the fixation point (at the arrow) is (a) unlike the ones in the string, (b) the first letter in the string (from the fixation point), (c) the middle one in the string, and (d) the last letter in the string. Incorrect report of position was taken as error. The solid symbols signify averages, the bars show standard deviation. Three differences were calculated: $\bar{F}^f - \bar{F}^d$, $\bar{M}^m - \bar{M}^d$, and $\bar{T}^t - \bar{T}^d$. The differences were all significant ($p < 0.001$ for all three).

enhancement in the presence of lateral masking 'demasking'. The detailed distinction between eccentric enhancement and demasking will be given later.

The analysis showed significant enhancement for all letters except for the letter I.

Figure 4 also reveals that there was some enhancement (not significant) of correct identification of letters next to the ones enhanced by an appropriate inducer. That is, as one letter became obviously distinct as a result of demasking, the probability of correctly identifying the neighbouring letters seemed to be elevated.

Eccentric enhancement and demasking were not confined to the domain of letters and reading.

3.2.2 *Experiment 3: Nonliteral displays.* The procedure and the display structure were as in the previous experiment except that the letters were replaced by the six visual signs: □, △, ○, ◇, ⌉, and Ɔ. These were arranged in configurations as shown in figure 2, IIIa-d. There were twelve displays of peripheral configuration and, therefore, forty-eight trials per subject. Six subjects participated. Evaluation of the data was done in the same way as in the previous experiment.

The results are shown in figure 5. Enhancement of correct identification was significant. The signs laterally masked each other, usually in the same way as letters. Therefore demasking is a phenomenon not confined to letters and reading only. However, in order to determine if higher-order functions (identification by meaning) are involved in the phenomenon we performed the next experiment.

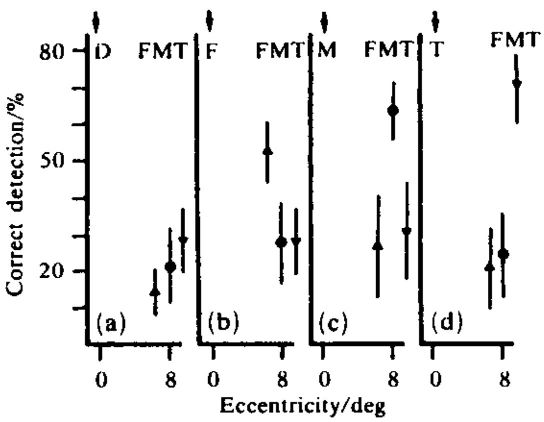

Figure 5. Demonstration of eccentric enhancement and demasking for nonliteral signs only (experiment 3). Details as in figure 4. The enhancement of correct identification was significant for all three configurations (all $p < 0.02$).

3.2.3 *Experiment 4: Lowercase and uppercase letters—a test for intervention of higher functions.* In this experiment the inducer and peripheral elements were visually disparate but identical in meaning, as suggested to us by R Savoy (personal communication). We used uppercase and lowercase letters which have different appearances, eg N and n.

The procedure and the displays were similar to the ones in experiment 2. The difference was that the letters at the fixation point were lowercase letters and the letters in the strings remained uppercase (see figure 2, IVa-d). The letters were taken from a group of six letters. Each of the five subjects was exposed to forty-four displays.

When the inducer lowercase letters were of the same reference as uppercase letters in the string the identification of letter pairs showed no significant enhancement. This suggests that eccentric enhancement and demasking are precognitive phenomena.

3.3 *Why eccentric enhancement and demasking?*

3.3.1 *Experiment 5: Fixating away from the stimuli.* How much do eccentric enhancement and demasking depend on the subject fixating on the inducer at the center of gaze?

The first thing we did was to test whether eccentric enhancement and demasking persisted when we moved the inducer between the fixation point and the string of letters (as shown in figure 2, Va–d). We left the position of the string, relative to the fixation point, as in experiment 2, and moved the inducer 3 deg to the right towards the string. By doing so we altered two things: the inducer was presented outside the fovea, and the distance between the inducer and the string was 5 deg ie smaller than in experiment 2. A study by Bouma (1970) indicates that the range of the effective distance of lateral masking is half the eccentricity. In this case it would have been 4 deg. This implied that we had placed the inducer outside the effective masking range of the string of letters at the periphery.

The method and letter combinations used in the displays were the same as in experiment 2. So also was the treatment of the data. Five subjects were tested, with sixty trials each.

The results in figure 6 show that there was significant eccentric enhancement of the first letter in the string (nearest to the inducer) and no significant enhancement for the remaining two letters. Demasking was impaired either by the distance of the inducer (too near to the string), or by the inducer having been placed outside the fovea. In the former case we can argue that demasking was not compromised by proximity to the string, since the first letter in the string was enhanced.

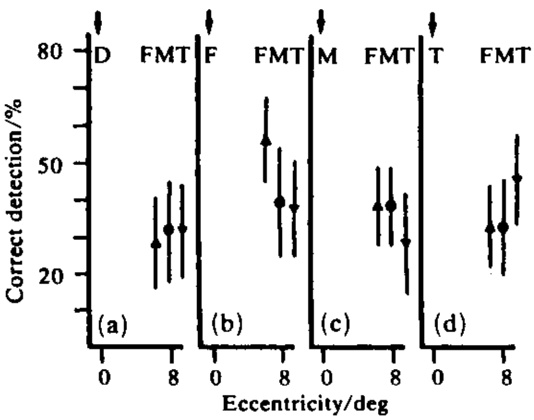

Figure 6. Eccentric enhancement and demasking for fixation away from the stimuli (experiment 5). There was significant ($p < 0.01$) eccentric enhancement for only the first letter in the string and only slight enhancement for the other two. The inducer in this experiment was 3 deg to the right, and the middle letter in the string was 8 deg to the right. Other details as in figure 4. The average $\overline{T}^{t}$ [in (d)] is elevated but not significantly different from the average $\overline{T}^{d}$ [in (a)].

3.3.2 *Experiment 6: Fixating within the display.* Experiment 2 was repeated with the distance between inducer and string the same but with the fixation point moved 3 deg to the right of the inducer. In this way the inducer was placed outside the fovea, while the distances between the inducer and the string remained as in experiment 2 (see figure 2, VI a–d). In this modified experiment 2 five subjects were tested with sixty trials each, and the data were treated as in experiment 2.

Figure 7 clearly shows eccentric enhancement of the first letter in the string and a very slight enhancement of the other two letters.

Demasking was impaired, yet eccentric enhancement in the form similar to single-letter enhancement was evident. It is interesting to note that the inducer lay in the left visual field and the string in the right visual field. As shown in figure 7, the correct identification of all letters was better than in experiment 2 (figure 4). This was because the distance from the fixation point to the string was smaller than in experiment 2, and this is as expected from the Aubert–Foerster law.

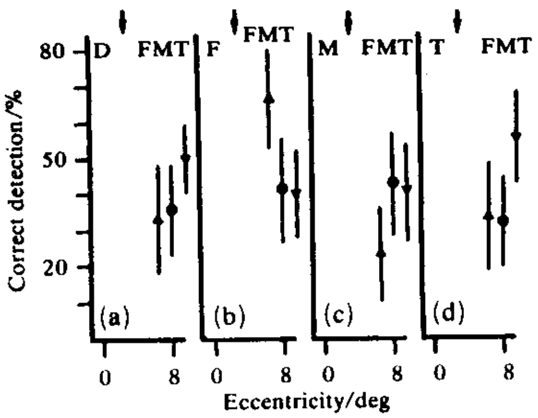

Figure 7. Eccentric enhancement and demasking for fixation within the display (experiment 6). Significant ($p < 0.001$) eccentric enhancement of the first letter in the string and slight (not significant) enhancement for the others. All details as in figure 4 except for the fixation point, which was between the inducer and the string, 3 deg to the right from the inducer.

3.3.3 *Experiment 7: Vertical stimuli.* Until now we have described only experiments with horizontal displays. But we also measured the effect when the string lay in a vertical triad with vertical eccentricity to the axis of gaze, as shown in figure 2, VII a–d. The procedure and the letters used in the stimuli were as in experiment 2. Three subjects were tested with sixty trials each.

The results shown in figure 8 demonstrate a significant eccentric enhancement of the first letter in the string nearest the inducer and a small enhancement (not significant) of the other two letters in the string. This showed that eccentric enhancement persisted, but demasking was impaired. Such a difference justifies our separation of the two effects.

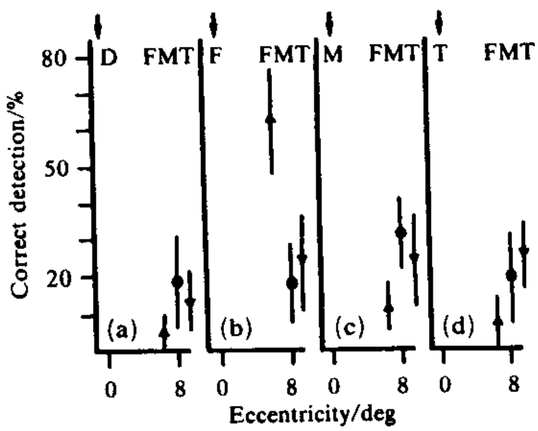

Figure 8. The letters in experiment 7 were arranged along a vertical line above the fixation point. Other details as in figure 4. Eccentric enhancement is significant ($p < 0.001$) only for the first letter in the string (nearest to the inducer) and there is little, if any, enhancement for the others.

3.4 *Where demasking and eccentric enhancement fail*

3.4.1 *Experiment 8: Embedding the letters in a noise pattern.* Previous experiments produced eccentric enhancement and, in some cases, demasking. We looked for a condition in which both interactions would fail. In all previous experiments the inducer and the string were arranged in two distinct pattern clusters against a blank background. We repeated experiment 2, adding a noise pattern between the inducer that lay at the fixation point and the string of letters at the periphery. The unit size of elements in the noise pattern was the same as the width of the lines composing the letters. Six subjects were tested, sixty trials each.

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The results, shown in figure 9, make clear that the enhancement described in experiment 2 was now small and not significant. This indicated that eccentric enhancement and demasking were profoundly affected by texture in the background.

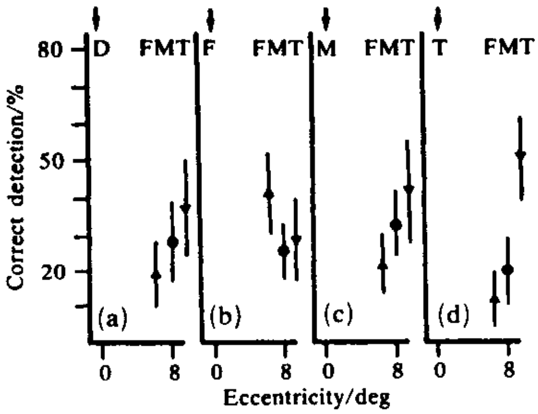

Figure 9. Eccentric enhancement and demasking with visual noise between inducer and string (experiment 8). Eccentric enhancement and demasking were small and not significant. The details and the stimuli were as in figure 4 with the addition of noise pattern between inducer and the string. It seems there was a significant enhancement of the terminal letter (T) in (d); however, as T was best identified in all trials, the difference of identification with the correct inducer was insignificant.

4 Discussion

The visual objects used in this study were black boldfaced Helvetica-medium capital letters and geometric figures, presented at high contrast against a white background. This is stipulated because it has become obvious to us that letters and geometric figures differ from other simpler symbols (of equal size and contrast) in how they are handled by peripheral vision. We will report on this work in another paper. Both kinds of elements used are here called figures.

A figure kept at a fixed visual angle loses clarity against a blank background the more eccentric it is to the axis of gaze. This is consequent to the Aubert-Foerster law in vision. A figure embedded in a string of other figures of like size and contrast loses its clarity far more rapidly with eccentricity of the string. This effect increases as the space between figures decreases. It is called 'lateral masking' (Bouma 1970; Eriksen and Eriksen 1974; Mackworth 1965).

In such a string of more than three figures seen eccentrically, only the most eccentric figure retains some clarity. The least eccentric figure has somewhat less clarity, and the interior figures of the string have almost none (Banks et al 1979; Bouma 1973; Townsend et al 1971). In the shortest string (three unlike figures long), the most eccentric figure is clearest, while the other two are less so (figures 4a, 5a, 6a, 7a, and 8a). The exception is that if both end figures are the same then both are clear (although not as clear as when they are different), while the middle one, which differs from the two ends, is thoroughly masked (unpublished results).

This degeneracy of an aggregate of figures into a texture of unclear forms occurs equally with flashed and continuous presentation. One might suppose that the loss of clarity of a single figure and of the interior figure of a string testify to a change of processing that is rooted both in the lower density of cones and in the larger size of receptive fields in the retinal periphery. In that case, the loss of clarity becomes a necessary property of peripheral vision.

But, as Julesz (1981) has pointed out in his studies on texture, there are attentive influences that alter the perception of the nature and composition of an aggregate. His observations show that information is not irretrievably lost in the visual interactions

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between elements in a texture. Furthermore, common experience suggests that the peripheral field is not as confused as we report verbally, for if it were so there would be less certainty on where to look next after we fix our gaze on one part of a scene (Antes 1974; Mackworth and Morandi 1967). These observations are consistent with the material reviewed by Rayner (1978).

Our tachistoscopic experiments show that a figure seen at the center of gaze enhances the perception of that same figure when it lies in the periphery, providing both are of the same orientation. There are, provisionally, two such effects. One we call eccentric enhancement. This occurs when a single figure alone in the periphery becomes much clearer if the same figure is presented at or near the center of gaze (experiment 1). The other is called demasking. This occurs when a figure obscured by lateral masking in an eccentric string is clarified (demasked) if the same figure is presented at the center of gaze (experiments 2 and 3). Enhancement is robust and does not depend on the enhancing figure being presented specifically at the fixation point (experiments 5 and 6; in these experiments only the first letter was enhanced and could be regarded as only partially masked). Demasking is more delicate, and the inducing figure must be at the fixation point. Furthermore, demasking occurs only along a horizontal string that lies on a line passing through the fixation point, whereas enhancement occurs as easily in all directions away from the fixation point (experiment 7).

This interaction at a distance between foveally and peripherally seen figures, when both are tachistoscopically presented and then erased as described, raises questions about the nature of peripheral vision. There are three basic points to be addressed. The first is why the inducing figure (that was presented at the fixation point) must have the same orientation and contrast as the letter to be enhanced or demasked. That there is no cognitive influence is shown by the lack of effect when an inducing letter is lowercase while the peripheral letter is uppercase (experiment 4). It is as if the inducing figure sets up a global filter for shape, but not in the way that is used for shape filtering in holograms (Van der Lugt 1964), since orientation matters. The problem of process design becomes compelling (see Koch and Ullman 1985).

The second and, to us, most important point is whether lateral masking and compromise in clarity that so characterize peripheral vision are intrinsic to the visual system or represent a learned way of attending. Certainly in nocturnal vision, when foveal vision fails, the clarity in the periphery seems far greater than expected. That this is not simply a difference between rod and cone vision appears clinically in those cases where foveal degeneration has occurred. Such patients, when young, develop both reading skills and detail vision parafoveally.

Peripheral clarity with cone vision also appears in entoptic viewing, as of the Purkinje tree, where attention can be made to wander widely over the visual field and, in so doing, obscures what is not attended.

Probably the strongest argument for attentive obscurement of the periphery comes from the few dyslexics we have tested (although this anticipates another report). In these individuals there is a great weakness of lateral masking even at 8 deg eccentricity. They see all three letters in the strings we present. Similarly, there is little loss of clarity for single letters eccentrically given. It is as if their cone of visual attention is not as constricted as it is in good readers. If this is confirmed by more extensive study, we must suppose that the information about shape is always present in peripheral vision but is suppressed by a higher-order attentive process that is superposed. This is in accord with the notions of Julesz (1981). Enhancement and demasking then become easier to understand, since the information has not been destroyed by lower-level processing.

The third point is consonant with the second, that demasking is a horizontal operation when letters and geometric figures are used. Since the results are the same whether one or both eyes are open during the experiments (one of the subjects had been blind in one eye

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for many years), we feel that the strategy of reading and scanning of detailed sequences imposes a specific way of attending for which the consequence is a lateral masking that is as profound as what we measure. (From this viewpoint, dyslexics seem to present supportive evidence.) Similarly, Julesz and Bergen's (1983) 'preattentive processing' is both germinal and relevant, although what we are treating is better described as 'coattentive'.

As a final point, and significant in the light of Julesz's studies on texture, we find neither enhancement nor demasking for bars like the capital letter I. We have a small set of such elements that we call 'simple', in distinction to letters and figures, such as O and E and □, that are 'complex'. Only complex elements show enhancement or demasking, which again suggests that a higher-order process is involved in the suppression of clarity in the peripheral field of vision.

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