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Confusability and interference between members of parafoveal letter pairs

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In each of three experiments, confusability between members of a parafoveally exposed pair of letters affected accuracy of identifying the peripheral, but not the central, letter. Confusability was determined from a confusion matrix developed for each subject. In Experiment 1, only one letter in each pair was identified on each exposure, and the position of pair members was varied over trials while the absolute position of the pair was held at a constant distance from fixation. In Experiment 2, both letters were identified on each exposure. In Experiment 3, the criterion letter was presented at a constant distance from fixation, and both letters were identified on each exposure. Since results in Experiment 3 were the same as in Experiments 1 and 2, the effect cannot be explained with reference to an interaction between confusability and acuity. The implications of the findings for various models of visual information processing are discussed.

A number of studies have compared the effect of placing a nontarget on the peripheral side of a parafoveally projected target with placing it on the central (foveal) side (Banks, Bachrach, & Larson, 1977; Banks, Larson, & Prinzmetal, 1979; Chastain, 1981; Chastain & Lawson, 1979; Krumhansl, 1977; Krumhansl & Thomas, 1977; White, 1981). The inclusion of target-nontarget confusability as a variable in these studies has been occasional and largely incidental, with inconclusive results. White (1981) varied the similarity of adjacent borders of parafoveally presented geometric forms. Although performance was poorer when adjacent contours were similar, the magnitude of the effect was not significantly different for central peripheral targets. However, it is difficult to directly relate this finding to the effects of stimulus confusability and target position on performance. Only similarity between adjacent borders, and not confusability between stimuli, was varied. It would also be inappropriate to draw conclusions from the absence of a significant effect.

Krumhansl and Thomas (1977) used three sets of letters as stimuli. Inter- and intraset confusability was not examined for those particular letters, but instead was derived from Townsend's (1971) alphabetic confusion matrix. Although some tendency was noted for the difference between performance with confusable and performance with nonconfusable stimuli to be smaller when the nontarget was peripheral than when it was central, the effect was not statistically significant. Krumhansl (1977), using those same sets of letters, found a similar effect. She also found that the difference between the effects of placing the nontarget on the target's foveal side and on its peripheral side was greater with nonconfusable stimuli. Krumhansl (1977) attributed this result to the mislocalization of features from the nontarget, which was supposedly more disruptive when these features were dissimilar than when they were similar to those of the target. According to Krumhansl's theoretical assumptions, mislocalizations in the foveal direction predominate (Wolford, 1975; Wolford & Shum, 1980); thus, the confusability difference should reside in performance on targets in the central, rather than peripheral, position. An examination of the data reported by Krumhansl (1977) indicates just the opposite: performance on central targets was almost identical on confusable and nonconfusable trials, whereas performance on peripheral targets was much lower on confusable trials than on nonconfusable ones. Thus, the larger position effect on nonconfusable trials was due to better performance on peripheral targets, not poorer performance on central targets.

In the current experiments, confusion matrices from individually exposed target letters were generated for each subject. The letters were then paired for simultaneous exposure. Pairs composed of letters that were similar were expected to produce about the same level of performance on central targets as pairs composed of dissimilar letters. Performance on peripheral targets was predicted to be much lower when letters were similar than when they were dissimilar.

EXPERIMENT 1

In the first experiment, four letters (D, P, T, and W) were first exposed individually to each subject to provide a confusion matrix. These letters were selected after an

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examination of Townsend's (1971) alphabetic confusion matrix, with D, T, and W chosen to display a progressive decrease in similarity to the letter P. A number of exposures on which D, T, or W was presented to the left or right of fixation followed; the letter presented was always flanked on its foveal or peripheral side by the letter P. A significant difference in the effect of the position of the flanker on the accuracy of identifying the letter most and least often confused with P for each subject was predicted. For foveally flanked targets, performance was expected to be better on the letter most similar to P than on the one least similar to P. No effect of similarity to P was expected on the identification of peripherally flanked targets. The two letters were presented in a constant position, so the target was farther from fixation when flanked foveally than when flanked peripherally.

Method

Subjects. Ten students, each of whom reported normal or corrected-to-normal vision, served for extra credit in a general psychology course.

Apparatus. The subject triggered presentations with a handheld microswitch for binocular viewing within a Scientific Prototype, Model N-1000, three channel tachistoscope. The fixation field and the stimulus field were each illuminated to 130.0 cd/m^2.

Stimuli. The letters D, P, T, and W were traced onto white index cards from a Berol RapiDesign lettering guide, R-2960, in black ink with a Pilot razor point pen. Each letter was 4 mm in height and subtended a vertical visual angle averaging .21 deg in height and width. Single letters were positioned to the left or right, with the innermost edge of the letter 2.78 deg from the center of the card. On those cards containing two letters, the innermost edge of the central letter was 2.65 deg from the center of the card, and the second letter was separated by approximately .05 deg from the foveal or the peripheral side of the target. The fixation card contained only a single dot, .05 deg in diameter, in the middle. All cards were centered on Masonite slides.

Experimental design. Each subject was initially shown one letter on each exposure. Each letter was presented two times on each side of fixation within each of 5 blocks of 16 trials. These presentations were preceded by 1 block of 16 practice trials. The subject was then given 12 blocks of trials with D, T, or W paired with the nontarget P on each exposure. The first block was considered practice, and in each block each target letter was shown twice to the left and twice to the right of fixation. The flanking P appeared to the foveal side of the target on one presentation within each visual field and to the peripheral side on the other. P was never considered a target letter. All combinations of variables (with each set of stimuli) were presented in a random order to each subject with the constraints mentioned above.

Procedure. After being familiarized with the single-letter stimuli, each subject was instructed to fixate the dot in the middle of the fixation field before initiating each exposure with the microswitch. A 200-msec tone from the tachistoscope signaled the subject that the stimulus side was in place. After each exposure, the subject verbally identified the letter, with a response required after each presentation. The same procedure was followed when pairs of letters were presented. No feedback regarding accuracy was given. Stimulus duration was initially set at 200 msec with each set of stimuli, and was lowered during the practice trials to allow overall accuracy to stabilize at between 60% and 70% by the beginning of the criterion exposures. Thereafter, the duration was adjusted only between blocks of trials to maintain overall accuracy at between 60% and 70%. Trials with each set of stimuli were run in an uninterrupted series.

Table 1
Mean Proportion of Responses in Error in the Interaction Between Position and the Letters Most and Least Confusable with P in Experiment 1

	Position of Target	
Confusability with P	Inner	Outer
Most	.409	.509
Least	.445	.368

Results and Discussion

Data from the single-letter exposures were first examined for each subject to determine which letter was incorrectly reported as P most frequently and which was so reported least frequently. For six subjects, D was most frequently called P, for two subjects, T was, and for two subjects, W was. For three subjects, D was least frequently called P, for two subjects, T was, and for five subjects, W was. Between-subject differences in patterns of confusions may have been due to differences in the aspects of letters upon which subjects were basing decisions. Although not all aspects are equally informative, different ones can apparently be used to discriminate letters (Shimron & Navon, 1981).

Data for each subject on the task in which target letters were flanked by P were then divided into errors on the letter most and least frequently misnamed as P. Proportions of responses in error when each of these two target letters was in the central position and in the peripheral position were computed for each subject and entered into analysis of variance. Although there was no significant main effect of either position or letters most and least confusable with P (both ps $> .10$), the interaction of these two variables was significant [$F(1,9) = 24.06$, $p < .001$]. Means for the significant interaction appear in Table 1. Individual comparisons showed a significant difference in confusability at the peripheral position [$t(9) = 2.57$, $p < .05$] but not at the central position [$t(9) = .45$, $p > .10$]. In consonance with the results of Krumhansl's (1977) study, most of the difference in accuracy when confusability of the letter pairs was varied resided at the peripheral position. However, Krumhansl used pairs of letters in which both members changed from trial to trial. To more closely replicate her stimuli and to demonstrate the general nature of the effect, pairs in which both letters varied were presented in the second task of Experiment 2.

EXPERIMENT 2

Method

All aspects of the method were identical to those in Experiment 1, except that 10 new subjects served and the stimulus letters were B, R, T, and X. Again, a confusion matrix was developed initially by presenting the letters individually. Pairs of letters were then presented in five blocks, with all possible combinations of different letters appearing in each visual field once per block. The subjects reported the left and then the right letter on each exposure in this task.

Results and Discussion

Mutual confusions among all possible pairs of letters presented individually were tallied for each subject. The three pairs that were most often confused and the three that were least often confused were noted. Two subjects exhibited ties for the third and fourth most often confused pairs, and in those instances, both the third and fourth most often confused pairs were considered to be part of the set of least often confused pairs (since their frequency was below the mean of all confusions). The mean numbers of confusions per subject, in descending frequency of occurrence, were: B/R–13.2; T/X–8.5; R/X–5.5; B/X–2.6; R/T–1.9; B/T–.5.

Data for stimuli presented in pairs were partitioned for each subject as described above, and the resulting mean proportion of responses in error for letters in the central and peripheral positions at each of the two levels of confusability were entered into an analysis of variance. Both letters appearing on each exposure were analyzed as targets. The interaction between confusability and position was significant [$F(1,9) = 11.81$, $p < .01$], although neither main effect approached significance (both $ps > .10$). Means for the interaction appear in Table 2. Individual comparisons showed a marginally significant effect of confusability at the peripheral position [$t(9) = 2.15$, $.05 < p < .10$], but no such effect at the central position [$t(9) = .93$, $p > .10$].

As in Experiment 1, confusability had different effects at the two positions. More errors were made at the peripheral position when the two letters were confusable than when they were not. Confusability had much less effect at the central position. Since various combinations of letters were used, and their confusability was determined separately for each subject, the current analysis is probably more sensitive than those made in Experiment 1 or by researchers such as Krumhansl (1977) and Krumhansl and Thomas (1977).

In the two preceding experiments, both the relative positions of the letters and their absolute distances from fixation were varied. The interaction described in both experiments as being between confusability and position could instead have resulted from a combination of confusability and acuity differences at the two positions. To eliminate the possibility of this source of interaction, the following experiment was run. The criterion position was situated at a constant distance from fixation and was rendered relatively central or relatively peripheral by placing a second letter to the peripheral or foveal side. Although both letters were reported after each exposure, only identification accuracy at the criterion position was analyzed. A new set of four letters was chosen for presentation, a confusion matrix was again generated for each subject, and confusability of pair members was varied factorially with relative position.

Table 2
Mean Proportion of Responses in Error in the Interaction Between Position and Confusability in Experiment 2

Confusability	Position of Target: Inner	Outer
Most	.394	.429
Least	.351	.341

EXPERIMENT 3

Method

The method was identical to that in Experiment 2, except that 12 new subjects served and the letter set comprised C, G, N, and S. The criterion letter was centered 2.75 deg to the left or right of fixation, and in the task involving letter pairs, the second letter was placed .10 deg from its foveal or peripheral side. In the condition in which letters were presented in pairs, the subjects always reported the left letter first.

Results and Discussion

As in the preceding experiment, the three pairs that were most and least often confused were noted for each subject. Five subjects produced ties for the third and fourth most often confused pairs. These were considered to be part of the set of most confused pairs for one subject and were included with those least confused for four subjects (depending upon whether their frequency was above or below the mean of all confusions for each subject). The mean numbers of confusions per subject, in descending frequency of occurrence, were: C/G–9.0; G/S–4.833; C/S–3.75; G/N–3.25; N/S–3.083; C/N–3.0.

Data for letters presented in pairs were analyzed after being divided as described above. Although report-order transpositions did not pose a problem with regard to data interpretation in the first two experiments, they were excluded from the current analysis. Transpositions might have been more likely when a pair containing similar members was presented farther from fixation (when the criterion letter was in the central relative position), since acuity limitations might have made it more difficult to distinguish a minor feature or features that differentiated the location of the pair members. This localization difficulty would not be as pronounced with pairs containing dissimilar members. Mean proportions of responses in error for letters in the central and peripheral relative position at each of the two levels of confusability were subjected to analysis of variance. The interaction between relative position and confusability was significant [$F(1,11) = 8.39$, $p < .02$], whereas neither main effect approached significance (both $Fs < 1.0$). Means for the interaction are shown in Table 3. Individual comparisons revealed a significant effect of confusability at the peripheral position [$t(11) = 2.45$, $p < .05$], but not at the central position [$t(11) = .72$, $p > .10$].

With the criterion letter presented at a constant distance from fixation, there was no difference in performance at the relatively central position between confus-

Table 3
Mean Proportion of Responses in Error (Net of Transpositions) in the Interaction Between Relative Position and Confusability in Experiment 3

	Relative Position of Target	
Confusability	Inner	Outer
Most	.211	.243
Least	.232	.178

able and nonconfusable pairs, but a significant difference at the relatively peripheral position. This finding replicates those in Experiments 1 and 2. Holding the distance from fixation of the criterion letter constant provides assurance that the effect is not due merely to a relationship between confusability of pair members and acuity factors.

GENERAL DISCUSSION

The three experiments just described consistently demonstrated differences in the effect of confusability of members of letter pairs on the accuracy of identifying the letter at the central and peripheral position. At the central positions, no significant effect of confusability was evident, whereas at the peripheral position, performance was significantly poorer when pair members were more confusable. These results were observed when the position of the letter pair was held at a constant distance from fixation and performance at the central position was compared with performance at the peripheral positions. The same results were obtained with accuracy measured only on one criterion letter, which was held at a constant distance from fixation and rendered relatively central or peripheral by placing the second letter on the criterion letter's peripheral or foveal side.

The significant interaction between confusability and target position that occurred in all three experiments was not observed in the other two studies that examined confusability effects (Krumhansl, 1977; Krumhansl & Thomas, 1977). However, these researchers did not directly determine the confusability of the letters they used, but paired the letters to be confusable or nonconfusable on the basis of a complete alphabetic confusion matrix (Townsend, 1971) that had been developed with a different type font and under substantially different viewing conditions. Since confusions were determined individually for each subject in the current study, the distinction between confusable and nonconfusable letters was likely more precise. The results made it apparent that an effect of confusability is produced by targets in the peripheral, but not central, position. On the basis of a model developed by Wolford (1975), Krumhansl (1977) argued that feature mislocalizations, which proceed in a foveal direction, should produce an effect of confusability at the central position. This would be expected because nonconfusable letters share fewer features than confusable ones and thus features mislocalized to the central position would produce a mixture incompatible with any single letter. However, mislocalizations from a confusable letter would yield a feature combination consistent with the correct letter, and thus performance should be better than with nonconfusable letters. The identity of the peripheral letter would be equally well specified with confusable and nonconfusable letters from the features that remain if others are mislocalized. The current results are inconsistent with these predictions.

The current results also seem inconsistent with the predictions of certain models that propose particular types of limits on feature extraction. Estes (1972, 1974) outlined his interactive channels model in which input channels to feature detectors decrease in density as distance from the fovea increases. Characters that are presented close together in the parafovea thus would compete for input channels, and excitation of an input channel would result in inhibition of other input channels. Bjork and Murray (1977) proposed a modification that they called the feature-specific inhibitory channels model. Their model additionally assumes more inhibition among channels going to the same feature detector than among those leading to different feature detectors. In the first two experiments of the current study, in which relative position was manipulated by reversing the target and flanking positions, the same retinal areas were consistently being stimulated and hence the same input channels would have been activated. Since the modified model does not assume that inhibition is stronger in one direction than in another, it provides no basis for predicting an interaction between target position and confusability. The model would, however, predict such an interaction in Experiment 3. Since the target position was held constant, placing a flanking letter on the peripheral side of this position would have been more likely to stimulate a channel close to the target than would placing the flanker on its foveal side (since channels increase in size and decrease in density with increasing distance from the fovea). Thus, the model predicts that increased featural similarity between the target and flanker would be more likely to result in the inhibition of channels at the target position when the flanker is peripheral to the target, thus producing lower performance with more confusable pair members. What was observed instead was an effect of confusability only when the flanker was on the foveal side of the target.

The current results could be accommodated with a model of lateral inhibition that is asymmetric (Chastain, 1981) in a manner that depends upon the similarity between features at the two positions. This model would place the locus of the interaction at the stage of feature extraction. However, Estes (1982) conducted experiments that showed that visual similarity of parafoveally exposed letters affects subjects' criteria or response bias. Further research is needed to clarify the extent to which feature extraction limitations, as opposed to decision or response biases, contribute to the interaction between confusability and target position.

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