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On the Nature of Input Channels in Visual Processing

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The research reported herein was designed to assess whether the presence of noise elements in a visual display affects the detection of target letters at the perceptual or feature extraction level of processing, as well as at the decision level, and more specifically, whether (a) input or processing channels operate in an independent or interactive fashion and (b) how the spatial relation between signal and noise items affects detection performance. In order to distinguish among current theories proposed to account for the influence of noise items on visual processing, a forced-choice detection task was modified to incorporate a cueing procedure, which permitted the independent variation of signal–noise similarity, confusability, and proximity. The results provide evidence for feature-specific inhibition at the perceptual level, and a theory is proposed that assumes hierarchically organized, limited-capacity feature detectors and feature-specific inhibitory channels.

There is now considerable evidence that the detectability of a designated signal is impaired by the presence of noise elements in the same visual display. The degree of impairment has been shown to vary as a function of the confusability of noise elements with the set of alternative targets (Estes, 1972; Gardner, 1973; McIntyre, Fox, & Neale, 1970) and the spatial proximity of target and noise (Strangert & Brannstrom, 1975; Wolford & Hollingsworth, 1974). However, whether the effects of signal–noise similarity on target detection might be different than the effects of signal–noise confusability and how either of these variables might interact with signal–noise proximity has not been established; nor is it clear at what level of processing noise items impair the visual detection of signals. Evidence to date suggests that noise items affect detection performance by creating signal–noise confusion at a decision level of processing rather than by creating interference at a perceptual level (Eriksen & Eriksen, 1974). The primary purpose of the present article is to determine whether effects of noise elements also occur at a perceptual or feature extraction level of processing and, if so, to clarify the perceptual mechanisms responsible for such effects.

Current models proposed to account for the detrimental effects of noise elements on signal detection can be divided into two general types: those that assume noise items influence the decision or response level exclusively, and those that assume noise items influence the perceptual or feature extraction level as well. Examples of the decision-level type are the models of Gardner (1973), Shiffrin and Geisler (1973), and the model developed by Eriksen and his associates over several papers (e.g., Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972, 1973; and Eriksen & Spencer, 1969). The only example of the perceptual-level type is the interactive channels model proposed by Estes (1972). These two types of models can also be distinguished with respect to their assumptions concerning the nature of input or processing channels. In general, decision-level models assume that information extraction occurs over independent, parallel processing channels,

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whereas the perceptual-level model assumes that information extraction occurs over interactive, parallel processing channels.

In both types of models, noise elements affect detection at the decision level by increasing the likelihood that a noise item will be misidentified as a signal, and the more items present, the greater the likelihood of such a false detection. In the interactive channels model, however, this effect of noise items on detection performance is subsidiary to their effect at the feature extraction level. At the latter level of processing, input channels to feature detectors are assumed to undergo inhibitory interactions, and the more noise items in the display, the greater the likelihood that channels to detectors necessary for the detection of signals will be inhibited, thereby lowering detection accuracy and increasing response time.

In spite of their different underlying assumptions, it is difficult to discriminate between the two types of models, both being consistent with the major empirical effects of noise items on detection accuracy and response time. Two factors seem primarily responsible for this situation. First, in previous studies confusability of noise characters with the target present on a trial and with the alternative possible targets have varied together (e.g., Banks & Prinzmetal, 1976; Gardner, 1973). Thus, any inhibitory effects of similar noise letters on the perception of a target have been confounded with opportunities for signal–noise confusions. Second, in the few previous studies directed at the issue of the locus of noise item effects, visual detection tasks have been used in which response time is the primary dependent measure, with stimulus exposure durations being relatively long and no masking stimuli employed. Under such conditions, any inhibitory effects of noise items at the perceptual level may simply have been obscured by the strong effects of response conflict observed in these studies, leaving unanswered the question of whether perceptual effects occur (e.g., Eriksen & Eriksen, 1974). In short, because the two types of models assume such similar effects of noise elements at the decision level, they can not be empirically discriminated if the experimental task allows the effects of noise items at the decision level to dominate performance.

In order to circumvent these difficulties, the present study introduces a paradigm in which (a) the contributions of noise items to the response-decision process should be minimal, if not eliminated; (b) similarity of noise elements to the target presented and confusability of noise elements with alternative targets can be varied independently; and (c) detection accuracy and response time can be examined separately in an attempt to utilize their possibly differing sensitivities to processes occurring at the perceptual and decision levels of visual detection. These properties of the paradigm allow us to address not only the question as to whether noise items influence detection at the perceptual level, but also whether input channels are independent or interactive, and whether the effects of signal–noise proximity on detection performance vary in relation to signal–noise similarity.

The Paradigm

The present paradigm employs a partial-report cueing procedure in a forced choice detection task. A typical trial sequence is shown in Figure 1. First, the premask matrix is briefly exposed. Next, the stimulus matrix, containing either one or two letters with all remaining positions filled by a single, repeating background character, is tachistoscopically presented and then replaced by a postmask matrix that remains in view until the subject responds. Simultaneously with the presentation of the postmask, an upward pointing arrow appears under one of its four columns. The subject's task on each trial is to report which of two signal elements, B or R, appeared in the column of the stimulus display cued by the arrow. In the trial illustrated in Figure 1, the second column is cued and the correct response is "B." Since the subject's response is to be based only upon the information perceived in the cued column, it does not matter that the alternative target appeared in another column of the display.

Four types of displays can occur, examples of which are shown in Figure 2. All display types contain exactly one of the two possible targets, B or R, in the cued column. They

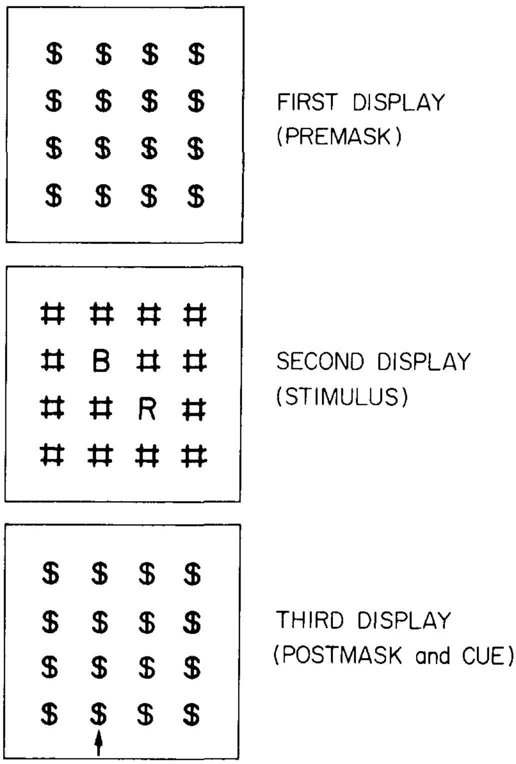

Figure 1. An example sequence of the displays presented on a single trial.

differ with respect to what letter, if any, appears as the noise letter in one of the uncued columns. All positions of the display not containing the target or noise letter are filled with a nonconfusable character resembling a number-sign.

Single-target displays contain no noise letters. *Noise-same-as-target* displays contain two instances of the same target letter, either two Rs or two Bs, as shown in Figure 2. However, because of the cueing procedure, only one instance of the letter B—the one located in the column to be cued—is to serve as the basis for the subject's detection response. The other B, located in an uncued column, is to act as a noise character and not as a redundant signal. *Noise-alternative-target* displays contain both target letters, one appearing in the cued column and the alternative appearing in one of the uncued columns. *Noise-nontarget* displays contain one of the target letters in the cued column and one of two nontarget letters, P or K, as the noise letter in one of the uncued columns. For all displays the target letter can appear in any display position, and for the double-letter displays, the distance between signal and noise letters is systematically varied. For all four display types shown in Figure 2, the correct response is B, given that the second column is cued.

The cueing procedure of the present paradigm serves two important functions. First, since a subject's response is to be based only upon information extracted from the cued column, it creates a situation in which the effects of noise letters occurring at the decision level should be minimal, if present at all, thus allowing any noise-letter effects occurring at the perceptual level to be revealed in the subject's detection performance. Second, it allows letters that are physically identical to the target to function as noise items rather than as redundant signals, thereby creating a situation in which the effects of signal–noise similarity and signal–noise confusability can be separated. For example, in the noise-same-as-target displays, signal–noise similarity is maximal, but confusion about what is noise and what is signal at the decision level would not lead to overt response errors. If poorer

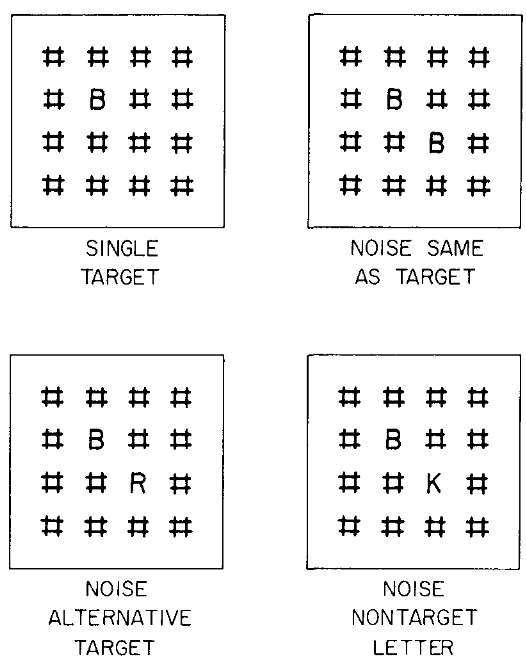

Figure 2. An example of the four display types.

detection performance were to be obtained for these displays as compared, say, to single-target displays, the decrement in performance would have to be attributed to noise letter interference at the perceptual level. Thus, with respect to the present task and display types, the decision- and perceptual-level models are forced to make different predictions concerning the effects of noise letters on detection performance.

Predictions of the Decision-Level Models

The Gardner and the Shiffrin and Geisler Models. The decision-level models of Gardner (1973) and of Shiffrin and Geisler (1973) predict no differences in performance among the four display types of the present paradigm. This prediction arises primarily from the assumption of these models that information in the various letter locations of a brief visual display is extracted over separate input channels operating independently and in parallel so that information being transmitted over one channel does not interact with information being transmitted over another channel. In the present situation, only information extracted from locations in the cued column would be considered in the response decision process and, for all four display types, this information is identical. Thus, detection performance must be the same.

With respect to the variable of signal–noise proximity, these models make no predictions, since they do not take into account effects of the spatial relationship between the signal and noise characters in a visual display.

Although, as presently formulated, the Gardner (1973) and the Shiffrin and Geisler (1973) models do not assume that the subject is uncertain of the location of an item extracted from a visual display, one could easily extend these models to allow some localization uncertainty to occur in the present paradigm. For example, one might assume that a central processor or scanner can occasionally become confused as to which input channels are associated with the locations in the cued column of the display—such confusions being more harmful for some displays than others and, for such displays, more harmful the smaller the signal–noise separation. The predictions of these models would then become identical to those of the Eriksen model discussed below.

The Eriksen model. The decision-level model developed by Eriksen and his associates predicts (a) that performance on single-target displays will be poorer than performance on noise-same-as-target displays but better than performance on noise-alternative-target or noise-nontarget displays, and (b) that performance will be better on noise-same-as-target displays than on noise-alternative-target displays, with intermediate performance on noise-nontarget displays. With respect to the variable of signal–noise proximity, the Eriksen model predicts increasing performance on noise-alternative-target and noise-nontarget displays as signal–noise separation increases, but a decline in performance with increasing signal–noise separation on the noise-same-as-target displays.

These predictions of the Eriksen model arise primarily from its assumption of limited attentional selectivity. That is, although the Eriksen model assumes independent, parallel processing channels, it does not assume a one-to-one mapping between processing channels and display items as in the Gardner (1973) and the Shiffrin and Geisler (1973) models. Stimuli close together or within the limits of selective attention (presumed to be approximately one degree of visual angle) are assumed to be simultaneously processed over the same channel and thus to begin evoking their respective responses simultaneously. A decision process is then required to select which response should be made and which inhibited.

According to this model, then, the noise letter in the noise-same-as-target displays, if adjacent to the signal letter, could be processed and initiate a "correct" overt response by mistake. Performance on noise-same-as-target displays should thus, on the average, be better than performance on single-target displays for which there would be no opportunity for such overtly "correct" false detections to occur. On the other hand, the noise letter in the noise-alternative-target displays would, on some trials, evoke the incorrect response, thereby decreasing average detection accuracy and increasing average response time as compared to performance on either single-target or noise-same-as-target displays. Similarly, the average performance obtained on noise-nontarget displays should be poorer than that obtained on single-target displays and fall between the performance levels obtained on noise-same-as-target and noise-alternative-target displays, since on some trials the nontarget noise letter could be misjudged as either the letter in the cued column or the alternative target.

The Eriksen model predicts that performance on noise-alternative-target and noise-nontarget displays should improve as signal–noise distance increases because the efficiency of selective attention improves with greater signal–noise separation. That is, the further the noise letter is from the target, the lower the probability that it will be processed over the same channel, and thereby produce response competition. In contrast, the occasionally beneficial effect of the noise letter in the noise-same-as-target displays should decrease as the signal–noise separation increases, producing a decline in performance with increasing signal–noise distance.

Predictions of the Perceptual-Level Model

The interactive channels model of Estes (1972) predicts detection performance to be best on single-target displays, intermediate on noise-nontarget displays, and poorest but equal on noise-same-as-target and noise-alternative-target displays. Further, the Estes model specifically predicts equal performance for both target letters B and R on the noise-nontarget displays. With respect to signal–noise proximity, the interactive channels model predicts increasing performance for all three double-letter display types with increasing signal–noise separation.

The counterintuitive prediction of the Estes model—detection of a target letter will be better when there is one instance of that letter in the display (i.e., single-target displays) than when there are two instances (i.e., noise-same-as-target displays)—arises as follows. In the interactive channels model, only inputs from locations within the cued column would enter into the response decision process. Thus, at the decision-level of this model, there would be no effect on detection performance of the noise letter in the noise-same-as-target displays. However, at the feature extraction stage of this model, the noise letter in the noise-same-as-target displays can have a detrimental effect on detection performance. At this level, features of stimulus elements excite input channels to feature detectors; however, excitation of any input channel exerts inhibitory effects on other channels going to the same or other feature detectors. Further, excitation of an input channel is more likely if the channel is in a heightened state of excitability. Input channels to feature detectors associated with the target letters of the present paradigm would be in such a state of heightened excitability as a result of the instructional set of the subject. However, input channels to feature detectors associated with the number-sign characters of the present paradigm would not be in a state of heightened excitability. Thus, the noise letter in the noise-same-as-target displays would be more likely to excite one or more input channels to feature detectors necessary for its detection, thereby inhibiting input channels necessary for detection of the target letter in the cued column, than would the corresponding number-sign character of the single-target displays. For the same reasons, detection performance on noise-alternative-target displays should also be poorer than performance on single-target displays.

The prediction that performance on noise-alternative-target and noise-same-as-target displays should be equal and poorer than performance on noise-nontarget displays arises as follows. Input channels to feature detectors associated with either target letter would be in identical states of heightened excitability. Thus, at the perceptual level, it should be equally interfering to the detection of the letter in the cued column to have either the same target letter or the alternative target letter somewhere else in the display. Better performance on the noise-nontarget displays is predicted because the nontarget noise letters cannot have as many features in common with the target letters as the target letters themselves. Thus, only a subset of their features—those that overlap with the combined set of target features—will have input channels in a heightened state of excitability with a consequent increased probability of being activated.

The prediction that performance on noise-nontarget displays should be the same for either target letter arises from the assumption of the Estes model that the potential inhibitory effect of a noise letter is determined by its similarity or feature overlap with the combined set of target letter features—not just its feature overlap with the target letter appearing in the same display. As a possible test of this prediction, we chose as our nontarget noise letters, two letters (P and K) which, on the basis of Gibson's (1969) feature list, Townsend's (1971) interletter confusion matrices, and our own perceptual judgments, we thought should be more similar to the target letter R than to the target letter B.

Finally, improved detection performance on all three double-letter display types with increasing signal–noise separation is predicted because the inhibitory effects an active input channel exerts on other channels are assumed to diminish as a function of distance in the visual field. Thus, the perceptual interference produced by the noise letters in each display type should decrease with increasing distance between the signal and noise letters.

Method

Subjects

Twelve male and female young adults responding to advertisements posted in the psychology building at the University of California, Los Angeles, served as subjects in the experiment. All were right handed, had normal or corrected-to-normal vision, and were paid for their participation.

Apparatus

Character displays were presented on the screen of a Hewlett–Packard 1300-A Precision X-Y display scope under the control of a Hewlett–Packard 2100 computer. The subject sat at a combination desk-chair located approximately 112 cm in front of the display screen which was visible through a 10 × 12 cm aperture cut in a white cardboard panel. Each character in the 4 × 4 matrix displays was .7 cm high by .5 cm wide, and the space between adjacent columns and rows was .5 cm. The entire display subtended 1.79 degrees of visual angle in the horizontal direction and 2.20 degrees in the vertical. A keyboard interfaced to the computer was located on the desk surface in front of the subject with all response keys except the two used in the experiment covered by a piece of plastic.

The experiment was conducted in a sound insulated room with low illumination. With the room lights on and the display on, the luminance of the screen was 45.05 cd/m^2; with the room lights off and the display on, the luminance was 8.05 cd/m^2.

Design

The experimental variables were type of display (i.e., nature of the noise letter; see Figure 2) and distance between target and noise letters. For each double-letter display type, three different levels of signal–noise separation, measured in city-block fashion, were investigated. Thus, if the target letter was in cell (i, j) and the noise letter in cell (m, n), the distance between them was either 1, 2, or 3 units, as measured by the formula $|i - m| + |j - n|$.

The target letters B and R occurred equally often as the cued letter in all display and distance conditions, and they appeared equally often in the same display locations for all display types and all levels of signal–noise proximity. The letters P and K, used as the noise letters in the noise-nontarget displays, appeared equally often with each target letter and at each level of signal–noise proximity. Displays were presented in eight blocks of 48 trials each and within each block, both target letters, each of the four display types, and each level of signal–noise proximity occurred equally often and in random order. Further, across all the above variables each column of the stimulus display was cued equally often. Finally, the two possible target and response-key assignments occurred equally often across subjects.

Comparisons among the various experimental conditions will be based on detection performance of the cued letter in only four locations of the display, one from each column, and each containing target letters B and R equally often for each display and distance condition. However, B and R appeared and were cued as the target letter in all possible locations of the 4 × 4 matrix display.

Procedure

All subjects were first read a set of instructions describing the task and the various display types. Subjects were also told (a) to base their detection responses only upon the information perceived in the cued column, (b) that the cued column would equally often contain either a B or an R but never both, and (c) that no matter what the uncued letter in the display happened to be, half the time the letter in the cued column would be B and half the time it would be R. They were also instructed to respond as quickly as possible, but not so quickly as to make unnecessary motor errors.

Each subject then practiced the task while the exposure duration of the stimulus display was systematically lowered until a suitable performance level was obtained; final display duration ranged from 25 to 50 msec.

As illustrated in Figure 1, each trial began with a 500-msec premask display that both served as a ready

Table 1
Correct Detection Proportions for Each Display Type and Each Target Letter

Display type	Target letter B	R	Pooled
Single target	.93	.88	.90
Noise same as target	.70	.76	.74
Noise alternative target	.85	.82	.84
Noise nontarget	.85	.77	.82

signal and defined for the subject the location on the screen in which the stimulus display would appear. In addition, a small black dot permanently affixed to the screen in the exact center of the displays served as a fixation point. Immediately following the premask display, the stimulus appeared for the appropriate duration for that subject and was then replaced by the postmask and cue display, which remained on the screen until the subject responded. Three seconds later, the next trial began.

Results and Discussion

Influence of Noise Characters on Detection Accuracy

Both the overall correct detection proportions obtained for each display type and those obtained separately for target letters B and R are shown in Table 1. An analysis of variance was performed separately on the correct detection proportions obtained for the single-target displays and for the three double-letter display types, since only for the latter displays was the distance variable manipulated. In the analysis for single-target displays, the one experimental factor, target letter, did not attain significance.

In the analysis of variance for the double-letter displays, the main effects of display type and signal–noise distance were significant, with larger signal–noise separations leading to better performance, $F(2, 22) = 10.49$, $p < .01$; $F(2, 22) = 3.60$, $p < .05$, respectively. The main effect of target letter did not attain significance, but the Target Letter × Display Type interaction did, $F(2, 22) = 8.41$, $p < .01$. It can be seen from Table 1 that a primary contributor to this interaction is the better detection of the target letter B than the target letter R in the noise-nontarget displays. This difference is, in fact, significant by a planned comparison t test for dependent measures, $t(11) = 7.60$, $p < .001$.

The most striking aspect of the results shown in Table 1 is that the counterintuitive prediction of better performance on single-target displays than on noise-same-as-target displays by the Estes perceptual-level model has been dramatically upheld, $t(11) = 8.59$, $p < .001$. Clearly, the prediction of no difference between single-target and noise-same-as-target displays by the Gardner (1973) and the Shiffrin and Geisler (1973) models has been strongly violated. Further, the difference obtained between these two display types is in the opposite direction to that predicted by the Eriksen model or the modified versions of the Gardner and the Shiffrin and Geisler models.

The better performance on single-target versus noise-alternative-target displays is also significant by a planned comparison t test for dependent measures, $t(11) = 2.90$, $p < .02$, consistent with the predictions of the Estes, the Eriksen, and the modified Gardner and Shiffrin and Geisler models.

The pattern of results among the three double-letter display types is not totally consistent with the predictions of either the decision-level models or the interactive channels model, although it is less damaging to the latter. The better performance on noise-alternative-target displays than on noise-same-as-target displays is significant by a planned comparison t test for dependent measures, $t(11) = 5.60$, $p < .001$, violating both the prediction of no difference between these two display types by the interactive channels model and the prediction of a difference in the opposite direction by the Eriksen and the modified versions of the Gardner and the Shiffrin and Geisler models. However, the better performance on noise-nontarget displays than on noise-same-as-target displays is also significant by a planned comparison t test for dependent measures, $t(11) = 2.54$, $p < .05$, consistent with the interactive channels model and inconsistent with the various decision-level models.

The combined findings of better performance on singlet-target than on noise-same-as-target displays and poorer performance on noise-same-as-target displays than on either noise-alternative-target or noise-nontarget displays clearly demonstrate the influence of noise letters on detection performance at the perceptual level of processing and strongly support the notion of interactive rather than independent processing channels. Thus, two key assumptions of the Estes (1972) perceptual-level model have been upheld. However, two findings of the present study imply that the interactions among processing channels differ from those specified in the Estes model. First, there is the finding of a significant difference between detection performance on noise-same-as-target and noise-alternative-target displays. Second, there is the finding of a significant difference between correct performance on noise-nontarget displays when B is the target versus when R is the target. These two results imply that the interactions among channels are more specific than conceptualized in the interactive channels model. In particular, they imply that an active input channel exerts more inhibition on input channels leading to the same feature detector than to ones leading to other detectors, in which case, intrastimulus signal–noise similarity would be the primary determiner of noise letter interference effects, as was observed in the present experiment.[1]

Influence of Signal–Noise Proximity on Correct Detection Performance

The overall correct detection proportions as a function of signal–noise proximity are .79, .78, and .83, respectively, for separation levels of 1, 2, and 3 city-block units. From the analysis of variance, the estimated standard error for these proportions is .029. Thus, the significant main effect of signal–noise distance arises from the difference in performance at the distance levels of 1 and 2 versus the distance level of 3. This pattern of results is not surprising when one examines the various double-letter displays at each level of signal–noise proximity in terms of a Euclidian metric. For displays with signal–noise separations of 1 or 2 city-block units, the noise letters are essentially located on the perimeter of an imaginary circle, centered about the target letter and having a radius slightly greater than 1 cm; for displays with separations of 3 units, the noise letters are essentially located on the perimeter of a similarly constructed circle having a radius of approximately 2.5 cm. Thus, in terms of a Euclidian metric, only two levels of signal–noise proximity were investigated in the present study—the city-block distances of 1 and 2 collapsing into the same separation level. For these reasons, the correct detection proportions obtained at distances of 1 and 2 are combined in Table 2 in which the distance functions for each double-letter display are shown.

Table 2
Correct Detection Proportions for Each Display Type as a Function of Distance Between Target and Noise Letters

Display type	Distance (city-block metric) 1 & 2	3
Noise same as target	.72	.76
Noise alternative target	.83	.85
Noise nontarget	.79 (.84, .74)	.85 (.86, .84)

Note. Values in parentheses denote performance on displays containing the target letters B and R, respectively.

For noise-nontarget displays, separate dis-

[1] Some readers may wonder whether guessing biases play a role in the detection results. Thus, on trials when only the noncued noise letter is seen, the subject might adopt the strategy of guessing the least similar target. Such a guessing strategy might produce the obtained advantage of noise-alternative-target displays over noise-same-as-target displays, and it might also produce the differences in performance obtained on noise-nontarget displays containing the target letter B versus the target letter R. This explanation is implausible for several reasons: (a) Such a strategy is, in fact, nonproductive, given the nature of the displays, and all subjects were carefully informed that the nature of the letter in an uncued column provided no information about the target letter in the cued column. (b) During the debriefing of subjects, none of the 12 subjects reported using anything like such a guessing strategy, and of the strategies reported, none would have biased the results in any particular direction. (c) Furthermore, the guessing hypothesis predicts that noise-alternative-target displays would yield better performance than single-target displays, which did not occur. (d) Finally, as discussed below, there are systematic changes in performance with increasing signal–noise separation, and these changes make no sense in terms of the guessing hypothesis.

Table 3
Reaction Times (in msec) for Correct Detections as a Function of Display Type

Display type	Reaction times[a]
Single target	631 (.90)
Noise same as target	720 (.74)
Noise alternative target	740 (.84)
Noise nontarget	702 (.82)

[a] Values in parentheses are the proportions of correct detections obtained for each display type.

tance functions are shown in Table 2 for target letters B and R, since for this display type average detection performance is significantly different for the two target letters. At a signal–noise separation of 1 or 2 units, the better detection performance for B versus R shown in Table 2 is significant by a t test for dependent measures, $t(11) = 2.44$, $p < .05$, whereas the difference between B and R at a signal–noise separation of 3 units is not. Thus, the greater perceptual interference of noise letters P and K for the target letter *R* than the target letter B decreases with increasing signal–noise proximity until, at a separation of 3 units, detection of either B or R is essentially the same. Further, this finding that the B versus R difference decreases with increasing signal–noise distance argues strongly against attributing the overall B versus R difference on noise-nontarget displays to a base-rate difference in the detection of B and R, which might have been a possibility given the difference in detection of B and R on single-target displays, even though this latter difference is not significant.

Although all double-letter display types show improved performance at the signal–noise separation of 3 units, it is apparent that performance on noise-same-as-target displays remains considerably lower than that on the other double-letter display types. This difference is, in fact, significant by a t test for dependent measures, $t(11) = 3.40$, $p < .01$. Nonetheless, the improvement in performance shown in Table 2 for noise-same-as-target displays is significant by a planned comparison t test for dependent measures, $t(11) = 3.34$, $p < .01$, consistent with the Estes model and inconsistent with the Eriksen and the modified versions of the Gardner and the Shiffrin and Geisler models.

Influence of Noise Characters on Response Latencies

The average response times obtained for correct detections as a function of display type are shown in Table 3. As with the detection data, separate analyses of variance were performed for the single-target displays and for the double-letter displays. In the analysis for single-target displays, the one experimental factor, target letter, did not attain significance. The analysis for double-letter displays revealed main effects of display type and signal–noise distance, $F(2, 22) = 3.29$, $p < .05$; $F(2, 22) = 12.15$, $p < .01$, respectively.

In general, the response latencies follow the proportion-correct data with the interesting exception of the noise-alternative-target displays. Although the target letter in the noise-alternative-target displays is significantly more likely to be detected than the target letter in the noise-same-as-target displays, the response times in the former are significantly slower than in the latter, $t(11) = 9.33$, $p < .001$. This finding points to the occurrence of noise letter interference effects at the response-decision level in the noise-alternative-target displays, replicating the effects of signal–noise confusability on response time found by Eriksen and Hoffman (1972) and Eriksen and Eriksen (1974) and indicating the differential sensitivity of accuracy and response time measures to processes occurring at the perceptual and decision levels of visual detection.

An alternative explanation of these results is that the reverse ordering between response times and accuracy for noise-same-as-target and noise-alternative-target displays reflects the adoption of a different speed–accuracy criterion for the two display types. Such an explanation seems quite implausible, however, in view of the fact that the display types were presented in random order throughout the experiment, and thus the subjects had no way of adopting different speed–accuracy criteria for one display type versus another. Furthermore, the same argument cannot be used to explain the significant difference in detection accuracy between noise-same-as-target and noise-nontarget displays, whereas both accuracy differences are consistent with the perceptual interference explanation. Finally, the speed/accuracy trade-off explanation is inconsistent with the detection and response time performance obtained for noise-alternative-target and noise-same-as-target displays as a function of signal–noise proximity presented below.

Influence of Signal–Noise Proximity on Response Latencies

The average response latencies obtained for correct detections at signal–noise separations of 1, 2, and 3 city-block units are 748, 730, and 648 msec, respectively. Although there is a systematic decline in response latency across the three levels of signal–noise separation, the effect is largely due to the difference between latencies obtained at separations of 1 and 2 city-block units versus those obtained at a separation of 3 units. The difference in response time for distance levels of 1 and 2 failed to obtain significance by a t test for dependent measures. Thus, in Table 4 in which average response times are shown for each display type as a function of signal–noise proximity, the response times obtained at distance levels of 1 and 2 are combined.

Two results shown in Table 4 should be noted. First, the finding of decreasing response times with increasing distance between the target and the opposite-response noise letter is consistent with the previous findings of Eriksen and Eriksen (1974). Second, at a distance level of 3 units, there is essentially no difference in response latency between noise-alternative-target and noise-same-as-target displays, but the significantly superior detection accuracy for the noise-alternative-target displays persists, $t(11) = 2.25$, $p < .05$. This finding is inconsistent with a speed/accuracy trade-off explanation of the superior average correct detection accuracy on noise-alternative-target versus noise-same-as-target displays shown in Tables 1 and 3. If the difference in average correct detection performance for noise-same-as-target versus noise-alternative-target displays is to be attributed to a speed/accuracy trade-off, then when response times are the same for the two display types, the accuracy difference must also disappear.

Table 4
Reaction Times (in msec) for Correct Detections as a Function of Distance Between Target and Noise Letters

Display type	Distance (city-block metric): 1 & 2	Distance (city-block metric): 3
Noise same as target	737 (.72)	686 (.76)
Noise alternative target	765 (.83)	689 (.85)
Noise nontarget	714 (.79)	676 (.85)

Note. Values in parentheses are the proportions of correct detections.

Thus, the present paradigm, by separating the effects of signal–noise similarity and signal–noise confusability, has been successful in showing that noise letter effects occur at a perceptual level of visual processing as well as at a later response-decision level. More interference occurred at the perceptual level for noise-same-as-target displays than for noise-alternative-target displays, as reflected in the lower proportion of correct detections obtained on the former as compared to the latter displays. On the other hand, significantly more interference occurred at the response-decision level for noise-alternative-target displays than for noise-same-as-target displays, as reflected in the response times obtained on the former at the smaller target–noise separations.

A Feature-Specific Inhibitory Channels Model

The present study has been successful in clarifying or answering the three questions it addressed. First, the presence of noise elements in a visual display was found to affect signal detection performance at both the perceptual and decision levels of visual processing. Second, at the feature extraction level of processing, input channels were observed to operate in an interactive fashion. Third, the detrimental effects of noise elements on detection performance were found to decrease as the spatial distance between signal and noise characters increased.

On the basis of the total pattern of results obtained in the present study, we have developed the outline of a new model of visual processing—a feature-specific inhibitory channels model—which borrows freely from the interactive channels model, keeping its assumptions concerning the effects of noise letters at the decision level intact, but diverging from its perceptual level assumptions in two important ways. First, the new model assumes that channels to the same feature detector inhibit each other more than they inhibit channels going to different detectors. Second, it assumes that feature detectors have limited capacity and are hierarchically organized. These assumptions are described in more detail below as we compare the Estes interactive channels model and the new feature-specific inhibitory channels model.

Assumptions of the Model

Inhibition. In the feature-specific inhibitory channels model, we assume that two different processes create inhibition among input channels. One is the type of inhibition assumed by Estes: It occurs when input channels to detectors necessary for target detection are put into a heightened state of excitability as a function of the instructional set of the subject and thus are more likely to be activated by appropriate stimulus features than are input channels to detectors not associated with the target letters. These latter channels are thus, relatively speaking, inhibited.

The other process of inhibition assumed in the present model operates specifically among input channels to the same feature detector. Here, rather than assuming that the activation of one channel inhibits the activation of another, we assume that the arrival of information over one channel momentarily delays the reception by the detector of information arriving over any other channel. This delay could perhaps be necessitated by the feature detector needing time to somehow encode the location in the visual field from which a particular feature was transmitted. During this delay, the feature information being transmitted over the unattended channel can be lost.

Feature detectors. In addition to having limited capacity to deal with information arriving over different input channels, feature detectors are assumed to be arranged in a hierarchical manner according to the complexity of the input they process, much like the system proposed by Hubel and Wiesel (1965, 1968). Similarly, we expect the more complex detectors to have larger receptive fields than the simple detectors, because the output of the latter becomes the input for the former. Further, we assume that for all levels of detectors, their receptive fields are smaller in the foveal region of the visual field than in the periphery.

Nature of features. As in the Estes model, we assume that the various alpha-numeric characters are represented in the perceptual and memory systems by distinct subsets of a relatively small population or master set of features. Presently, we are thinking of simple features as the distinct features comprising this master set (e.g., vertical, horizontal, and oblique lines; and convex and concave curves). More complex features would correspond to combinations or intersections of two or more simple features (e.g., various types of angles formed by intersecting lines, and distinct patterns formed by combining curves and lines). A particular character is thus represented in the perceptual and memory systems by a hierarchical listing of features, which would be unique for that character, but which would also have varying degrees of overlap with the unique feature sets representing other characters. Thus, detection of a given target may sometimes require activation of only one or more simple feature detectors and sometimes require activation of the higher, more complex feature detectors, depending upon the overlap between its features and those of the particular alternative target and noise characters employed. With practice in the typical detection task, the subject develops a listing of features, some of which may be simple and some complex, but all of which serve to discriminate the target characters from one another and from the current population of noise characters. Before a given trial, the representations of these discriminative features are placed in an active state in immediate memory along with their connections to the mechanisms necessary for implementing the appropriate overt detection response. In the typical detection experiment, as soon as inputs from the display activate one or more of the feature detectors corresponding to the discriminative features of a target, the appropriate overt detection response could be initiated.

Spatial interaction. The feature-specific inhibitory channels model assumes that noise letters interfere with detection at the perceptual level to the extent that the target and noise letters in the same display utilize the same limited-capacity feature detectors. This sharing of detectors is in turn a function of the similarity, proximity, and retinal location of the target and noise items. In the present model, then, the signal–noise distance effect would be attributed to a lower probability that common features of signal and noise characters need access to the same detectors as their spatial separation increases, rather than to the general decrease in inhibition among input channels with distance in the visual field assumed in the Estes model.

Predictions of the Model

From the two major assumptions of (a) feature-specific inhibitions among input channels and (b) a hierarchical organization of limited-capacity feature detectors, several predictions follow. First, the present model, like Estes's model, predicts or is consistent with our finding of better performance on single-target displays than on either noise-same-as-target or noise-alternative-target displays. Unlike the Estes model, however, the feature-specific inhibitory channels model does not predict equal performance on noise-same-as-target and noise-alternative-target displays, since the amount of interference occurring in the latter displays would be a function of the degree of feature overlap between B and R. Although we do not know exactly what this overlap is, we do know that it is less than the overlap between identical letters. Thus, the present model would predict better detection performance on noise-alternative-target than on noise-same-as-target displays, as was observed.

Another prediction of the present model not made by the Estes model is that noise letters sharing only simple features with a target letter should not interfere with its detection except at small signal–noise separations, whereas noise letters sharing complex features with the target should continue to interfere with its detection at greater signal–noise separations. The distance functions obtained in the present study offer some support for this prediction. At the smaller signal–noise separation, detection performance is essentially the same for noise-same-as-target displays and noise-nontarget displays with R as the target letter. At the larger signal–noise separation, however, the interference of the nontarget noise letters, P and K, with the target letter R has been considerably reduced, whereas for noise-same-as-target displays, in which the target and noise letters share the most complex features, performance remains significantly lower than that of the other double-letter displays.

The feature-specific inhibitory channels model is admittedly post hoc; it does however make a number of yet untested predictions, particularly concerning how the variables of signal–noise similarity, signal–noise proximity, and retinal location might interact. For example, the model predicts an interaction between similarity and retinal location. That is, recognition or detection of similar letters, with a constant interletter distance, should decrease more rapidly as a function of distance from the foveal area of the visual field than should the recognition or detection of dissimilar letters.

Finally, the feature-specific inhibitory channels model brings together some apparently contradictory results from previous studies—some of which support the hypothesis of independence among input channels (e.g., Gardner, 1973) and some of which support the notation of interaction among input channels (e.g., Estes, 1972, 1974). Since in the present model, inhibitory interactions among input channels are largely limited to channels accessing the same feature detectors, channels can operate independently to the extent that they do not lead to common detectors. The picture is fairly complicated, however, since the input channels to detectors at one level may operate independently, but the input channels from these detectors to the next level of detectors may be interactive. For example, two letters with common features could be far enough apart not to require access to the same simple detectors, but close enough to require access to the same complex detectors. Nevertheless, as demonstrated by the present results in which the interference between dissimilar letters like B and K was quite limited even at small separations, input channels can operate in a largely independent fashion, given the proper choice of signal and noise letters and the proper spacing between them.

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