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MASKING EFFECTS OF SIMILAR AND DISSIMILAR LETTERS: A TEST OF THE INTERACTIVE CHANNELS MODEL[1]

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Summary.—Subjects identified which of two target letters was presented when the target was accompanied by a similar or dissimilar noise letter, the target appeared on the right or left of fixation, and the target was central or peripheral to the noise letter. Although performance deteriorated in the presence of noise letters compared to control conditions, masking was no greater with similar than dissimilar noise letters. Rather masking effects were specific to particular target-mask pairs, suggesting facilitation of target perception when mask and target shared features critical to the target-discrimination task. Thus, no evidence for Estes' interactive channels model was obtained. Neither the left vs right position of the target nor its centrality had any effect on accuracy or speed. Correct latencies to a target covaried with its accuracy of detection, but incorrect latencies were more strongly associated with the target identified than with the target presented.

It is a well-established finding that visually exposed letters are harder to detect when surrounded by other, unrelated letters (although they would appear to be easier to detect when surrounded by letters making up a word, e.g., Reicher, 1969; Wheeler, 1970). It is of considerable interest to determine why letter perception is interfered with by other letters. At least two loci for the phenomenon have been suggested. Estes (1972, 1974) has proposed an interactive channels model which suggests that interference takes place at the letter feature level. Specifically, Estes suggests that letters sharing features compete for the same feature detectors and hence mask one another more than letters not sharing features. Gardner, in contrast, argues that the effect of letter similarity occurs at the decision rather than at the feature detection or sensory level (1973).

Evidence on which both models are based comes from studies varying the heterogeneity of a noise background and the multiplicity of target elements. However, direct evidence that similarity of noise elements to target elements interferes with target detection is lacking. The most straightforward test of such an empirical relationship, and hence a test of the interactive channels model, appears to be one in which similarity of letter masks to letter targets

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is varied directly, to determine what effect similarity has on detection performance. Some investigators have found that similar masks can actually enhance target detection over dissimilar masks (e.g., Eriksen & Eriksen, 1974; Gilmore, 1975).

The present experiment investigated lateral masking effects of similar and dissimilar letters in the two alternative forced-choice recognition paradigm used by Estes and Taylor (1964). Similarity between target and mask is varied by selecting each from two sets of letters—those sharing curved features (D and O) and those sharing straight features (I and L). Thus a target could be any of four letters as could its accompanying mask. In addition, targets could be either central or peripheral with respect to the mask. The stronger effects of a space on more central compared to peripheral letters has been shown in several studies (Bouma, 1973; Estes & Wolford, 1971; Shaw, 1969; Townsend, Taylor, & Brown, 1971).

Finally targets could appear in either the right or left visual field. Possible left vs right visual field differences have been the subject of even more experimental and theoretical attention, with right-field advantages when there is a difference (Bouma, 1973; Bryden, 1970; Mishkin & Forgays, 1952; White, 1969) although only recently has this variable been specifically manipulated in the context of lateral interference. Both accuracy and latency measures were collected over a large number of experimental sessions so that relationships among dependent variables could be studied.

METHOD

Subjects

The subjects were four adults employed in various capacities at Rockefeller University and were paid for their participation. The vision of all subjects was normal or corrected to normal.

Apparatus and Stimuli

The displays were presented in a Scientific Prototype 3-field tachistoscope. The subject's response choice and latency were recorded by a logic controlled Beckman counter and printed out on a Teletype. Field 1 was set to maximum luminance and then the other two fields were matched to be subjectively equivalent in brightness to field 1 and to one another by one of the experimenters. The illuminating lamps were changed after every run of 40-subject sessions (approximately 2 wk.).

The upper case letters I, L, D, and O were used in pairs for a particular block of trials as stimuli, and presented either to the right or to the left of a fixation point. They were typed on blank white cards with an IBM executive typewriter; this produces a clean font with no extruded seriphs. The height of the letters subtended 2/3 degree and the widths were I = 1/4 degree, L = 1/3 degree, D = 2/5 degree, and O = 1/2 degree. The closest visual angle between any parts of two letters was between 8/100 and 17/100 degree. The target letter always appeared 1.25 degrees to the right or left of fixation, and the accompanying noise letter was either central or peripheral, i.e., inside or outside relative to the fixation point, to the target letter. Thus the total viewing angle varied from about 2.5 degrees when the noise letter was central to the target to about 3 degrees when it was peripheral.

Procedure

Before the experiment proper, subjects received 10 days of practice, during which display durations were calibrated to yield approximately 75% accuracy. The final display durations varied from 14.5 msec. to 17 msec. and were held constant throughout the remainder of the experiment. Calibration was achieved using stimuli selected at random from the main experimental conditions. Subjects were given feedback after all trials.

Two types of control conditions, a response control and a retinal control, were run in addition to the main experimental (masking) conditions. The *response control* condition was employed to provide an upper bound on performance in a stimulus situation involving minimal discrimination difficulty, optimal retinal locus of the target, and in the absence of interference from a noise letter. The letters I and O were generated singly in a random order (subject to the constraint that no more than three successive presentations of the same letter were allowed). Letters were presented directly above the fixation point, and the subject's task was to press the appropriate response identification button. The response control condition was run 192 trials on the first day after calibration and on the last day after running the main experimental condition, resulting in a total of 384 trials of this type.

The *retinal control* condition was the same as the main experimental condition except no masking letters were present. As in the main condition, either the two curved letters (D and O) or the two straight letters (I and L) were used as possible targets during a given block of trials, but curved targets were not mixed with straight targets. Targets appeared at the same retinal positions as in the main condition. Thus, each block of retinal control trials was composed of a random sequence of Ds and Os or, alternatively, of Is and Ls each presented randomly to the right or left of fixation. The retinal control trials were run on main experimental days, alternatively at the beginning or end of the experimental blocks. There were two retinal control blocks of 12 trials each per day, one block using curved targets and the other using straight targets. Since there were 24 main experimental sessions, 288 retinal control trials per subject per target class were collected.

The masking conditions tested performance on curved and straight letters as targets, varying left-right location and noise-letter within blocks, and target pair (D and O or I and L) and central-peripheral location between blocks.

Thus, there were four major types of blocks: (1) D or O as targets in the periphery; (2) D or O centrally; (3) I or L peripherally; (4) I or L centrally. For a given block of trials, then, the subject knew which pair of targets he was to identify and whether the targets would be central or peripheral to the masks, but any of the four masks could be used and the target/mask pairs could appear either to the right or the left of fixation. The blocks were constrained so that one-half of the trials were with one of the two targets, one-half were on the left, and one-fourth were with each of the four noise-letters.

It is important to emphasize that "peripheral" and "central" refer to the position of the target relative to the noise letter, and that the target itself was always placed the same distance away from the fixation point; the noise letter on any given trial was inside or outside the placement of the target.

The main experimental trials were run in blocks of 48. During each session, there were four blocks; first, two blocks with the curved or straight letters as targets and then two blocks with the other pair as targets. Within each pair of blocks, one contained peripheral targets and the other contained central targets. The orders of target pair and central-peripheral placement were counterbalanced across sessions. There were a total of 24 main experimental sessions plus two sessions devoted to the response control. In both control and main experimental conditions, the fixation point was presented for 2 sec. followed by the stimulus presentation, which in turn was followed by a blank field that lasted until the next trial. Each trial was initiated by the subject with a foot switch.

RESULTS

As expected, the response control condition showed much higher accuracy than either the retinal control or masking conditions: over-all accuracy was 97% in response control as opposed to 67% in both the retinal control and masking conditions. In addition, response control latencies were shorter than retinal control latencies by about 90 to 100 msec.; retinal control latencies were on the order of 590 msec.

In the retinal control condition, there were no significant differences among the targets in percent correct, a finding which did not hold for the masking conditions, as will be shown below. Although over-all accuracy between the retinal control and masking conditions was identical, under masking conditions correct latencies were about 100 msec. longer and incorrect latencies were about 150 msec. longer than those in the retinal control condition. Thus, subjects were able to keep their accuracy approximately the same in the masking conditions by spending more time processing the displayed information.

Masking Conditions

A six-way analysis of variance was carried out on each of the three dependent measures, percent correct, correct RT, and error RT. The six factors were target (O, D, I, or L), mask (O, D, I, or L), position of the mask to the target (central or peripheral), position of the target (left or right), sessions block (with five levels), and subjects (with four levels).

Only one of the main effects of interest was significant on any of the three dependent variables, and this was target condition, significant at the .01 level for percent correct and at the .05 level for correct and incorrect RTs. The main effects of mask, central versus peripheral location, and left versus right position of the target were all insignificant for all three dependent variables. The less important main effects of session and subject were insignificant for percent correct, but significant for both correct and incorrect RT. RTs tended to decrease over sessions, and subjects not unnaturally showed large individual differences in their mean RTs.

It should be emphasized that since no differences among targets were obtained in the retinal controls, the over-all differences in performance on the four targets in the masking conditions were due both to the addition of masks to the task, and to the resultant interaction of masks with targets.

Interaction Between Mask and Target

The primary purpose of the present experiment was to determine whether target-mask similarity enhanced masking effects. Table 1 presents the significant pattern of interactions between mask and targets for percent correct ($F_{9,27} = 5.50$, $p < .0005$). The pattern of interactions shows that there is no over-all effect of similarity but rather masks and targets interact in ways not specific to the similarity dimension. That is, similar masks do not consistently lead to decrements or increments in performance although patterns of performance are clearly linked to whether masks fall in similar or dissimilar classes.

TABLE 1
TARGET BY MASK INTERACTIONS FOR PERCENT CORRECT

Target	Mask			
	O	D	I	L
O	72	72	68	67
D	58	54	65	64
I	73	70	76	77
L	64	68	64	64

Specifically the target O is helped by round or similar masks while the target D is helped by straight or dissimilar masks. It is as if the straight line features of the masks I and L enhanced perception of D, which includes a vertical feature, but were detrimental to perception of O, which lacks a vertical feature. Like O, target I is helped by similar masks whereas target L shows no consistent pattern. Thus similarity of the mask can help or hinder (or not affect) the classification of the target, depending on what it is.

It is noteworthy that, while the effects of similarity of mask to target vary across targets, masks which are classed as round or straight have similar effects on particular targets. Thus whatever is taking place in the interaction of masks with targets is consistent within a pair of round or straight masks.

A very similar pattern of results was obtained for correct reaction times, as shown in Table 2. The target/mask interaction was significant ($F_{9,27} = 6.78$, $p < .0005$) and fast RTs occurred in conditions of high accuracy and vice versa. For correct RT target D is apparently helped by straight masks and target I by round masks; this result was also obtained for the percent correct data for target D although the opposite result was obtained for target I. In addition the advantage of round over straight masks for the target O in percent correct is not quite so apparent in the RT data. However, over-all there is a fairly strong relation between percent correct and correct RT for the 16 mask-target combinations ($r = -.753$, $df = 14$, $p < .001$).

TABLE 2

TARGET BY MASK INTERACTIONS FOR CORRECT RT (IN MSEC.)

Target	Mask			
	O	D	I	L
O	721	783	738	775
D	854	853	794	784
I	726	739	762	775
L	760	779	796	796

The target/mask interaction for incorrect RTs was only marginally significant ($F_{9,27} = 1.99$, $p < .10$). Nonetheless, the pattern obtained is very different from that for correct RTs when error RTs are classified according to target presented.

Table 3 presents the incorrect RT results. The pattern of results for incorrect RTs is the opposite from that for correct RTs in that fast incorrect RTs occurred in conditions of *low* accuracy, and vice versa. The correlation between incorrect RTs and percent correct is .514 ($p < .05$) in contrast to the correct RT data.

TABLE 3

TARGET BY MASK INTERACTIONS FOR INCORRECT RT (IN MSEC.)

Target	Mask			
	O	D	I	L
O	893	915	840	848
D	788	818	812	804
I	883	890	836	828
L	786	785	791	814

It is apparent from a comparison of Tables 2 and 3 that RTs are more similar when classified by response made than by stimulus presented. In Table 3, we have presented the incorrect RTs as a function of target presented on the trial. However, when subjects made an incorrect response to target O, for example, they are telling us that they think it is target D. When incorrect RTs are classified by target identified rather than target presented (accomplished by interchanging adjacent rows of Table 3) the relationship between percent correct and incorrect RT becomes much like that between percent correct and correct RT (Pearson $r = -.791$, $p < .001$). Thus high accuracy on a target stimulus was associated with short RTs to either correctly or incorrectly identify that target, and vice versa.

DISCUSSION

The main results of the present experiment may be summarized as follows. First comparisons among the response control, retinal control, and masking conditions show that performance deteriorates as single targets are moved from central to peripheral locations, and deteriorates still further when peripheral targets are accompanied by lateral masks. These results are consistent with a large body of literature (e.g., Flom, Weymouth, & Kahneman, 1963; Eriksen & Hoffman, 1972; Eriksen & Eriksen, 1974).

In the masking conditions no main effect of either central versus peripheral placement of mask or of right versus left field location of target-mask pairs was observed. The absence of right-left differences for peripheral targets is consistent with results reported by Bouma (1973) for random 4-letter strings, although he did find substantial differences between central and peripheral target letters, in contrast to our results. Although no significant central-peripheral by left-right interaction was obtained for any dependent variable in the present study, there was a tendency for left peripheral and right central letters to have slightly higher percentages correct, a trend which is consistent with Bouma's result of a slight advantage for the right side with central targets. Similarly Townsend, Taylor, and Brown (1971) found a dramatic central-peripheral asymmetry for 9-letter strings, with a space being a more effective disinhibitor to the more central letter.

Spatial position effects in letter recognition accuracy and latency, or the lack of them, are obviously relevant to the question of distinguishing serial from parallel processing in letter identification. The present results of no significant effect of target letter position on either accuracy or latency would support either a parallel model or a serial model with random initial position and scanning direction. The present authors are disposed to favor a strong element of parallel processing in the brief visual-display, target-search task. Results of several studies are compatible with this view; for example, perceptual independence in Wolford, Wessel, and Estes (1968), relative inability to direct visual scan (Eriksen & Spencer, 1969; Shiffrin & Gardner, 1972), and studies that manipulate the degree of temporal overlap existing among letters in a string display (e.g., Townsend & Fial, 1968; Travers, 1974).

The most important finding of the present study was the lack of a deleterious effect of similarity on target detection, measured either by accuracy or latency. While over-all differences in detectability of targets and significant interactions between targets and masks were obtained for both percent correct and correct RT, the expected pattern of interactions based on the interactive channels model was not obtained. Both the interactive channels model of Estes and the decision model of Gardner might predict that targets would be better masked by similar than by dissimilar letters. In contrast to these predictions, the present results suggest that the effect of a mask is specific both to the target letter it is masking and to the set of possible targets from which it must be discriminated. In perhaps the clearest example of this, target letter D is helped by straight masks and hurt by round masks in both accuracy and latency. The reason for this is presumably because D contains a straight feature, in contrast to its alternative O, and so the detection of D is helped by irrelevant letters sharing straight features and hurt by irrelevant letters sharing only round features. However, such a result may be specific to the D-O discrimination, and the masking effects of straight letters might be reversed for the discrimination D-B.

Whether the specific masking effects actually occur at the perceptual level, as the preceding discussion implies, or at the decision level, is an interesting question. Since all four masking letters were presented within a block for a particular pair of target letters, it would have been impossible for subjects to adopt a consistent bias toward one of the two target letters across a block of trials. Any decisional or response-bias explanation would have to assume that subjects changed their biases dependent upon which masking letter was present on a particular trial, and such rapid response-bias changes seem implausible within the constraints of the rapid visual presentations used here and the relatively short response latencies observed here. Instead, the authors favor an explanation based on feature interactions at the perceptual level. Such a proposal is very similar in general to the interactive channels model of Estes but, instead of proposing that features always compete for the same channels, we are proposing that identical features from masks may complement target features and actually enhance letter perception.

The present results are similar to those reported by Gilmore (1975), who used the same two-alternative forced-choice detection paradigm, with foveally presented targets and two rather than a single-letter mask. He also found that the effects of target-mask similarity were idiosyncratic, and that target-mask similarity could actually enhance target letter identification.

Finally we turn our attention to the result that correct and error RTs are more closely related by which target was identified by the subject than by which target was actually presented on the trial. To put it another way, error and correct latencies are more closely related by the response made than by the stimulus presented. The closer dependence of error latencies on the response rather than the stimulus has been noted previously both in a situation of low discriminability such as this one (Carterette, Friedman, & Cosmides, 1965), and in a situation of high discriminability in which errors were generated by payoffs for fast responses (Snodgrass, Luce, & Galanter, 1967).

One class of models that is capable of yielding the qualitative structure of these latter results in the present experiment is based on two feature counters, one for O and one for D (in the case of the O and D trial blocks). When an O is presented, the O counter (correctly) counts O features and the D counter (incorrectly) counts D features, the latter counts occurring at a slower rate than the correct O counts. The reverse situation obtains when a D is presented. Each counter is assumed to have its own unique criterion on when to signal the associated response. If we further assume a lower criterion on the O counter than on the D counter and that false O features from the D stimulus are accrued at a faster rate than false D features from the O stimulus (although the correct O and correct D feature counting progresses at the same rate), such a model predicts the appropriate ordering of response frequencies and conditional expected response times.

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