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Asymmetry of visual interference

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This research studies lateral interference among items in the visual field under conditions in which central cognitive factors such as attention and memory limitations are eliminated or controlled for. Under these conditions lateral masking is still found, and it is still asymmetrical (peripheral items interfere with recognition of central items more than central with peripheral). These experiments therefore add to the evidence that both lateral interference and the asymmetry of interference have a component that does not result from cognitive strategies. The experiments also add to the evidence that the asymmetry effect at the sensory level can be attributed to the falloff in acuity from the center to the periphery of the retina, since the mean eccentricity of the target-mask cluster is more peripheral with a peripheral mask than with a central mask. The hypothesis is advanced that the asymmetry effect, as well as lateral interference itself, at the sensory level results from the grouping of target and mask into a single Gestalt-like configuration. The final experiment in the series supports this hypothesis.

Two or more letters presented simultaneously to the eye do not, in general, have independent perceptual effects. A particularly important interaction among letters is that which reduces their perceptibility relative to individual presentation. This reduction is termed lateral interference or lateral masking. Previous studies of lateral interference have shown that a target letter can be interfered with by letters (or shapes) the observer is not attempting to report (Andriessen & Bouma, 1976; Loomis, 1978), that the interference is not entirely a result of simple contour interaction (Shaw, 1969), and that the amount of lateral interaction between elements declines as the distance between them increases (Eriksen & Eriksen, 1974).

An important characteristic of lateral masking is its asymmetry in the visual field. The target is interfered with more by a mask on the peripheral side (the side away from the fixation point) than by a mask on the central side (the side of the target toward the fixation point). Several experiments have supported the proposition that asymmetry of interference (and the lateral interference effect itself) has a purely sensory component and does not depend on central cognitive processes such as inspection of a fading iconic trace or rehearsal strategies in short-term memory (Banks, Bachrach, & Larson, 1977; Taylor & Brown, 1972; Townsend, Taylor, & Brown, 1971). While cognitive strategies might increase or decrease the magnitude of the asymmetry effect, the effect still exists when such strategies are controlled for or eliminated.

The present experiments extend and find further support for an explanation of asymmetry of masking advanced by Banks et al. (1977), and they yield evidence on the role of Gestalt-like configurational processes in lateral masking. The Banks et al. (1977) paper had two purposes: First, to obtain measures of asymmetry of masking uncontaminated by cognitive strategies and, second, to test an explanation of asymmetry of masking. This explanation, also investigated here, is based on a critical difference between arrays with a peripheral and a central mask, as seen in Figure 1. Figures 1a (top) and b (bottom) show a target (T) at a constant distance from the fixation point in both cases but with a central mask (M)

\+ TM

\+ MT

Figure 1. Illustration of two-element arrays (with target, T, and mask, M) with a peripheral mask (top portion) and a central mask (bottom portion). Note that the entire target-plus-mask configuration is further from the fixation point when the mask is peripheral to the target than when it is central to it.

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in a and a peripheral mask in b. The asymmetry effect would be shown by the fact that detection of the target is less accurate with arrays like b than with arrays like a.

While Figures 1a and b hold the target at the same distance from the fixation point, they differ in that the whole target-plus-mask configuration is further from fixation in Figure 1b than in 1a and therefore in a region of lower acuity. If the retinal eccentricity (i.e., distance from fixation point) of the whole target-plus-mask configuration determines performance, and not just the eccentricity of the target by itself, configurations like Figure 1b should be expected to give worse performance than 1a simply because they are further from the fixation point. Asymmetry of masking would then be a result of the acuity gradient affecting performance at the level of mask plus target. If a subject's task requires that the features of target and mask be disentangled for recognition to take place, it seems reasonable that the position of the target-mask configuration (rather than of the target alone) in the visual field should determine performance. And, in fact, the experiments of Banks et al. (1977) support the acuity gradient hypothesis. Those experiments showed that the amount of asymmetry of masking was approximately what would be predicted by the acuity gradient; correcting for retinal position almost exactly compensated for the difference in perceptibility between mask-central and mask-peripheral arrays.

Several investigators have pointed out that the central-peripheral retinal acuity gradient for a single element is less steep than the acuity gradient for two or more elements (Andriessen & Bouma, 1976; Bouma, 1973; the difference in gradient was demonstrated quite elegantly by Loomis, 1978). Any number of hypotheses might be advanced to explain why the acuity gradient is steeper for multiple than for single-element arrays, but the practical consequence of the difference for the present application is that the appropriate acuity gradient must be used in testing the acuity gradient hypothesis. It is not to be expected that the difference between mask-peripheral and mask-central conditions, which have at least a pair of elements in the field, can be predicted from the acuity gradient for a single element.

The first experiment in this article makes a strong test of the acuity gradient hypothesis. In this experiment, a pair of letters separated by a constant distance along the horizontal axis is moved along a straight horizontal line from the periphery toward the center of the subject's visual field. If the hypothesis underlying the acuity gradient hypothesis is correct and subjects must analyze the features of the target letters out of a target-plus-mask configuration, then the central and peripheral members of the pair should be seen at the same time. To put this prediction another way, there should be asymmetry of interference between the two letters such that, to be seen by the subject, the more central one must be closer to the fixation point than the more peripheral one, but the distance between the points at which they are seen should be equal to their horizontal separation.

Experiment 2 in Banks et al. (1977) is similar to this one in some respects. In that experiment, the target was stationary at one of three distances from the fixation point, and a single noise element was moved away from it toward either the center or the periphery of the field. The mean target-noise distance at which the target could be seen showed the asymmetry effect (the noise element had to be moved further toward the periphery than the center for the target to be seen), and the asymmetry effect was almost exactly compensated for by taking the center of the target-plus-noise configuration as the measure of retinal eccentricity. The present Experiment 1 provides a check on the possibility of some artifacts that might have affected the results of the previous experiment. In that experiment, only the noise element moved. It is possible that the asymmetry effect was found because motion near the center of the field causes less interference than motion in the periphery. A moving noise item near the center of the field might also be less blurred and thus easier to distinguish from the target than a noise item moving in the periphery. Furthermore, when the noise was on the peripheral side of the target, it moved away from the fixation point, and when it was on the central side, it moved toward it. The central vs. peripheral placement of the noise was therefore confounded with the direction of motion. Any possible artifacts resulting from this confounding are eliminated in Experiment 1.

The second experiment tachistoscopically presents pairs composed of one target and one mask. It differs from the first experiment in that fixed retinal positions are sampled and the dependent variable is percent correct rather than the threshold retinal position, but it could be considered a different approach to answering the same questions of Experiment 1, since the magnitude of the asymmetry effect can be derived from it. This experiment is similar to Experiment 1 of Banks et al. (1977), which was intended to reduce memory load and cognitive capacity limitations to the vanishing point in order to arrive at an estimate of the amount of asymmetry of lateral masking attributable to interaction between target and mask at the sensory level alone. This experiment eliminates one more possible non-sensory factor that may contribute to performance, this being the order of inspection or identification of the elements in the field. In Banks et al.'s (1977) Experiment 1, the mask was placed alternatively on the central or peripheral side of the target at random from trial to trial.

The subject did not know which was the target before a trial and thus may have had to inspect both items before responding. The estimate of the magnitude of the asymmetry effect could be biased if subjects tended to start their inspection of the array with either the more central or the more peripheral item. Experiment 2 reduces the possiblity of subjects adopting a consistent central-peripheral or peipheral-central order of inspection by presenting mask-central and mask-peripheral stimuli in separate blocks. The subjects know on every trial that they are to decide on the identity of only the central or only the peripheral element.

Experiment 3 examines one possible interpretation of lateral masking in the configurations used in Experiments 1 and 2 (and in all three experiments of Banks et al., 1977). This explanation is that the target and noise (or pair of targets) are joined together by the visual system into a single Gestalt from which the features of the elements must be extracted for the inidividual elements to be identified. If this interpretation is correct, then the lateral masking effect of a given masking element should be reduced if other elements are added to the array in such a way as to cause the mask to form a group with the other elements rather than with the target to be identified. As it turned out, this prediction was upheld, and the Gestalt explanation as well as alternatives will be considered in the discussion of that experiment.

EXPERIMENT 1

Method and Procedure

Subjects directed their regard to a fixation point on either the left or right side of the same large luminous panel used in Banks et al.'s (1977) Experiments 2 and 3. Two black letters, 20′ wide and separated 20′, 35′, or 50′ from center to center were presented on the panel outside the subject's field of vision. One second after the target letters were presented, they were moved together toward the fixation point at a rate of 1°/sec, and when the subject, keeping his or her gaze on the fixation point, identified both letters, the trial was concluded. The targets were kept in motion until both were identified. Half of the subjects were instructed to respond as soon as they throught they knew the identity of the target, and half had a more stringent criterion, being instructed to respond when they could clearly see each target. Trials where the subjects moved their eyes, incorrectly identified targets, or failed to identify targets were repeated later in the session. When the subject identified each target, the experimenter noted its eccentricity, as well as the order of identification (inside first, outside first, or simultaneous). The experimenter waited until the end of the tiral to record the data.

There were four target letters: A, H, V, and Y. The letters, black Rotex rub-on letters (48Pt/R-1948-C), measuring approximately 20′ wide and 50′ high, were mounted on thin strips of transparent plastic exactly the width of each letter.

Stimuli were viewed against a 56-cm-wide × 25-cm-high back-illuminated milk Plexiglas panel from a distance of 2.1 m. The luminance of the panel was 12 fL, and the letters were opaque. The luminous panel was set in a larger black frame and covered by an opaque shutter that was hinged above the panel. The subject fixated a small (10′) bright (approximately 18 fL) light on one side of the panel prior to a trial. Once fixation was achieved, the experimenter pulled a cable to raise the shutter, exposing the panel and the stimuli used for that trial. While the subject kept his or her gaze on the fixation light, the experimenter moved the targets at a rate of 1°/sec toward the fixation point until the subject correctly identified both targets.

The subjects (eight females and four males aged 18-32, all with vision at or corrected to at least 20/25) had three 30- to 60-min sessions, some on separate days. The first session was always devoted to 72 trials of practice. During this session, the subjects practiced maintaining a constant fixation and generally became accustomed to the task, the appearance of the letters, and so forth. An important function of the practice session was to train subjects to maintain fixation, since eye movements were not electronically monitored during data-collection trials. Banks et al. (1977, Experiments 2 and 3) compared results using this apparatus in a similar experiment with and without monitoring of eye movements, and found that the results did not change in any systematic way when eye movements were monitored in order to train subjects and to exclude data trials on which eye movements occurred. The Banks et al. (1977) research indicated that subjects could follow instructions to maintain fixation, that saccadic eye movements during data trials usually occurred only after the target was identified, and that the experimenter, by watching the subject's eyes, could detect saccadic glimpses at the target nearly as well as he could by monitoring the electronic apparatus that measured eye movements.

The experiment had 72 unique conditions defined by the orthogonal combination of the 12 different pairs of the 4 target letters, 2 visual fields, and 3 different separations between letters. The 72 conditions were given to each subject twice in two separate randomized blocks.

Results

Figure 2 shows the eccentricity at which the more peripheral and the more central element was identified. This plot displays asymmetry of masking, assuming each target serves as a mask for the other target, since the more central target had to be moved closer than the peripheral target to be seen. This asymmetry effect is reliable [$F(1,10) = 16.1, p < .01$]. Also apparent in Figure 2 is the effect of the distance between the targets. This effect indicates that there was mutual masking between the targets, since both targets were seen at greater eccentricities as they were separated farther, the mean points of visibility

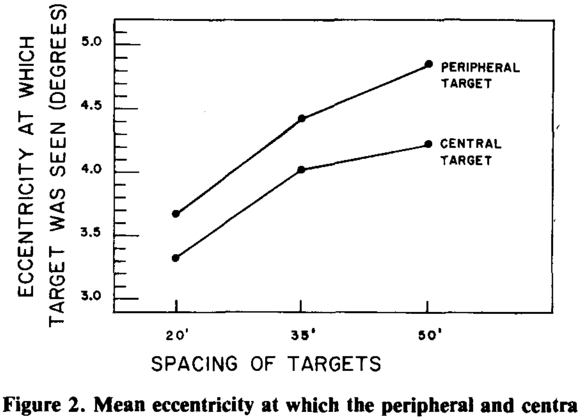

Figure 2. Mean eccentricity at which the peripheral and central members of a pair of targets was seen as a function of the target-target spacing (Experiment 1).

being 3.5°, 4.2°, and 4.5° for separations of 20′, 35′, and 50′ respectively. This effect is reliable [F(2,20) = 64.5, $p < .01$]. There was a small but reliable ($p < .025$) interaction between target-target separation and central vs. peripheral placement of target [F(2,20) = 4.6], as can be seen in the slight nonparallelism of the functions in Figure 2. The mean effect of instructions was extremely small (about .01°), and instructions, as well as all interactions with this variable, had a F ratio well below reliability. Finally, there was a right visual field superiority: targets were seen at a mean eccentricity of 4.24° in the right field but had to be brought to 3.92° in the left to be seen [F(1,10) = 8.3, $p < .025$].

The asymmetry effect seen in Figure 2, as well as the interaction between asymmetry and target-target separation, can both be accounted for if the subject is not assumed to see the two items independently but, rather, analyzes both out of a cluster simultaneously. Support for the idea of analysis of targets from an initial cluster will be given below, but first we should consider the evidence that both seen at the same time.

Data on the order of seeing the items indicate that neither the central nor the peripheral item has an advantage, that is, that they are on the average seen simultaneously. For target-target spacings of 20′ the central item was seen first 40% of the time and the peripheral one 44% of the time; for spacings of 35′, the central item was seen first 47% of the time and the peripheral one 43% of the time; and for spacings of 50′, the central item was seen first 50% of the time and the peripheral item 39% (the percentages do not add up to 100% because the report "simultaneous" was allowed). The overall central-peripheral difference in item reported first (45.7% for the central item vs. 42.0% for the peripheral one) is not reliable ($F < 1.0$ both with an arc sine transformation and with untransformed percentages). While the trend of differences is not reliable, the pattern suggests that when the two items are close together, neither has an advantage, but as they are spaced farther apart (and are thus less likely to be proximity-grouped together), the central item begins to be seen first more often than the peripheral item.

Some effects involving the order of report did attain significance. The decrease in "simultaneous" reports with target-target separation is nearly reliable [F(2,22) = 3.0, $p < .10$], and the increase in central-first relative to peripheral-first reports with increases in target-target separation is highly reliable [F(2,22) = 7.8, $p < .01$]. The only differences between the two groups that even approached significance turned up in this analysis. The group instructed to use the looser criterion ("report the letters as soon as you think you know what they are") was less likely to give a "simultaneous" report than the group instructed to use a stricter criterion ("report the letters as soon as you can clearly see both"). The probabilities of simultaneous reports for the two groups were .034 and .21, respectively [F(1,10) = 19.3, $p < .01$]. The other reliable effect was an interaction with groups such that the group with the looser criterion had the same proportion of "simultaneous" reports at all target-target separations, while the stricter group had a decrease in "simultaneous" as target-target separation increased. The F(2,20) was 7.78, $p < .01$, for this test, but the interaction is quite possibly a floor effect.

The near-simultaneity of reporting the central and peripheral items indicates that the asymmetry effect observed in Figure 2 may only be the inevitable consequence of the fact that the central item is closer to the fixation point than the peripheral one and so must be closer to the fixation point when the two are simultaneously detected. The separation between the two functions in Figure 2 is, indeed, approximately equal to the target-target separation. A correction procedure like that used in Banks et al. (1977) can be used to adjust the position of each target in the field so that the eccentricity recorded for the point at which the item is seen is not the item's position but rather the midpoint of the cluster in which it falls.

This correction applied to the data almost perfectly compensates for the asymmetry effect, giving a grand mean of 4.11° for seeing the peripheral target and 4.05° for the central target. The very small asymmetry effect remaining after the correction (only .05° or about ¼ the width of a letter) is not reliable [F(1,10) = 0.20, n.s.]. The interaction between target-target distance and asymmetry declined to marginal significance [F(2.20) = 2.6, $p < .10$] and was changed in form by the correction. Whereas with uncorrected scores the apparent degree of the asymmetry effect increased monotonically with target-target separation (see Figure 2), the asymmetry effect remained (though it was reduced) only for the 20′ target-target separation, and it was reversed for both 35′ and 50′ separations.

Two comments on this experiment seem in order. First, the results could be misinterpreted as showing there was no lateral masking at all. However, the data clearly show that there were lateral interactions among the items. The very fact that the eccentricity at which either target was seen increased with target-target separation indicates that there was some inhibitory interaction between targets that declined as their separation increased. Furthermore, single targets were seen at far greater eccentricities than either member of the pairs presented in this experiment. Because data for the points at which the 12 subjects saw singly presented targets were not systematically recorded, new data had to be obtained. A group of 5 subjects was given the task of detecting single targets under the same conditions as those under which the 12 experimental subjects had seen the pairs of targets (the stricter reporting criterion was used for these 5 subjects). These subjects saw the target at a mean eccentricity of 9.4°, with a range from 7.5° to 11.5°; this is reliably further in the periphery than the 12 experimental subjects could see the target on the average [$t(15) = 2.74$, $p < .01$], and it is considerably more peripheral than for any of the conditions with the dual target.

A second comment concerns the technique for recording a subject's responses. The procedure was well practiced and designed to minimize errors of recording. Nevertheless, there is always the fear that some systematic bias affected the results. Rather than attempt to ferret out the possible remaining biases in the technique, we decided to perform Experiment 2, which approaches many of the same questions as Experiment 1 but with an altogether different technique.

EXPERIMENT 2

Method

Subjects viewed a computer-controlled cathode-ray tube display and decided, on each of 512 trials, whether an uppercase A, U, Y, or T had been presented. Each array consisted of a target and an uppercase H (the masking letter). All letters were PDP-11/10 hardware characters, seen at 57 cm. The target-mask pair was separated by either ½° or 1° center-to-center, and the mask could be either on the central or peripheral side of the target. (Letter width was approximately .3° and height was approximately .4°.) The target was placed either 1°, 2°, 3°, or 5° along the horizontal axis from the fixation point in either the left or right visual field. The experiment was therefore similar to Experiment 1 in that pairs of letters a constant distance apart were presented, but instead of moving the pairs toward the center of the field until they were seen, as was the case in Experiment 1, in this experiment the target-mask pairs were presented briefly at certain positions in the field, and accuracy of detection of the target was the dependent variable.

Subjects (eight male and female Claremont College students paid $2/h for participating, all having 20/25 or better vision) performed on 2 different days. On the 1st day, they had a 90-min session, of which the first 30 min was devoted to 128 practice trials and the remaining 60 min to 256 data trials. Stimulus duration was reduced from 200 to 75 msec during practice and was 75 msec on data trials. The 2nd day had a short block of practice trials and 256 data trials, which, with rest periods, lasted 1 h. The stimulus duration was 60 msec on all data trials on the 2nd day.

Procedure. The subjects were instructed to respond on every trial with one of the four alternatives even if they had to guess. Within each session, there were 4 blocks, each containing all combinations of the 2 target-mask separations, the 4 targets, 4 positions of the target, and 2 visual field locations (a total of 64 stimuli/block). The blocks differed in whether the mask was on the central or peripheral side of the target. This procedure was used to prevent the subject's having any uncertainty as to which item to inspect. On every trial, the subject knew in advance whether the target was the central item or the peripheral item. The within-block stimuli were presented in a different random order for each block. The between-block variable (mask central vs. mask peripheral) was presented in an ABBA order over the four blocks on the 1st day and BAAB on the 2nd, with A being the mask peripheral condition for half the subjects and mask central for the other half.

Results

Figure 3a plots the falloff in accuracy of detection with eccentricity of target for the two target-mask separations and the mask-peripheral and mask-central conditions. This figure collapses the data over session, day, identity of target (A, U, Y, or T), and visual field of presentation.

The asymmetry effect ranged from .4% at an eccentricity of 1° to 11% at 5°, with a mean of 5%. It was highly significant [$F(1,7) = 16.2$, $p < .005$] and was found for every subject. The effect of target-mask separation was also reliable [$F(1,7) = 5.9$, $p < .05$]. The decline in proportion correct with retinal eccentricity was an extremely strong and regular effect [$F(3,21)$ of 76.8, $p < .005$]. The final reliable main effect is retinal field [$F(1,7) = 8.5$, $p < .025$], with the left visual field having a slight (3%) advantage over the right. The only reliable interaction is a three-way interaction between asymmetry, eccentricity of target, and visual field [$F(3,21) = 3.8$, $p < .05$]. This interaction is one in which the shapes of the retinal eccentricity functions are slightly different for the four combinations of asymmetry and visual field, but it seems uninterpretable. Probably more important than this interaction is the lack of interaction between any of the other variables.

Figure 3b plots detection accuracy as a function of the eccentricity of the midpoint of the target-noise cluster. The lines in the figure connect points in the

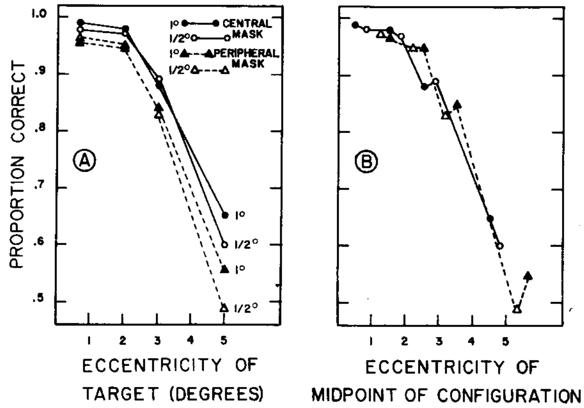

Figure 3. (A) Accuracy of target recognition in Experiment 2 as a function of eccentricity of target for conditions with a central and a peripheral mask and for two target-mask spacings (½° and 1°). (B) Data of Figure 3A plotted with midpoint of target-mask configuration rather than position of target as abscissa. The solid line connects data points from conditions with a central mask, and the dotted line connects points from conditions with a peripheral mask. Note that the asymmetry effect seen in panel A is eliminated with the plotting in panel B.

mask-peripheral (dashed line) and the mask-central (solid line) conditions. As can be seen, the functions for mask-central and mask-peripheral conditions show only slight and unsystematic differences when plotted this way. Figure 4 presents a plot that shows the asymmetry effect (or the lack thereof) more clearly than the sort of plot seen in Figure 3. Here the proportion correct, Pp(x), for the mask-peripheral condition is plotted against the proportion correct for the mask-central condition, Pc(x), at the same eccentricity. Asymmetry of masking would be indicated whenever the plotted point fell below the positive diagonal, drawn in the figure and labeled as $Pp(x) = Pc(x)$. This is just the graphic expression of the definition of asymmetry of masking, which is that $Pp(x) < Pc(x)$ for any value of x (degree of eccentricity).

As can be seen from the open symbols plotted in Figure 4, when the position of the target alone is taken as the measure of retinal position, the masking appears to be asymmetrical. However, when the position of the midpoint of the target-mask configuration is taken as the measure of retinal position, there is no asymmetry of masking at all for the 1° target-mask separation and a slight superiority for the mask-peripheral condition (i.e., the reverse of the usual asymmetry effect) for the ½° separation.

The points in this figure are for eccentricities of 1°, 2°, 3° 4°, and 5°. For the open symbols, only the points for 4° (next-to-worst performance) are derived from fitted curves; all the other points simply plot the experimental data for those eccentricities. All the closed points are derived from curves fitted to points in a plot like that in Figure 3b. A smooth curve was drawn through the points to get the proportions plotted as solid symbols in Figure 4, but very nearly the same plot in Figure 4 is obtained with a strictly linear interpolation between points in the plot of Figure 3b. The functions in Figure 4 are, in fact, quite insensitive to the form of the function fit to the plots in Figure 3. It is interesting that the plots in Figure 4 are very nearly linear. A number of speculations could be made about the linearity, but that would take us too far from the points at issue here.

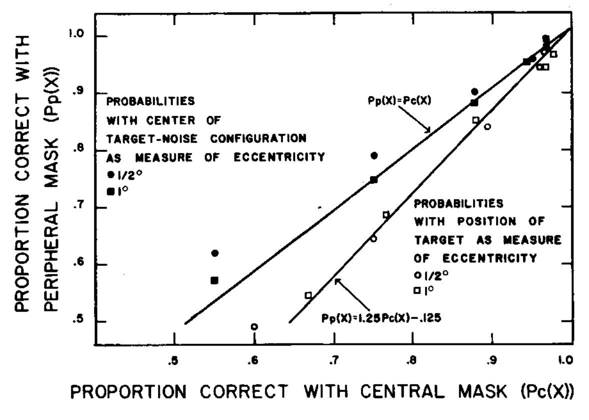

Figure 4. Accuracy with peripheral mask plotted as a function of accuracy with central mask (Experiment 2). Open symbols represent data with target location taken as measure of eccentricity; closed symbols represent data with center of target-noise configuration taken as measure of eccentricity.

EXPERIMENT 3

Theoretical explanations of lateral masking have put the locus of the effect at several different levels. Bouma and his colleagues (e.g., Andriessen & Bouma, 1976) have suggested that an interaction among line or feature detectors may be responsible for the interference. Taylor and Brown (1972) speculate that lateral masking may be similar to "erasure" in metacontrast masking among successively presented elements (1972, pp. 98-99). Presumably, they, too, have in mind a mechanism that, like Andriessen and Bouma's lateral interference, operates at a fairly early stage of visual processing, prior to processes of recognition or decision-making.

Estes, Allmeyer, and Reder (1976) have proposed that the interference among letters results from recognition difficulties caused by the positional uncertainty of features (they also allow for lateral masking at a sensory level if elements are close together). By assuming that positional uncertainty increases with retinal eccentricity and that the positional uncertainty gradient is skewed such that features are shifted centrally, they can explain the essential phenomena of lateral interference. The steeper retinal acuity gradient for multiple than for single letters follows simply, as does the proximity effect (interletter interference declines as their separation from each other is increased). The asymmetry of masking follows from the skewed uncertainty gradient, since features of the more peripheral letters of an array will intrude upon the more central letters to a greater extent than the central ones will intrude upon the peripheral ones. Still higher level explanations include Mackworth's (1965) explanation in terms of scanning strategies and Shaw's (1969) explanation based on processing limitations and effects in short-term memory.

Here we suggest a mechanism for lateral interference that might be at a higher or lower level, depending upon one's interpretation. The mechanism is similar to that of Estes et al. (1976) except that the mixing or confusion of features among adjacent letters does not come from a positional uncertainty gradient that operates in the absence of other letters in the field. Rather, it comes about because of a tendency of the visual system to form single perceptual groups or channels by combining elements and features according to what are essentially Gestalt

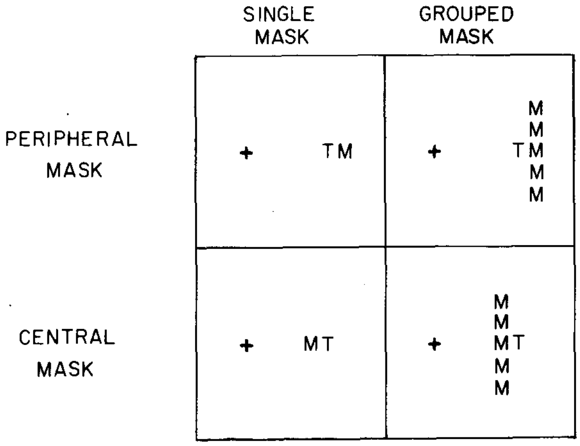

Figure 5. Schematic representation of the critical conditions of Experiment 3. The target (T) was a constant distance from the fixation point (±), and the mask (M) was either peripheral or central and was either single or grouped in a string of identical masking elements.

principles. This hypothesis does not assume a skewed uncertainty gradient or a peripheral-central drift of confusions, but it does assume that the periphery of the visual field is more prone to forming groups than the center is, as Beck's (1972) research has shown.

Experiment 3 tests two predictions of the grouping hypothesis. The predictions concern arrays like those in Figure 5. The ungrouped arrays (where T is target and M, mask) in the figure represent stimulus configurations used in Experiments 1 and 2 in Banks et al. (1977). The grouping hypothesis attributes at least a component of the lateral masking to the fact that target and mask get combined into a single perceptual channel (by proximity grouping), and detection of the target is therefore hampered because target and mask information must be separately analyzed out of the configuration. The asymmetry effect comes about because the configuration as a whole is in a more peripheral region, and thus one of lower acuity, with a peripheral than with a central mask.

The test in Experiment 3 compares the predictions of the grouping hypothesis with a class of theories we will term *linear* theories. A linear theory postulates no interaction among the letters, but assumes that masking is a result of events that take place both when either element is alone in the field and when it is combined with others. The theory of Estes et al. (1976) is an example of a linear theory, since the positional uncertainty gradient for an element is not assumed to vary with the number of other elements in the field. The grouping theory, on the other hand, is nonlinear in the sense that elements in the field are combined to create new elements and thus create effects that cannot be predicted from the effects created by single elements. Both a linear and a nonlinear theory like the grouping theory make the same predictions for the ungrouped mask condition in Figure 5. However, predictions differ for the grouped mask. First, the grouping theory predicts that if a stronger grouping principle than proximity can be used to cause the masking letter to group separately from the target, the masking effect will be released (this assumes that perceptual groups are exclusive: An element cannot join simultaneously with two different perceptual groups). Thus, there should be less masking and better overall performance in configurations like those with the grouped mask in Figure 5. The linear sort of theory, on the other hand, predicts no such release of masking. Regardless of the configuration, the mask and target should interfere equally as long as their distance from each other is kept constant. If anything, a linear theory predicts that the grouped configuration would give worse performance than the ungrouped one, since the additional elements should exert some masking effect of their own.

The second prediction concerns the difference in performance between grouped masks (see Figure 5). A linear theory, like Estes et al. (1976), would not only predict worse overall performance for grouped masks than for single masks, but would also predict that there would be more asymmetry with grouped masks than with single masks. This is so because, in the case of peripheral masks, there would be more opportunity for features to intrude on the target with multiple masks than with single masks. The grouping hypothesis, on the other hand, predicts that with grouped masks the masking items will group together separately from the target, reducing the cause of the lateral masking and the asymmetry effect, as well.

Method

The same computer-controlled CRT display used in Experiment 2 was used here, with the same computer-generated hardware characters. All targets were at 5° from the fixation point in either the left or right visual field, with target-mask separation alway 1°. The targets were A, Y, U, and T and the mask always H, as in Experiment 2. In the grouped mask condition, all displays had target and noise spaced exactly as those in the ungrouped conditions, except that 4 Hs were added to the array, two above and two below the masking H, separated by about 1° center to center on the vertical dimension and lined up exactly at the same point on the horizontal axis.

Design and Procedure. The experiment had four variables: grouped vs. ungrouped mask, central vs. peripheral mask, presentation in left vs. right visual field, and target (A, U, Y, or T), making 32 different experimental conditions (2 by 2 by 2 by 4). The trials were organized into four types of block: grouped central mask, grouped peripheral mask, single central mask, and single peripheral mask. This blocking was used to prevent subjects from having any uncertainty about the identity of the target; it was always either the most peripheral or the most central member of a configuration. All four types of block were presented twice on each of 2 experimental days in an order counterbalanced across subjects on each day and within each subject over the 2 days. Each block had eight repetitions of the eight within-block conditions; since each block was presented twice on each day, every condition was repeated 32 times, making a total of 1,024 experimental trials per subject.

Each day of testing began with a practice session in which subjects saw all 32 different stimuli. Stimulus duration was reduced during practice from 200 to 100 msec, which was the stimulus duration for all subjects on data trials. After practice trials were completed, the experimenter answered any questions the subject had and began data trials. All trials began with a fixation dot in the center of the field. The fixation dot appeared for 2 sec and then dimmed slightly ½ sec before the stimulus appeared. The stimulus then appeared for 100 msec, after which the field remained blank until the subject responded. Immediately upon the response, the fixation point reappeared, and the sequence began again. Subjects were given a rest period after the fourth block. The entire session lasted about 1 h on each day.

Results

Figure 6 presents the finding of central interest, the proportion correct for grouped and single masks on the central and peripheral side. As can be seen, the asymmetry effect is obtained in the single mask condition, a not surprising result since this condition replicates a condition of Experiment 2 that obtained the asymmetry effect. However, as predicted, the asymmetry effect is not found when the mask is grouped, even though there are actually more extraneous characters in the field with the grouped than with the single mask.

The interaction seen in Figure 6 is reliable [F(1,7) = 10.12, $p < .025$]. The direction of the interaction is just the opposite of what would be predicted by a linear theory. The simple main effects verify that it is reliably a crossover interaction: The inside mask condition is reliably better than the outside mask condition for the single mask [F(1,7) = 40.4, $p < .01$], and the reverse is the case for the grouped mask condition [F(1,7) = 8.9, $p < .025$]. The fact that the mask outside was better for the grouped mask condition was surprising, and a post hoc explanation in terms of grouping will be presented in the discussion.

Besides reversing the asymmetry effect, the grouped mask also increased performance reliably [F(1,7) = 8.44, $p < .025$]. This effect is predicted by the grouping hypothesis of masking. Unfortunately, we did not have a condition in which a target was presented alone, with no mask at all, and so we cannot tell to what extent the grouping released the lateral interference. A final reliable effect, but one of little interest, is the difference between the target letters [F(3,21) = 10.4, $p < .01$]. Accuracy for the letters Y, A, U, and T was, respectively, 38.5%, 63.5%, 62.9%, and 60.1%. The reliable main effect seems mainly to be due to the poor performance on Y. By the Scheffé test of differences among the means, which requires a 5.6% difference for the .05 level of reliability, accuracy for A, U, and T is equivalent and Y is different from the others. The effects seen in Figure 6 are qualitatively the same for all four targets, and F <1.0 for the interaction among grouping, peripheral vs. central mask, and target letter.

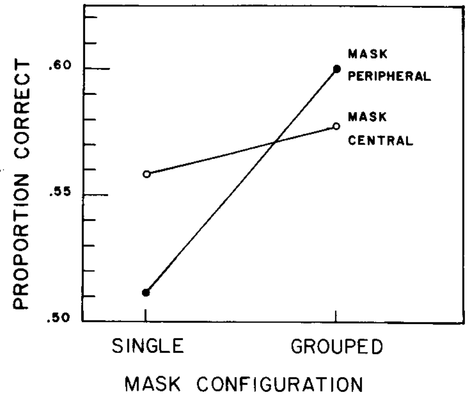

Figure 6. Accuracy of target identification as a function of single and grouped mask for mask central and mask peripheral conditions (Experiment 3).

GENERAL DISCUSSION

The three main points of this paper would benefit from a brief summary and some discussion here. First, this paper strengthens the conclusion that lateral interference among items in the visual field, as well as the asymmetry of interference, exists when such processing factors as readout order, capacity limitations, and memory load are controlled for or eliminated. Experiment 1 strengthens the conclusion because it provides converging evidence in support of a purely sensory component, and Experiment 2 eliminates at least one previously uncontrolled nonsensory factor that might have affected the outcome.

Second, the asymmetry effect, when all processing components of lateral masking are eliminated, can be accounted for by the central-peripheral retinal acuity gradient. The gradient to be used in the prediction is not the gradient for a single element but the steeper gradient found for multiple elements. The simplest way to test the prediction is to plot performance as a function of the midpoint of the target-noise cluster for arrays with both central and peripheral masks. Such a plotting automatically used the acuity gradient appropriate for the stimuli and "corrects" target position along this gradient so that the measure of stimulus position is more eccentric with a peripheral mask than with a central mask, and the poorer performance with the peripheral mask is accounted for.

We are aware that a number of studies have obtained asymmetry effects that are too great to be accounted for by the appropriate acuity gradient (cf. Bouma, 1973; Estes et al., 1976). However, in every study showing greater asymmetry than the acuity gradient can account for, there have been aspects of the experimental procedure that might implicate cognitive processes other than the strictly sensory ones. For example, Estes et al. (1976) required subjects to report an entire array of four elements on each trial. In addition to possible (but unlikely) short-term memory and processing capacity limitations, there is the problem that elements served as both target and masks. Whatever sensory interference effects there were may have been exacerbated by the difficulty of disentangling features from two or more letters. In the Bouma (1973) study, there were fewer demands on decision processes, but subjects still had to find and report both of the end items of a three-item array. Bouma's asymmetry effect is more nearly eliminated by correcting for the retinal acuity gradient than is the asymmetry effect of Estes et al. (1976), and the present asymmetry effect (obtained from experiments that attempt to remove the last bit of cognitive processing difficulty) are completely accounted for by the retinal acuity gradient. Since the corrected amount of asymmetry thus seems to decline to zero as the nonsensory factors are removed from the task, it seems reasonable to conclude that there is no asymmetry at the sensory level beyond the amount attributed to the acuity gradient.

Third, and finally, we should consider the configurational hypothesis evaluated in Experiment 3. The results of Experiment 3 are taken to show that causing the mask to form a perceptual group with elements other than the target prevents it from grouping with the target and from interfering with perception of the target. This result is consistent with the grouping hypothesis that the addition of grouped masks would improve performance. More noteworthy, contrary to predictions of a linear theory of masking, with a grouped mask the asymmetry was reversed: performance with the mask on the peripheral side was reliably better than with the mask central. A simple explanation in terms of the grouping hypothesis is that, in the mask peripheral condition, the mask elements group together separately from the target more than they do in the mask central condition. The greater grouping of mask elements in the mask peripheral condition results from the greater tendency for grouping in the periphery (Beck, 1972).

In retrospect, the Estes et al. (1976) finding of worse performance when the noise elements changed at the same time the stimulus string appeared than when they were left constant throughout may also be an effect of perceptual grouping. When the stimulus string is presented against an unchanging background of noise elements, it should be expected to group separately from the noise and so be perceived better than when it appears in the company of new noise and is perceptually grouped with it, just as the target in our Experiment 3 was seen better when the noise was grouped separately from it.

The configurational hypothesis provides, we think, an excellent rationale for the effectiveness of correcting for the acuity gradient in equalizing performance in mask-central and mask-peripheral conditions. The rationale follows because, by the hypothesis, the target-noise cluster is properly to be conceived of as a single perceptual object or channel of information, and therefore the position of the center of the configuration as a whole rather than of the target within it should determine performance.

The configurational hypothesis is also convenient in explaining the results of Experiment 1, in which the two elements of a pair brought in together from the periphery are generally seen at the same time even though one is closer to the fovea than the other at the time they are seen. The configurational hypothesis explains this as an effect of the confusing of the features of the letters in the perceptual cluster formed by the pair. As soon as the cluster reaches a point at which the grouping tendency is weakened enough to allow either target to emerge from the group, the other emerges and both are seen simultaneously. An alternative hypothesis that postulated an asymmetrical spread of intereference from an element in the field would have to explain the effect of Experiment 1 as a combination of the relative eccentricity of the two targets (which puts the more peripheral target in a region of lower acuity and therefore of worse performance than the more central target of the pair) and the relative degrees of masking of the two elements (which, because of the asymmetry of masking, puts the central element at a disadvantage relative to the peripheral one). To explain the results of Experiment 1 (or of Experiment 2 and all of the studies of Banks et al., 1977, for that matter), these two effects would have to cancel each other exactly for all degrees of interelement spacing. Postulating such a fortuitous cancellation of opposing tendencies seems inelegant at best and ad hoc at worst.

The question of the mechanism assumed by the configurational hypothesis has two parts. First, we can ask how a configuration is formed, and second, we can ask how, once formed, it affects performance. The Gestalt psychologists, when they attempted to explain how Gestalts are formed, generally proposed physiological mechanisms that we now know cannot be correct. The most promising modern theoretical developments on the question of Gestalt formation seem to be those that appeal to a spatial frequency analysis by the visual system (Broadbent, 1977; Navon, 1977). By this account, the Gestalt is of a lower spatial frequency than the component elements. It does, in fact, seem plausible that something like this account could apply to the grouping of a pair of elements, since the fundamental frequency component of the pair is lower than those of any of the elements. Furthermore, to explain Experiments 1 and 2, the grouping tendency would have to increase as elements are moved to the periphery, and it does indeed seem plausible both that grouping does increase toward the periphery (Beck, 1972) and that the predominance of sensitivity to lower spatial frequences increases toward the periphery. Experiment 3 also agrees with the spatial frequency hypothesis, since the grouping of masking elements introduces a cluster with a spatial frequency lower than that of the original pair.

The other question, how grouping could affect performance, is more difficult to answer and more uncertain empirically. Banks and Prinzmetal (1976) and Prinzmetal and Banks (1977) found performance on identifying a target to decline when the target was perceptually grouped with noise elements and to improve when the noise grouped separately. Their findings are analogous to those of Experiment 3, and the explanation they used is applicable here. They drew an analogy with findings in the selective listening literature. When a subject attempts to shadow a single voice, performance is better when the voice is perceptually grouped separately from (on a different channel from) other, interfering, irrelevant sounds or voices. By the same token, the perception of a visual target should improve when it is seen in a different channel (perceptual group) than the noise is. Kahneman (1973) has also developed this analogy. His "suffix effect" (1973, pp. 133) is, incidentally, quite similar to our grouping effect in Experiment 3.

Finally, we recognize that just because a manipulation of perceptual grouping will *release* target-mask interference (Experiment 3), it is not valid to conclude that perceptual grouping *caused* the interference in the first place. It is possible that a different mechanism altogether causes interference and that grouping is but one of many ways to overcome it. However, the explanatory convenience of the grouping hypothesis of lateral masking, combined with the results of Experiment 3, leads us to accept grouping processes as the basis of the sensory component of lateral masking until a more satisfactory hypothesis is found.

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