

## Coactivation in the Perception of Redundant Targets

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Reaction time (RT) to redundant stimuli was investigated while controlling for distraction effects and response competition. In Experiment 1, a redundancy gain was found for 2 target letters with identical features (redundant) compared to trials in which 2 different targets shared the same response assignment (compatible) indicating coactivation of stimulus inputs. No difference in RTs was found between compatible displays and displays containing 2 targets with different responses (incompatible), suggesting (with other evidence) that letters were serially processed. In Experiment 2, a redundancy gain was again found. Unlike in Experiment 1, incompatible displays produced response competition, indicating a redundancy gain with parallel processing. Three forms of redundancy gains operating under specific conditions are discussed.

In the redundant-targets paradigm, performance is compared between trials in which only a single target is presented and trials in which two or more identical targets occur. For example, in a two-choice reaction time (RT) task, the subject may be required to discriminate between the target letters A and B. A redundancy gain is obtained if the average RT is shorter when two As or two Bs are presented simultaneously on a trial than when a trial consists of only a single A or B. Although redundant signals can be presented across different sensory modalities as well as within a single modality, the present article will be concerned only with visual perception.

Over the years there have been several different models proposed to account for effects obtained when redundant signals are presented (Bjork & Murray, 1977; C. W. Eriksen, 1966; Keeley & Doherty, 1971; Raab, 1962), but recent interest in the problem has centered on the issue of separate activation versus coactivation in the processing of the redundant inputs. The separate activation position is well represented by van der Heijden, Schreuder, Maris, and Neerinx (1984). It assumes that each signal occurrence is separately and simultaneously processed. The signal that finishes processing first initiates the response. The system never combines activation from the processing of the separate signals in order to meet the criterion for responding. Responses to redundant targets are faster because they are produced by the fastest of the response activation processes or the winner of the race.

Miller's (1982a) coactivation model, on the other hand, proposes that activation from the different signals combine to satisfy a single criterion for response initiation. This model also predicts a redundancy gain because the two or more signal sources are pooled together to provide activation to satisfy a single response criterion. Miller (1982a) pointed out

that a race among separate activations requires that the minimal RTs in the distribution of latencies obtained with redundant targets cannot be less than the minimal latencies obtained for the fastest single-target presentations. If the latencies in the fast tail of the RT distribution obtained with redundant targets are significantly faster than the corresponding tails for single-target presentation, then clear evidence exists for coactivation.

Miller (1982a) proposed a method of analysis to test the assumptions of separate activation in speeded recognition tasks. Because separate activation models assume that recognition time is determined by the fastest of the individual target recognition processes, then for two simultaneously presented targets (T1 and T2) for all values of response time ( $t$ ):

$$P(\text{RT} < t/T1 \text{ and } T2) = P(\text{RT} < t/T1) + P(\text{RT} < t/T2) - [P(\text{RT} < t/T1) \text{ and } (\text{RT} < t/T2)].$$

The left side of the equation represents the cumulative probability density function (CDF) of reaction time on redundant-target trials. The first two terms on the right correspond to the CDFs for the two types of single-target trials. The last term on the right reflects a possible covariance between the two simultaneous target detection processes. As Miller pointed out, this last term is equal to or greater than zero. Thus, it then follows that for separate activation,

$$P(\text{RT} < t/T1 \text{ and } T2) \leq P(\text{RT} < t/T1) + P(\text{RT} < t/T2).$$

Miller (1982a) referred to this test of separate activation as Inequality 2. If Inequality 2 is violated, this would suggest that a response to a redundant signal is made before either signal alone has provided enough activation to produce a response. It is important to note that Inequality 2 can be violated only when response time  $t$  is relatively small (Miller, 1982a, p. 254). For large values of  $t$ , the inequality is sure to hold.

Miller (1982a) used the CDFs and Inequality 2 to evaluate separate activation models in a visual letter discrimination task. Stimuli were letter pairs, for example, target-target (AA), target-noise (AB), and noise-noise (BB). Subjects responded by pressing one switch if either or both letters were targets or

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a different switch if neither of the two letters was a target. Data revealed shorter mean RTs for redundant targets, and a few significant violations of Inequality 2 were found, suggesting coactivation of input. However, in a control experiment in which single-letter alone trials were added, redundant-target trials were not faster than single-target alone trials. Thus, Inequality 2 was satisfied in support of separate activation.

Miller (1982a) argued that the failure to find coactivation when single-letter targets were compared with the redundant displays was due to an additional speed gain in the target alone condition. Attention could focus completely on the single letter in the display, whereas attentional resources would have to be shared between the two letters in the redundant-display condition.

Miller's (1982a) results and conclusions were criticized by van der Heijden et al. (1984) and by Grice, Canham, and Boroughs (1984). Both articles noted that evidence for coactivation with visual targets was slight and inconsistent. Also, because violations of Inequality 2 were found only when redundant-target displays were compared with displays containing a single target and a noise letter, these authors suggest that Miller's coactivation conclusion may have been a result of response competition effects (B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & Hoffman, 1973). Instead of faster responding as a result of coactivation on redundant trials, delayed responding on target-noise trials due to response competition (target letter and noise letter requiring opposite responses) may be the basis for Miller's conclusion.

Van der Heijden et al. (1984) used a go-no go task to control for response competition effects. Subjects pressed a button in response to displays containing one or two Es and refrained from responding when one or more Os appeared. Reaction time results showed that the redundant-target conditions were significantly faster than single-target conditions. Analyses of the CDFs indicated that the smaller percentiles were in good agreement with Miller's (1982a) inequality; the minimal responses to redundant targets were not faster than the minimal responses to single targets. Van der Heijden et al. (1984) concluded that no evidence was found in favor of coactivation. Instead, their results supported separate activation with a negative correlation between the separate channels on trials with fast RTs and a positive correlation when RTs were longer.

Grice and his colleagues (Grice, Canham, & Boroughs, 1984; Grice, Canham, & Gwynne, 1984) avoided the response competition effect that might have affected Miller's (1982a) results by using a two-choice RT task. The subjects were required to discriminate between two target letters. The displays contained either a single target letter, a target letter with a neutral noise letter (which did not require a response), or two identical target letters. There was no redundancy gain when RTs for single-letter displays were compared with redundant displays. A redundancy gain was obtained only when redundant displays were compared with displays containing a single target and a neutral noise letter. However, when the reaction time distributions were evaluated with the scaling analysis of variable criterion theory, (Grice, Canham, & Boroughs, 1984), a coactivation-like effect was found. In the redundant displays both targets were found to contribute

jointly and equally to the growth of associative strength. These authors argue that the appropriate comparison for determining a redundancy gain is between the redundant displays and the displays containing a target and a neutral noise letter. The extra letter in the display causes a distraction effect. Support for such visual distraction or display numerosity effects has been reported in a number of other experiments (e.g., Colegate, Hoffman, & Eriksen, 1973; C. W. Eriksen, Hamlin, & Daye, 1973; Kahneman, Treisman, & Burkell, 1983; Treisman, Kahneman, & Burkell, 1983).

The issue of separate activation versus coactivation may not be easily resolved with Miller's (1982a) Inequality 2. Even if coactivation occurs, there are a priori reasons why the inequality would not be violated except under special circumstances. The inequality assumes that  $P(t/T1)$  and  $P(t/T2)$  remain constant under single-target and redundant-target conditions. If processing resources are limited, the amount of resources devoted to each stimulus on a redundant trial is likely to be less than the resources devoted to a single-target presentation. If the processing of each target on redundant trials is slower than on single-target trials, performance will not equal what would be predicted from single-target presentation performance even though the two targets are processed simultaneously and in parallel. (An exception would be if the coactivation gain is large enough to offset the slower processing of each target.) This, in turn, would obscure evidence for independent or separate activation.

A second factor that is likely to mask coactivation effects is a correlation between the parallel processing of each target on redundant presentation due to a common third variable. One can think of variables such as criterion variability between trials, varying motivation, or even eyeblinks that will introduce a significant covariance term.

A third reason why the inequality might be expected to be insensitive to coactivation effects is the possibility of a significant number of fast guesses in the subject's performance. C. W. Eriksen (1988) has pointed out that fast guesses can strongly bias Miller's (1982a) test against a finding for coactivation.

Experiments investigating redundant-target effects typically have paid little attention to the discrimination difficulty or featural complexity of the targets. Extensive research has shown that featurally simple forms can be discriminated automatically or preattentively, whereas more complex forms require (or at least can materially benefit from) focal attention (e.g., Bergen & Julesz, 1983; Shiffrin & Gardner, 1972; Treisman & Gelade, 1980). Preattentive processes are presumed to be carried out in parallel, whereas focal attention serially processes the separate stimuli. The outcome of an experiment on redundant targets might well be expected to vary with the choice of visual stimuli. For example, the Es and Os used by van der Heijden et al. (1984) would appear to satisfy the criterion of simple features. Parallel processing of complex stimuli could also occur and provide a redundancy gain if focal attention could be divided or focused simultaneously to two or more locations in the visual field, but there is evidence that such division does not occur (C. W. Eriksen & Yeh, 1985; Jonides, 1980, 1983; Posner, Snyder, & Davidson, 1980).

Recognition of attentional-like effects in the redundant-targets paradigm has occurred in the form of "preferred position effects" (see Mullin, Egeth, & Mordkoff, 1988, for a recent discussion of preferred position effects). Van der Heijden, La Heij, and Boer (1983) noted that a spurious redundancy gain could be obtained if the subjects had preferences among the locations in which the visual targets could appear. In a subsequent publication, van der Heijden et al. (1984) noted the relation of position preferences to attentional focusing on specific locations in the visual display. A large body of research has shown that attention can be directed to spatial locations (e.g., C. W. Eriksen & Hoffman, 1973, 1974; Posner et al., 1980), and it is common in redundant target experiments to have two specified locations where the stimuli can occur. With single-target presentation, the subject would be expected to have focused attention on the wrong location half of the time, but when the redundant targets are presented, one target will always occur in an attended location. Thus, the redundancy gain may result from the faster processing of a single target due to the prealignment of attention with the target location.

Recently, C. W. Eriksen, Goettl, St. James, and Fournier (1989) presented strong evidence that redundant targets are serially processed by focal attention when capital letters with similar features are used as targets. In addition to using the traditional displays consisting of a single target, a target and a neutral letter (noise), and two identical targets, they introduced the innovation of a display that contained both target letters. Because each target in both-target displays required a different response direction, they reasoned that if the stimuli in two-letter displays were processed simultaneously, then displays containing both targets would lead to response competition. Response competition would result in an increase in RT over the identical-target displays and those displays containing a single target and neutral letter. In their two experiments, however, average RT to both-targets displays did not differ significantly from the RT obtained from identical-targets displays. In addition, they found that average RTs to displays with a single target plus a neutral letter were significantly and appreciably longer than RTs to identical and both-targets displays. Single-target displays (without a neutral letter) had the fastest RTs.

The results were well described by an assumption that the subjects processed the stimuli in the two-letter displays serially. When a display consisted of a target and a neutral letter, on approximately half of the trials a subject would attend first to the neutral letter. This neutral letter would have to be processed sufficiently to determine that it was not a target and then attention would have to be redirected to the other letter in the display. The time required to process a noise letter and then redirect attention was on the order of 70 ms, a time that corresponds well with previous estimates (C. W. Eriksen & Yeh, 1985; Treisman & Gelade, 1980).

With the identical and both-targets displays, whichever position the subject attended first would result in a target identification. No response competition would occur in the both-targets condition because only one of the targets would be processed before a response was activated. Thus identical and both-target displays would yield comparable RTs. Anal-

yses of the minimal and maximal latencies of the RT distributions were consistent with the above interpretation.

Although a serial attentional processing of the display elements is incompatible with separate activation interpretations, it does not necessarily rule out the possibility of coactivation. Coactivation could occur at an early perceptual or preattentive level in which the processing of identical features on separate retinal areas has a synergistic action that expedites the recognition of the letter that is being attended. C. W. Eriksen et al. (1989) noted, however, that coactivation would require that identical-target displays be faster than both-target displays because only with the former would there be opportunity for pooling of inputs to expedite target recognition. Although these investigators failed to find that identical displays were significantly faster than both-target displays, in one experiment (the one most sensitive to possible coactivation effects) there was a 9-ms advantage for the identical displays. Although suggestive, this difference could have arisen by chance from some response competition effects in the both-targets displays or from some coactivation processes.

In our first experiment we have extended the procedure of Eriksen et al. (1989) to provide a more sensitive test of coactivation as well as testing further the serial attentional processing of display elements.

## Experiment 1

A classification task was used in which the targets were four capital letters (A, H, N, and K) and the subject was required to move a response lever in one direction for an A or an N and in the opposite direction for an H or a K. In addition there were four noise letters that did not have a response assignment: M and W were chosen for their high confusability with the four target letters and S and C for their low confusability. In addition to single-letter displays that contained only a target letter, there were five kinds of two-letter displays: (a) identical targets (e.g., AA); (b) response-compatible targets in which both letters required the same response (e.g., AN); (c) response-incompatible displays (e.g., AK); (d) a target letter and a low-confusable noise letter (e.g., AS); and (e) a target letter and a high-confusable noise letter (e.g., AM).

In addition to the different display types, cuing was also an experimental variable. In the precuing condition, one of the two possible target locations was underlined 50 ms before the letter display appeared. The location precued was always subsequently occupied by one of the target letters when the display came on. The other display location was underlined simultaneously with the onset of the letter display. In the simultaneous cue condition, both locations were underlined with the onset of the display.

This design provides a strong test of coactivation because it controls for the display numerosity or distraction effect as well as response facilitation or competition. If coactivation occurs, the mean RT for identical-target displays should be significantly faster than for response-compatible displays. In the former case the repetition of the same letter in the display would permit pooling of inputs for identification of the letter

form. With response-compatible displays, on the other hand, response facilitation would be comparable because both letters require the same response, but the difference in features between the two letters would preclude pooling of inputs in the letter identification process.

The precuing manipulation was used to provide information on the role of focal attention in the redundant-targets paradigm and to verify the conclusion of C. W. Eriksen et al. (1989) that the letters in two-letter displays were serially attended. We know from numerous experiments (e.g., C. W. Eriksen & Hoffman, 1973; C. W. Eriksen & Yeh, 1985; Posner et al., 1980; Tsai, 1983) that spatial precues can direct attention to a location in the visual field. Although the maximum attentional facilitation is not obtained until the precue precedes the target by 150 ms or more, a significant reduction in target RT is typically obtained when the precue occurs only 50 ms before the target (C. W. Eriksen & Hoffman, 1973; Murphy & Eriksen, 1987). In the present experiment the precue preceded the target by only 50 ms. Although the 50 ms was not long enough to ensure that attention would always be aligned with the cued location when the target appeared, nonetheless, if the letters were indeed serially attended, the precue would then serve to bias which letter was attended first.

A serial attending of the letters in the display leads to several clear predictions. First, mean RT to compatible and incompatible displays should not differ. Whichever letter is first attended in these displays should lead to a response. But if the letters are parallel processed, the incompatible displays should result in response competition causing an increase in RT. Second, mean RT to incompatible displays should be less than that for displays containing both a target letter and a noise letter. In the latter case, the noise letter would be attended first on approximately half of the trials. Time would be required to process the noise letter to the point that it would be identified as noise and attention would then have to shift to the target letter. Third, precuing, compared with simultaneous cuing, should improve performance more for the displays containing a target and a noise letter than for the other types of two-letter displays. Because the precue always underlined the location of the target letter in the target and noise letter displays, focal attention should be biased by the precue to attend the target first on significantly more than 50% of the trials. This would reduce the number of trials in which a noise letter may be processed first with the attendant need to shift attention to the other location.

The two classes of noise letters having high and low confusability with the target letters were used as a further check on the serial processing interpretation. If, in the target plus noise letter displays, the subjects processed the noise letter first on some proportion of the trials, the time required to process a noise letter sufficiently to determine that it was not a target letter should depend on the similarity of the noise letter to the targets. Subjects should require less processing time to determine that the noise letters S and C are not targets as opposed to the letters M and W because S and C do not share similar features with the target letters. Thus, mean RT for the confusable noise letters should be greater than for the nonconfusable noise letters under both cuing conditions.

## Method

**Subjects.** Four male and 7 female graduate and undergraduate students from the University of Illinois at Urbana-Champaign served as paid volunteers. All were right-handed and had normal or corrected-to-normal vision.

**Apparatus and stimuli.** Stimuli were presented on a Panasonic Matrox video display. Subjects viewed stimuli binocularly through a face mask to keep stimulus distance constant. A white fixation cross (+) measuring 0.1° visual angle appeared in the center of the screen before each trial. The fixation cross remained on the screen until subjects initiated the trial.

Stimulus letters were in uppercase, were colored white, and subtended 0.45° of visual angle in height. Target letters were H, K, A, and N. Noise letters (requiring no response) were M, W, C, and S. All letters contained an underline (cue). Cues consisted of a white underline that measured across the width of the letters. Cues appeared either simultaneously with the letter display (simultaneous cue condition) or one cue appeared 50 ms before the letter display and the second cue appeared simultaneously with the letter display (precue condition). A cue occurring 50 ms before letter onset only appeared in a position subsequently occupied by a target (i.e., a noise letter location was never precued).

In the two-letter displays, two letters were presented simultaneously in a vertical array separated by 2.9° visual angle (1.45° visual angle above and below the fixation cross). A block of double-letter displays contained four identical, four response-compatible, eight response-incompatible, eight neutral low-confusable, and eight neutral high-confusable trials. Letter pair combinations and letter positions (top/bottom) were randomly ordered within a block with the constraint that all letter combinations and locations were equally probable.

In the single-letter display condition, a letter appeared 1.45° of visual angle above or below the fixation cross. Letters were always target letters (H, K, A, and N). Target letter type and target letter positions (top/bottom) were randomized within a block, and both had equal probability of occurrence. Single-target trials (no-noise letter) were blocked separately.

Subjects initiated trials by depressing a foot pedal. They responded by moving a hand lever to the left or right, depending on the target letter they identified. Responses (correct/incorrect), response direction, and RT in milliseconds were recorded by an RT-11 computer.

**Procedure.** We instructed subjects to be sure that the fixation cross was in clear focus before they initiated a trial. They were told to move the hand lever to the right (left) when the letters A and/or N appeared and to move the hand lever in the opposite direction when the letters H and/or K appeared. We explained that a target letter would appear on each trial. Single-letter displays would yield single-target presentations and double-letter displays would yield any combination of two targets or any combination of a target and a noise letter. In the double-letter displays, because two targets with different responses could occur, we asked subjects to respond to the target letter they saw first or most clearly. Subjects were to respond as quickly and as accurately as possible.

When a subject initiated a trial by depressing a foot pedal, the fixation cross disappeared, and the stimuli that appeared 1 s later were dependent on the type of cue condition. In the precue condition, an underline appeared for 50 ms followed by the second cue and letter display, which appeared for 100 ms; total trial duration was 150 ms. In the simultaneous cue conditions, cue and letter displays appeared simultaneously for 100 ms; total trial duration was 100 ms. After each trial, the computer displayed the speed and accuracy of response.

Cue Type  $\times$  Letter Display conditions were blocked separately within subjects. In the precue condition, precue location (above or

below fixation cross) was randomized within blocks in the single-letter and double-letter displays with equal probability of occurrence.

Subjects completed four 1-hour sessions over a period of 4 to 5 days. The first session was considered practice and was not incorporated in the data analysis. Each session consisted of 12 blocks of 32 trials. The 12 blocks consisted of 4 blocks of simultaneous cued double-letter displays, 4 blocks of precued double-letter displays, 2 blocks of simultaneous cued single-letter displays, and 2 blocks of precued single-letter displays. Order of block presentation was counterbalanced across subjects, and no two similar conditions (Cue Type  $\times$  Letter Display) appeared one after the other within subjects.

### Results and Discussion

Mean RTs for the six display types under the simultaneous and precue conditions are given in Table 1. A within-subjects analysis of variance (ANOVA) revealed a significant main effect for display type,  $F(5, 50) = 18.58, p < .001$ , as well as for cuing condition,  $F(1, 10) = 11.13, p < .01$ . As shown in the table, precuing resulted in faster RTs for all six display types. The greatest reduction in RT with precuing occurred for the two displays containing a target plus a noise letter. The other four display types showed a smaller gain in speed that was approximately of the same magnitude across these four displays. The overall interaction from the ANOVA, however, was not significant,  $F(5, 50) = 1.64, p > .10$ .

The mean RT differences between the six display types, collapsed over the two cuing conditions, are shown in Table 2. The significance of these differences was evaluated by planned comparisons. (Differences that are significant at or beyond the .01 level are marked with asterisks.)

The first question that these data address is coactivation. As we pointed out earlier, evidence for coactivation requires that RT for the identical-targets condition be significantly less than RT for the compatible-targets condition. Because the display size effect and response competition are balanced in this comparison, any processing advantage resulting from the simultaneous presentation of identical stimuli should be revealed. As can be seen from the results, coactivation is supported: Identical targets are responded to over 13 ms faster than response-compatible targets, a difference that is significant.

There is, however, no advantage of identical targets over a single target when the single target is presented without any noise stimuli in the display. The RT to single-target displays

Table 1  
Mean Correct Reaction Times (in Milliseconds) as a Function of Display and Cue Types

Display type	Cue type	
	Simultaneous	Precue
Single	487	480
Identical	490	481
Compatible	503	495
Incompatible	505	501
Low-confusable noise	532	513
High-confusable noise	538	519

Table 2  
Correct Trial Mean Differences in Reaction Times (in Milliseconds) for the Six Display Types Collapsed Over Simultaneous and Precue Conditions

Display type	1	2	3	4	5	6
1. Single	—	1.96	15.37*	19.37*	39.28*	44.78*
2. Identical	—	—	13.41*	17.41*	37.32*	42.82*
3. Compatible	—	—	—	4.0	23.91*	29.41*
4. Incompatible	—	—	—	—	19.91*	25.41*
5. Low-confusable noise	—	—	—	—	—	5.50
6. High-confusable noise	—	—	—	—	—	—

\* Differences that are significant beyond the .01 level.

was approximately 2 ms less than that for identical targets. This is neither appreciable nor significant. But this result is consistent with the well-documented distraction effect (C. W. Eriksen et al., 1973; Grice, Canham, & Gwynne, 1984; Kahneman et al., 1983; Treisman et al., 1983). As we noted earlier, the presence of the distraction effect makes it inappropriate to use single-letter displays to assess the presence of a coactivation process. A redundancy gain obtained when identical targets are compared with single targets would require that the facilitation obtained from coactivation exceeds the loss in processing speed that occurs when additional stimuli are added to the visual field. In the present experiment, the gain from coactivation, as assessed by the identical versus compatible display difference, about equals the loss from distraction.

The compatible and the incompatible displays do not differ significantly, but both are appreciably and significantly faster than the two display types containing a single target and a noise letter. This finding is consistent with the results obtained by C. W. Eriksen et al. (1989). These investigators reasoned that if both letters in the displays were processed simultaneously, the two letters in response-incompatible displays should prime competing responses and should lead to a pronounced response competition effect. As has been frequently demonstrated (e.g., B. A. Eriksen & Eriksen, 1974; Flowers & Wilcox, 1982; Grice, Boroughs, & Canham, 1984; Miller, 1982a), response competition markedly increases RTs. C. W. Eriksen et al. (1989) found no evidence of response competition in their response-compatible displays and concluded that this was strong evidence that the letters were processed in serial order.

The failure to find a difference between compatible and incompatible displays in the present experiment reinforces this conclusion. In the compatible displays, although two different letters were presented, they both always called for the same response. In contrast, the incompatible display letters required opposing responses. Because distraction effects would appear to be equal in the two types of displays, the lack of difference in performance between them fits most readily with an interpretation that they were serially attended. If they were serially attended, whichever letter was attended to first would lead to a correct response in both compatible and



incompatible displays. No response competition effects would occur in the incompatible displays because a correct response would be initiated before the competing letter was processed.

A serial attending of the letters would explain the appreciably longer RTs for the two types of noise letter displays as resulting from the subjects' attending to the noise letter first on approximately half of the trials. On these trials the subjects would have to process the noise letter to the point of being able to identify it as a nontarget and then shift attention to the target letter in the display. In other experiments using comparable stimuli (C. W. Eriksen et al., 1989; C. W. Eriksen & Yeh, 1985), estimates of the time required to process a noise letter and then shift attention have yielded values on the order of 60–70 ms. A similar estimate can be obtained from the data in Table 1. The relevant data are those from the simultaneous cuing condition, because only with the simultaneous cues can we assume that the subjects were processing the noise letter first on approximately half of the trials. Mean RT was 28.4 ms longer for the low-confusable noise displays than the average for the compatible and incompatible displays and 34 ms longer for the high-confusable noise displays. Because the noise letter would be attended first on only approximately one half of the trials, we need to double these mean values in order to estimate the mean time required to process a noise letter and then shift attention to the target location. When these mean differences are doubled, the values of 56.8 and 68 ms are comparable to the previously obtained estimates for processing a noise letter and then shifting attention.

We included both confusable and nonconfusable noise displays in the present experiment because we anticipated that less time would be required to process a nonconfusable noise letter to the point that it could be identified as a nontarget. Indeed, the estimates of processing time obtained here do show that less time was required for the nonconfusable letters, but as Table 2 shows, the difference between these two types of noise displays was not reliable.

The significant effect obtained for precuing is also supportive of an interpretation that focal attention was involved in the processing of the display letters. If focal attention was involved, we would expect that an early cue designating target location in the display would expedite the processing of the subsequently appearing letter. The 50 ms by which the cue preceded the display was too short to ensure that attention was always deployed to the cued location (C. W. Eriksen & Hoffman, 1973; Murphy & Eriksen, 1987), but this previous research also shows that this time interval is sufficient to direct attention. The success of this method of attentional biasing can be checked by examining the subjects' response choices on the incompatible displays in the precuing condition. Because on these displays the two letters required different responses, the letter designated by the precue should have been the one responded to on better than 50% of the trials. On the average the subjects' responses matched the target that was precued on 66% of the trials. Each of the 11 subjects responded to the precued target on 55% or more of the trials, a result that is significant by a simple sign test.

More important evidence of serial attentional focusing on the display letters is provided by comparing the gain from

precuing for the compatible and the incompatible displays with the gain obtained for the confusable and nonconfusable noise displays. In the noise displays, it was always the target location that was precued. Thus, to the extent that the precue directed attention first to the target letter, the need to process the noise letter and then shift attention to the target would be eliminated. On the other hand, precuing incompatible and compatible displays would only benefit performance by giving attentional processing a small head start on one of the two targets.

Although the overall interaction from the ANOVA had not reached significance, the specific form of the interaction between cuing conditions with the compatible and incompatible displays and with the noise displays was a specific prediction in this experiment. The gain from precuing was only 8 ms for the compatible displays and 3.4 ms for the incompatible displays. On the other hand, the gain was 18.8 ms for the nonconfusable noise displays and 19.1 ms for the confusable displays. Correlated *t* tests of the differences between the two cuing conditions showed that the compatible and the incompatible display types each gained significantly less ( $p < .01$ ) than did either of the noise displays from precuing. This is the result that is predicted by a serial attentional interpretation.

Analysis of the error data is commensurate with these interpretations. Table 3 shows the mean percent of errors as well as the mean RT on error trials for the five display types in which errors could occur. An ANOVA of percent errors showed a main effect for display type,  $F(4, 40) = 14.69$ ,  $p < .001$ , and a significant Cue Condition  $\times$  Display Type interaction,  $F(4, 40) = 3.96$ ,  $p < .01$ . This interaction resulted from errors being less frequent with precuing for the two noise letter displays. This result is consistent with serial processing, because if the subjects tended to process the target first on the noise displays, there was less opportunity for the subjects to confuse a noise letter with a target and to make an error response.

The error trial RTs were also analyzed in an ANOVA. There was a significant main effect of display type,  $F(4, 40) = 5.70$ ,  $p < .001$ , but the cue condition and the Cue  $\times$  Display interaction did not reach significance. The significant display type effect strongly suggests that error trial RTs are influenced by the same variables that determined the RTs on correct trials. Error trial RTs are fastest for single-letter displays and slowest for the two displays containing a noise letter, a result

Table 3  
Mean Percent Error and Mean Error Reaction Times (RTs;  
in Milliseconds) as a Function of Display and Cue Types

Display type	Cue type			
	Simultaneous		Precue	
	RT	% error	RT	% error
Single	473.91	9.0	474.76	10.1
Identical	500.00	10.2	485.18	13.1
Compatible	501.00	10.0	474.82	8.8
Low-confusable noise	517.36	16.3	550.09	12.8
High-confusable noise	530.91	20.1	534.91	14.9

comparable with that obtained for correct trial RTs. This result argues against an interpretation of errors as resulting from fast guesses. This argument is further supported by a comparison of the error trial means in Table 3 with the means obtained for correct trials shown in Table 1.

The comparability of correct and error trial RTs eliminates a possible interpretation of the incompatible display results. With incompatible displays, errors are not detectable because either response direction would be correct for one of the letters in the display. The failure to find response competition effects with this display type could have resulted from undetected fast guesses counteracting the competition effects. The lack of evidence that error trials are faster than correct trials would seem to preclude this possibility. Furthermore, if the error trial RTs are added to the correct RTs for the compatible displays, the recomputed mean RTs (503 ms for simultaneous condition and 493 ms for the precued) are only slightly lower and still do not approach a significant difference from the comparable means of the incompatible displays. C. W. Eriksen et al. (1989) also failed to find that error trials differed in RT from correct trials.

The present results join those of Grice, Canham, and Boroughs (1984) as providing clear evidence for some form of coactivation in the processing of redundant targets. In addition, the present results and those of Grice, Canham, and Gwynne (1984) make quite clear that the occurrence of a processing synergy when two or more identical targets are presented in the visual field cannot be reliably assessed when the criterion for coactivation is based on the performance obtained with displays containing only a single target without an accompanying noise letter. The poorly understood display size or distraction effect can mask a processing gain that arises from coactivation, as can response competition and the allocation of processing resources to several stimuli. Along with the method of variable criterion analysis used by Grice, Canham, and Boroughs (1984), the method of the present experiment in which identical target displays are compared with response-compatible displays serves to control for the effect of these extraneous variables.

It might be argued that the significantly poorer performance of response-compatible displays over identical displays in the present experiment resulted from some small amount of response competition occurring with the response-compatible displays. With two different letters presented, there would be an increased probability that the features of one of the letters would resemble the features of one of the letters in the other response class. It has been shown that feature similarity can partially prime an opposing response (B. A. Eriksen & Eriksen, 1974; Miller, 1982b; Yeh & Eriksen, 1984). This argument can be readily dismissed by noting the performance for the response-incompatible displays (in which response competition would be maximal) was at the same level as that obtained for the response-compatible displays. In the previous experiments on response competition, RT to displays containing targets requiring different responses has always been appreciably longer than RT to displays containing neutral stimuli (those for which there is no experimentally defined response) or to nontargets that have a similarity to the other target class. In the present experiment there is no evidence

that response competition occurred even in the condition maximally conducive to competition.

The absence of response competition in the present experiment may seem surprising to some investigators. The results of response competition studies have been interpreted as showing that focal attention cannot selectively exclude processing irrelevant stimuli in the visual field to the point of identification. However, this is an overgeneralization. The experiments of Eriksen and associates (B. A. Eriksen & Eriksen, 1974; C. W. Eriksen & Hoffman, 1973; C. W. Eriksen & St. James, 1986; Murphy & Eriksen, 1987) have shown a gradient of processing around the attended stimulus. If response competitive stimuli are farther away than 1.5° from the attended target, no detectable effects are obtained. In the present experiment we chose a distance of 2.9° between the two letters in the displays. At this separation, focal attention located on one of the letters would be able to exclude simultaneous processing of the other display letter. We believe, however, that quite different results would have been obtained if the stimuli in the present experiment were separated by only 1° or less of visual angle.

In Experiment 1, we chose as stimuli letters that require or at least can materially benefit from focal attention in a discrimination task. As with closer spaced display letters, we also believe that quite different results would have been obtained if the target stimuli were such as to permit automatic processing. Indeed, the disparity in results reported by different experimenters using the redundant-targets paradigm may well result in part from their choice of stimuli and the spacing of the stimuli within the display. We test these possibilities in Experiment 2.

## Experiment 2

In this experiment, we used X and O as target letters for the two-choice RT task. The letters appeared above, below, or above and below the fixation point and were separated by .72°, 3.10°, or 5.24° of visual angle edge to edge. These stimuli were chosen because they could be discriminated on the basis of a single feature (Treisman & Gelade, 1980), and prior research (e.g., Shiffrin & Gardner, 1972; van der Heijden et al., 1984) had suggested that such simple figures could be processed in parallel or by distributed attention. Furthermore, to help ensure that the letters would be parallel processed, we systematically varied the visual distance separating the letters in two-letter displays. As we noted earlier, the research evidence strongly suggests that letters within approximately 1.5° of visual angle fall within a common attentional focus (C. W. Eriksen & Hoffman, 1973; Murphy & Eriksen, 1987). The displays were (a) single letter (X or O); (b) identical (XX or OO); (c) response incompatible (XO or OX); or (d) a target letter and a noise symbol (X\* or \*O).

Simultaneous parallel processing of the two-element displays should lead to a race situation. With the identical displays, the race would result in what Raab (1962) has termed *statistical facilitation in RT*. The resulting redundancy gain may, at least in part, offset the distraction effect. Thus, performance with identical displays would be more comparable

to the RTs obtained with single-letter displays. The RTs obtained with the incompatible displays would, on the other hand, be increased because of response competition. The simultaneous processing of both target letters would prime the separate responses with resulting inhibition. Because the target plus noise symbol displays are not expected to lead to response competition, simultaneous processing of these displays would be faster than response-incompatible displays.

We expected that the greatest likelihood of parallel processing of the two-element displays would occur when the two elements were separated by only  $0.72^\circ$  of visual angle. As the letters of the displays are separated by increasingly greater distances, each letter falls at increasing retinal eccentricity with a resulting drop-off in acuity. This loss in acuity has the effect of making the X and O less discriminable. As a consequence, serial focal attention might benefit performance at the greatest separation of the display elements. If at least some of the subjects began to use focal attention on at least some of the trials at the  $5.24^\circ$  separation, we anticipated that the response competition effect would be reduced and performance with the target plus noise displays would become slower. The slower performance for the target plus noise displays would occur because of the subject's focusing first on the noise symbol on about half of the trials with the consequent need to then redirect attention to the target.

In addition to determining whether closely spaced, easily discriminated targets would be simultaneously attended, this experiment serves another important function. It is capable of providing an important check on our argument that the absence of response competition in the incompatible display condition of Experiment 1 requires serial processing of the two targets. C. W. Eriksen et al. (1989) pointed out that there is an important difference between the methodology of the present experiments and those experiments that have demonstrated response competition when the alternative target is presented as noise (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; B. A. Eriksen & Eriksen, 1974; Flowers & Wilcox, 1982; Grice, Boroughs, & Canham, 1984). In these latter experiments the target for each trial is designated by its position in the display. Thus when a stimulus is identified, it must also be checked for position to verify that it is the target for that trial. In the present experiment, the target position is not designated. With the incompatible displays, each of the two presented targets is in a permissible location. Although robust response competition effects are well documented with the first methodology, one can legitimately question whether they would occur with the change in method. C. W. Eriksen et al. (1989) performed a control experiment that supported the conclusion that the change in method did not eliminate competition effects if processing occurred for the noise stimulus, but the present experiment is capable of providing unequivocal evidence on this point.

### Method

*Subjects.* Five male and 6 female graduate and undergraduate students at the University of Illinois, Urbana-Champaign, served as paid volunteers. All were right handed and had normal or corrected-to-normal vision.

*Apparatus and stimuli.* The equipment was the same as that used in Experiment 1. Here, however, the target letters were X and O. They were presented in uppercase, were colored white, and subtended  $0.24^\circ$  of visual angle in height. A white asterisk measuring  $0.19^\circ$  of visual angle served as a noise stimulus (no response assignment).

The stimuli appeared approximately  $0.36^\circ$ ,  $1.55^\circ$ , or  $2.62^\circ$  of visual angle above, below, or above and below the fixation cross. These three different stimulus distances were blocked separately. Each block contained 12 single targets (X or O), 8 identical targets (XX or OO), 6 response-incompatible targets (XO or OX), and 12 single targets plus neutral noise (X or O paired with an asterisk). Stimulus combinations and locations (top/bottom) appeared in random order within a block with the constraint that all letter-location combinations were equally probable.

*Procedure.* Subjects initiated trials by pressing a hand button held in their left hand. They responded with their right hand by moving a hand lever to the right or left, depending on the target letter identified. Responses (correct/incorrect), response direction, and RT in milliseconds were recorded by the computer.

We instructed subjects to be sure that the fixation cross was in clear focus before they initiated a trial. They were told to move the hand lever quickly and as accurately as possible to the right (or left) when the letter X appeared and to move the hand lever in the opposite direction when the letter O appeared. We explained that an X or an O or both letters would appear on each trial and that subjects should ignore the asterisk. Single-letter displays would contain either an X or an O and two-element displays would yield any combination of Xs and/or Os and Xs or Os paired with an asterisk. Because two targets with different responses could occur in the two-letter displays, subjects were asked to respond to the target letter they saw first or most clearly. In addition, subjects were informed that the stimuli would appear at three different distances away from the fixation cross over different blocks of trials.

When subjects initiated a trial by pressing a hand button, the stimulus display appeared immediately afterward for 200 ms. Response accuracy and correct RTs were both displayed to the subject after each trial. Subjects completed three sessions over a period of 3 days. The first session was considered practice and was not incorporated in the data analysis. Each session consisted of 12 blocks of 38 trials. The 12 blocks consisted of 4 blocks at each of the three distances. Order of block presentations was counterbalanced within subjects.

### Results and Discussion

Figure 1 shows correct mean RTs for the four display conditions at each of the three retinal separations. As would be expected, RT increases appreciably for all four display conditions as the display stimuli are located at increasing retinal eccentricities. This is consistent with the drop-off in acuity and an attendant increase in processing time (C. W. Eriksen & Schultz, 1977; Lefton & Haber, 1974). The results for the different display conditions at the  $0.72^\circ$  and  $3.1^\circ$  separations are quite different than those obtained in Experiment 1. In Experiment 1 the slowest RTs were obtained under the target plus noise condition, and there was no evidence that the incompatible condition resulted in response competition. In contrast, the present results show evidence of marked response competition at both the  $0.72^\circ$  and  $3.1^\circ$  separations. At these separations, not only is the RT for the incompatible condition appreciably greater than for the identical condition, but the RT is also greater than for the target plus neutral



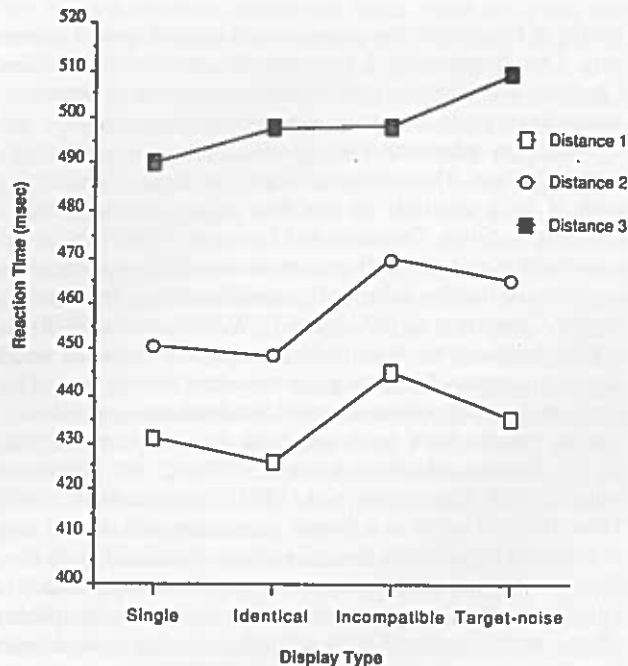


Figure 1. Mean correct reaction times for display condition for each of the three separations between letter stimuli.

noise condition. Most important, this effect is eliminated when the separation between the display elements is increased to 5.24°. At this separation the results are quite similar to those obtained in Experiment 1. Response competition is now eliminated with performance in the incompatible condition at the same level as that obtained for the identical condition, and the slowest RTs are obtained for the target plus neutral noise condition.

Statistical analysis supports these conclusions. A within-subjects ANOVA (Display Type  $\times$  Retinal Separation  $\times$  Subjects) revealed that the main effects for display type,  $F(3, 30) = 4.95$ , and retinal separation,  $F(2, 20) = 39.48$ , were both significant beyond the .01 level. Furthermore, the interaction between these two variables was also significant,  $F(6, 60) = 3.08$ ,  $p < .01$ . The significance of the differences between the four conditions at each of the three separations was evaluated by planned comparisons. Table 4 shows the mean differences between these conditions and whether they were significant.

At the two closest separations, RTs for the identical displays are slightly faster than for the single-letter displays, but not significantly so. At these separations, however, there is pronounced response competition. RTs for the incompatible displays are significantly slower than for the single-letter and identical displays as well as significantly slower than for the target plus noise displays at the 0.72° separation. Response competition decreases as the separation between the display elements becomes greater. At the 5.24° separation, the RTs to the incompatible displays are not appreciably or significantly different than RTs to the identical displays, but they are significantly faster than the RTs to the target plus noise displays.

This pattern of results is what would be expected if the subjects were parallel processing the display elements at the closer separations. In fact, the simple discrimination between X and O at a separation of up to 3.1° produced response competition or evidence for parallel processing, whereas high feature overlap among stimulus letters in Experiment 1 separated at a comparable distance of 2.9° showed no response competition, a result consistent with serial processing. However, at a more distant separation of 5.24°, the discrimination between X and O became more difficult because of degraded images resulting from reduced acuity. As a result, focal attention can contribute to the discrimination and thus subjects shift to a serial attending of these elements. The findings from Experiments 1 and 2 suggest that difficult discriminations (which lead to serial processing) can result from at least two factors: high feature overlap among stimuli and decreased stimulus clarity due to poorer acuity.

We appear to have been fortunate in the selection of spacings between the elements. Although we knew that the discrimination between the X and O targets would become more difficult with increasing retinal eccentricity, we did not know beforehand that the 5.24° spacing would be sufficient to result in a significant shift from a distributed attentional approach to focused attention on a single display element. The presence of response competition at the closer spacing and its absence at the 5.24° spacing reinforces our assumption in Experiment 1 that difficult discriminations lead to a serial attending of the display elements.

Analysis of the error trials is consistent with these conclusions. In Table 5 the mean percent errors and the mean of the error trial RTs are shown for the single-target, identical-targets, and target plus neutral noise conditions at each of the

Table 4  
Mean Differences in Correct Reaction Time Between the Four Display Conditions

Display condition	Separation											
	0.72°				3.1°				5.24°			
	1	2	3	4	1	2	3	4	1	2	3	4
1. Single	—	4.94	14.21**	4.37	—	2.40	19.29**	14.18**	—	7.56	8.01	18.96**
2. Identical	—	—	19.15**	9.31*	—	—	21.69**	16.57**	—	—	0.45	11.39*
3. Incompatible	—	—	—	9.84*	—	—	—	5.11	—	—	—	10.95*
4. Target-noise	—	—	—	—	—	—	—	—	—	—	—	—

\*  $p \leq .05$ . \*\*  $p \leq .01$ .

Table 5  
Means of the Error Trial Reaction Times (RTs) and Percent Error for Display Condition and Stimulus Separation

Condition	Separation					
	0.72°		3.1°		5.24°	
	RT	% error	RT	% error	RT	% error
Single	367	4.7	408	5.6	450	7.1
Identical	382	4.9	425	5.1	464	9.0
Target-noise	390	5.1	427	6.4	478	13.6

three retinal separations of the display elements (no errors are detectable in the incompatible display condition). A within-subjects ANOVA of the error trial RTs shows significant effects for display type,  $F(2, 20) = 4.24, p < .05$ , and for separation,  $F(2, 20) = 15.29, p < .01$ . The interaction between these variables, however, was not significant. This was most probably due to the absence of the incompatible display condition from the analysis. A similar ANOVA for the proportion of correct responses yielded a similar outcome.

Significant effects on error trial RTs for the display conditions and of the separation of elements in the display again show that error responses were affected by the experimental variables in the same manner as were correct responses. This suggests that fast guesses played a minor role, at best, in the production of errors in this experiment. C. W. Eriksen et al. (1989) also found that error RTs reflected the effect of the experimental manipulations. In their experiments the mean RT of error trials tended to be longer than for correct responses. In the present experiment, however, RTs on error trials tended to be somewhat less than for correct responses, as can be seen by comparison of the values in Table 5 with the values shown in Figure 1.

We noted in the introduction that the present experiments involved a change in methodology from the traditional response competition paradigm (B. A. Eriksen & Eriksen, 1974). The question could be raised as to whether response competition would be obtained when the subject was free to respond to either stimulus in the incompatible displays. The results of Experiment 2 show quite clearly that the change in methodology does not prevent response competition. If the target stimuli differ only on a single feature or are close enough together in the visual field to be encompassed in a single attentional focus or both (conditions that have previously been found to yield parallel processing), then significant and appreciable response competition effects are obtained. This finding adds substantially to our conclusion in Experiment 1 that the absence of response competition effects with the incompatible displays is diagnostic of serial processing of the display elements.

### General Discussion

The question as to whether redundant signals will yield faster discriminatory responses seems like an easy one to answer, but as we noted in the introduction, conflicting answers have been obtained by different investigators. The

results of the present two experiments suggest several reasons why. Our Experiment 1 supports the conclusion of Grice, Canham, and Gwynne (1984) that the presence or absence of redundancy gains cannot be assessed by comparing the performance on redundant displays with that obtained on single-target displays. The addition of another target to a display, even if it is identical to the first target, increases visual complexity. Grice, Canham, and Gwynne (1984) termed this a *distraction effect*, but diverse experiments have shown that increases in display complexity result in slower responses to targets. Colegate et al. (1973) and C. W. Eriksen and Hoffman (1972) have shown that adding irrelevant noise to visual displays increases RT to targets even when the location of the target in the display is known well in advance of presentation. Similar results have been obtained by other investigators (C. W. Eriksen, Hamlin, & Daye, 1973; C. W. Eriksen & Schultz, 1978; Kahneman et al., 1983; Treisman et al., 1983). Thus, RT to a target in a display containing two stimuli may be expected to be longer than to a single-stimulus display even if the two stimuli are identical. Any gain from redundancy in a display must be great enough to offset the display complexity effect if performance with the redundant display is to be faster than that obtained with single-target displays.

Based on the pattern of results obtained in the present experiments, several general conclusions can be drawn about the nature of redundancy gains, and a more specific conclusion can be drawn about one heavily debated form of redundancy gain, coactivation. The conclusions are as follows. When targets can occur in any position in a display and any target is sufficient to elicit a response, then redundancy gains come in three forms, and each operates under a specifiable set of conditions. Two of these forms of redundancy gain have to do with the difference between a situation in which there are two nonidentical targets in a display and a situation in which there is only one target and a noise stimulus. In both of these situations, coactivation cannot occur by definition. The first form, which has to do with attentional focus location, occurs under conditions that lead to serial processing. It results from the prealigning of attention to one of the possible target locations or the serial attending to the items in the display. The redundancy gain occurs due to the greater likelihood that a target will be attended early in the search as the number of targets present in the display increases. The second form is what Raab (1962) termed *statistical facilitation*. It occurs under conditions that lead to parallel processing and results from the fact that when parallel identification processes race to control responding, the race is more likely to end early when there are more processes in the race. Finally, a third form of redundancy gain, coactivation, can arise when the display contains two or more targets that are identical. Here, presumably either of the other two forms of redundancy gain can occur, but coactivation occurs in addition.

The results of the present experiments show that the process by which a redundancy gain is produced depends on whether the discriminatory task requires or can materially benefit from focused attention. Our first experiment used as stimuli letters that previous research had suggested required focal attention. Furthermore, the stimuli presented in the displays were separated in the visual field far enough to ensure that they did

not fall in a common attentional focus. Analyses of the data strongly supported the conclusion that subjects serially attended and processed the two stimulus displays. Here a redundancy gain was obtained not only for the identical displays but also for response-compatible and response-incompatible displays as well. All were significantly faster than displays containing a single target and an irrelevant noise letter.

The redundancy gain achieved by the compatible and the incompatible displays was attributed to the fact that with these displays, whichever stimulus was attended first could result in a target identification. Performance on these displays was faster than on the target plus irrelevant letter displays because with the latter, on half of the trials the subject would first attend to the irrelevant letter. (Performance on the identical displays was faster than both the compatible and incompatible displays and is discussed later.) This result is comparable to the "positional preference" effect (Mullin et al., 1988), which has previously been related to attentional direction (van der Heijden et al., 1984).

In Experiment 2, we chose as target stimuli the letters X and O that previous research had suggested could be discriminated without focal attention. Also, in one condition, the two display letters were close enough together so as to ensure that they would fall in a common attentional focus. With the two closest spacings, the results strongly indicated that two-letter displays were simultaneously and parallel processed. The main evidence for parallel processing was the significant response competition effect obtained with the incompatible displays. At the two closest separations, the incompatible displays produced the longest RTs, which were not only significantly longer than the identical displays but also significantly longer than the target plus noise displays. Because both the 3.1° and 0.72° spacing showed this evidence of parallel processing, we cannot be sure whether the parallel processing resulted from the ease of discriminating Xs from Os or from the fact that at these spacings, both stimuli fell within the minimum size of the attentional focus. As we noted earlier, research has suggested that stimuli within about 1.5° of an attended target appear to be processed along with the target (Murphy & Eriksen, 1987).

As with serial processing, parallel processing of the displays also results in a redundancy gain. But with the parallel processed displays, we suggest that the basis of the redundancy gain is different. At the two closest spacings, identical displays yield RTs that are actually faster than single displays, although not significantly so. The real test of redundancy gain, however, is the comparison of the identical displays with the target plus noise displays. Here the identical displays are clearly and significantly faster than targets plus noise, but unlike the serially processed displays in Experiment 1 and the 5.24° spaced displays in Experiment 2, the redundancy gain with parallel processing arises from statistical facilitation (Raab, 1962). Reaction time is determined by the winner of the race between the two simultaneously processed targets.

So far, our experiments have substantiated two of the bases of redundancy gains that have been previously advocated in the literature. Our main contribution has been to more clearly delineate the conditions under which each occurs. If the conditions are such as to permit a distributed attentional approach or the stimuli are close enough together in the visual

field so as to be encompassed by a common attentional focus, they are parallel processed and statistical facilitation contributes to a redundancy gain. If the discrimination is difficult and requires or can materially benefit from focal attention, the separated stimuli are serially processed, and the redundancy gain arises in part from the reduction in positional uncertainty as to where to direct the attentional focus. With two targets, either position is correct as far as choosing where to direct attention.

In addition to these two bases for redundancy gains, our research also provides strong evidence for a third. In Experiment 1 the finding that identical displays were faster than compatible displays supports the existence of some form of coactivation. Miller (1982a) had proposed that the inputs from the two separate occurrences of the target pooled together to reach a criterion of recognition, but as van der Heijden et al. (1984) and Grice, Canham, and Boroughs (1984) pointed out, Miller's evidence was flawed by the possibility of response competition. In our Experiment 1, performance on identical displays is compared with displays in which the target letters are different but both call for the same response. Thus, response competition is eliminated as a variable in the latter displays. Pooling of featural information to expedite recognition would only be plausible when the two targets are identical. Our finding that identical displays are significantly faster than response-compatible displays strongly suggests that repetition of an identical form speeds recognition. This is consistent with the Grice, Canham, and Boroughs (1984) conclusion that the input from each of the identical targets contributes equally to the growth of associative strength.

This coactivation effect may be presumed to have contributed to the redundancy gain in conjunction with statistical facilitation in Experiment 2, in which we have concluded that the stimuli in the displays were parallel processed. But it was most clearly identifiable in Experiment 1, in which we have concluded that the display stimuli were serially attended. This poses an apparent contradiction. If the stimuli were serially attended in Experiment 1, how can the inputs from the separate stimuli pool to expedite recognition? There are most probably several ways that coactivation could occur at early perceptual or preattentive levels. Common sense tells us that many stimuli direct and guide behavior without the benefit of focal attention and laboratory experimentation confirms our commonsense observations (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The simultaneous appearance of an identical form on a separate retinal area could have a synergistic effect that expedites the processing of the attended form. The nonattended member of the identical pair may not gain access to focal attention but it makes a contribution to information processing at these early levels that is not available to introspection or consciousness. It is tempting to localize the effect at the feature detector level because prior theorizing has rather thoroughly explored the possibility of interactions of channels feeding feature detectors (Bjork & Murray, 1977; Estes, 1972). However, research that has followed from these ideas has at best been controversial in the findings.

The interactive channels model proposed by Bjork and Murray (1977) actually predicted that recognition perfor-

mance would be worse if a target form was accompanied by an identical form in the display than if it was accompanied by a dissimilar form. Santee and Egeth (1980) confirmed the Bjork and Murray findings, but C. W. Eriksen, Morris, Yeh, O'Hara, and Durst (1981) pointed out several response biases that could have been operating in the experiments of Santee and Egeth as well as those of Bjork and Murray. C. W. Eriksen et al. (1981) used procedures that precluded these response biases and found no evidence that the feature similarity between target and noise letters in a visual display had any effect on target recognition. The definitive research on this problem was carried out by Estes (1982). He used a procedure that permitted separation of discrimination from criterion effects and concluded that there was no evidence that discrimination of letter forms was affected by the degree of similarity of features between the target and accompanying noise letters. On the other hand, he found that feature similarity did have a measurable effect on response bias and criterial shifts. He concluded, as had C. W. Eriksen et al., that the results of Bjork and Murray and of Santee and Egeth were attributable to these response biases.

It should be noted that all of the above summarized research used recognition accuracy as the dependent variable. Different results are obtained if choice response time is used. B. A. Eriksen and C. W. Eriksen (1974, 1979) have quite consistently found that RT to a target letter is faster if the letter is flanked by repetitions of itself than if it is flanked by different but response-compatible letters. Also, in the Bjork and Murray (1977) experiment, RT was faster if the designated target in the display was accompanied by a repetition of itself than if it was presented with the alternative target, even though recognition performance was superior in the latter condition.

Another distinction needs to be drawn in this research area. In the above summarized experiments, the subject knows that there is only one target in the display and its position is designated. The remaining letter(s) in the display are noise and are supposedly irrelevant. However, in the typical redundant-targets paradigm, the subject is permitted to respond to any letter in the display. In some cases the subject is even instructed that if more than one letter occurs in the display, the letters will all be identical. In this latter procedure, redundancy gains are consistently obtained (e.g., Doherty & Keeley, 1969; C. W. Eriksen, 1966; C. W. Eriksen & Lappin, 1965). If subjects are as flexible in shifting their criterion as a function of task demands as Estes's (1982) data suggest, then it is possible that these differences in experimental procedures can determine whether facilitation from processing a form on a different retinal area is used.

An important factor may be whether active suppression is involved. There is accumulating evidence (e.g., Neill, 1977; Neill & Westberry, 1987; Tipper, MacQueen, & Brehaut, 1988) that noise stimuli presented with a "to be attended" target are actively suppressed or inhibited. This inhibition could determine whether facilitating effects arising from the simultaneous processing of identical forms is used. Thus, differences in methodology that determine subjects' strategy with respect to multistimuli that appear in the display may be crucial as to whether coactivation is detected.

G. R. Grice (personal communication, September 2, 1989) suggests that the superior performance found for identical

displays over response-compatible displays in Experiment 1 may be due to less distraction effect for identical displays. If the forms in a display are all the same, they might constitute less distraction than if they are different. This is a plausible explanation for the coactivation effect that we have obtained, but one that appears quite difficult to test experimentally. The distraction effect itself is poorly understood. It may well turn out that as the various components composing the distraction effect are delineated, interactions at the feature processing level may be found to be one of the factors involved.

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