Interactions of signal and background variables in visual processing*

W. K. ESTES
The Rockefeller University, New York, New York 10021

Three variables which determine the opportunities for signal-noise confusions, display size (D), number of redundant signals per display (N), and number of alternative signals (A) were studied in relation to nature of the noise elements, confusable or nonconfusable with signals. Data were obtained in a forced-choice visual detection situation, the displays being linear arrays of letters on a CRT screen. For all three performance measures used, frequency of correct detections and correct and error latencies, strong interactions were obtained between all of the other variables and signal-noise confusability. The functions obtained, together with other data bearing on the role of confusions and on spatial relations among characters within the display, suggest a model whose initial phase is a parallel feature extraction process involving inhibitory relations among input channels.

On the assumption that the perceptual and cognitive processes involved in abstracting information from brief visual displays require measurable time to operate, latency data provide one of our principal avenues of approach to the mechanisms involved. However, theoretically significant analyses must always be guided by models which make specific assumptions as to how processing time is allocated to different constituent processes. In the recent literature, three types of models have received serious consideration.

1. Serial scanning models. It is assumed that representations of the characters of a display in the visual system are compared one by one with representations of the signal characters in memory, the process continuing at a rate of 10-40 msec per character until either a signal element is discovered or the entire display has been scanned without detection of a signal (Bamber, 1969; Estes & Taylor, 1964, 1966; Sperling, 1963).

2. Concurrent Poisson processes. In a model proposed by Rumelhart (1970), processing time is taken up by a feature extraction process. Each character in the display is assumed to be composed of a number of critical features, and information concerning these features is extracted in parallel from all of the characters in the display, the processing continuing until the traces of the characters in the visual system have decayed below threshold. The amount of time required to extract a criterion number of features of any particular character is Poisson distributed.

3. Parallel, unlimited capacity models. In the type of model suggested by the work of Eriksen and Spencer (1969) and Gardner (1973), it is assumed that each character in a display has its separate input channel and that information can be transmitted over all of these simultaneously. A principal component of response latency in this type of model would be the decision time required for a central attentional mechanism to examine the inputs from the various channels and choose as a basis for response the one whose input most closely meets the criterion of a signal.

Up to the present, no purely parallel model has been developed to the point of making detailed predictions about latencies. Models of Types 1 and 2, and especially that of Rumelhart, have had considerable success in accounting for some quantitative features of latency data, for example, functions relating reaction time to display size. However, none of these models has come off well in dealing with the problem of redundant signal elements. If more than one instance of the signal element chosen for a trial is included in the display, these models predict that latency should be reduced, in Type 1 because a signal will be discovered sooner on the average, and in Type 2 because the criterion number of features will be extracted sooner. However, several experiments agree uniformly in showing latency of correct responses, when corrected for guessing, to be independent of number of redundant signal elements (Bjork & Estes, 1971; Wolford, Wessel, & Estes, 1968).

The data of Bjork and Estes pose an especially difficult problem for the serial and Poisson models in view of the strenuous efforts that were made to provide a sensitive test. Further, these data hint at a possibly important role of a factor, namely, confusability of characters, which, though readily accommodated in models of Type 3, has not had explicit representation in models of Type 1 or Type 2. The pertinence of this factor was first indicated by Eriksen and Spencer (1969), in order to account for their finding that the usual function relating detection accuracy to display size was obtained even when the elements of a display were presented sequentially rather than simultaneously, Eriksen and Spencer proposed that incorrect detections arise when a response appropriate to a signal element is triggered by a noise element which shares features with it. Bjork and Estes found that the decreasing function relating error latency to number of redundant signals could be most simply accounted for on the assumption that errors represent a mixture of guesses and misidentifications resulting from signal-noise confusions. Finally, a study by McIntyre, Fox, and Neale (1970) showed that, as might have been anticipated on the basis of discrimination literature, detection accuracy decreases as the similarity between signal and noise characters increases.

On the basis of these considerations, it seemed in order to examine more systematically the role of opportunities for confusion errors in the detection situation, with special reference to effects upon response times. Thus, the present experiment was designed to compare the standard noise condition, imbedding the signal in a background of randomly selected letters, with a condition falling at the opposite extreme of the confusability continuum, namely, imbedding the signal in a background of identical noise elements which are maximally dissimilar from the signal.

Of central concern are the interactions of noise condition with display size and number of redundant signals, the variables most studied in recent research. For the standard noise condition, each of these variables can be considered a major determiner of the number of possible signal-noise confusions—the greater the number of different noise letters in a display, the larger the number of possible signal-noise confusions, and the larger the number of redundant signals in a display of given size, the smaller the number of possible confusions.

But also, it seemed desirable to find a method of varying the possible number of confusions which did not involve changes in display characteristics, in order to provide information as to the level of processing at which confusions occur.

---

*This research was supported in part by USPHS Grant GM16735 from the National Institute of General Medical Sciences. Edith Skaar contributed materially to the data collection and processing.

To this end, the number of alternative signal elements was added as a fourth experimental variable. Two possible signals have been the standard condition in previous research, but the set of admissible signals can be increased without otherwise changing the procedure. If, for example, the S must determine which of four possible signal elements is represented in the display on any trial, the number of possible confusions between signal and noise elements is increased over the standard condition, but without any change in characteristics of the display. Following usage in other research involving the matching of a displayed signal letter with a set held in memory (e.g., Sternberg, 1966), I shall refer to this variable as size of the memory set.

In order to provide controlled comparisons of all of the variables within a single experiment, the two noise background conditions were combined factorially with three display sizes, three different numbers of alternative signals in the memory set, and four different numbers of redundant signals per display. Data were obtained for all of the resulting 36 combinations of conditions on each S, and the experiment was replicated for each S with two different sets of particular stimulus materials. The data expected to be of primary interest are the functions relating probability of correct detection, correct response latency, and error latency to each of the other three variables under the confusable and nonconfusable noise conditions.

METHOD

Apparatus

Character displays were presented on the screen of a Tektronix 503 oscilloscope under the control of a PDP-8/I computer. The S sat at a table with a response box centered in front of him and faced a 50 x 50 cm black panel 32 cm from the edge of the table. The screen of the oscilloscope was visible through a 13.25-cm-diam aperture in the panel. The two response buttons, which activated microswitches interfaced to the computer, were 2.1 cm deep and 2.7 cm wide, with a .6-cm space between them.

Displays of characters were constructed by illuminating the appropriate pattern of points in a matrix 6 points high x 5 points wide. Characters were .75 cm high and .55 cm wide, and characters in a row were spaced .47 cm apart. At the normal viewing distance, the width of a character subtended approximately ¾ deg and the intercharacter space slightly less than ½ deg. The CRT screen had a P_2 phosphor.

Subjects

Five young adults were paid $2.00 per hour for their services. All had had considerable previous experience in the laboratory, serving as Ss in other experiments, and were generally familiar with the apparatus and the type of character display used.

Design

Two sets of signal letters were used, the set A, B, C, D (Set 1) being assigned to one response button and the set S, T, U, V (Set 2) to the other for each S. Noise elements for the confusable background (C) condition were drawn without replacement from a set comprising two instances of each of the letters I, J, K, L, M, N, O, P, Q, R. The noise element for the nonconfusable background (NC) condition was a 5 x 6 dot matrix whose height and width were the same as the maximum dimensions of a letter.

Three display sizes (D) were used: 4, 6, and 8 elements. In all cases, the elements were presented in a horizontal row, centered on the oscilloscope screen. Each display contained 1, 2, 3, or 4 instances of the signal letter selected for the trial (denoted variable N), the remaining spaces in the designated display being filled with noise elements, either letters or dot matrices, as appropriate. For each of the two replications of the experiment with each S, these variables were combined factorially with size of memory set—2, 4, or 8 alternative signals (A). In one replication, under Condition 2A, the S was to press one button if the letter A appeared in the display and the other if a T appeared; under Condition 4A, he was to press one button if either A or B was in the display and the other if S or T was present; under Condition 8A, he was to press one button if any member of Set 1 was in the display and the other if any member of Set 2 was present. In the other replication, A vs T was replaced by D vs U for Condition 2A and A or B vs S or T was replaced by C or D vs U or V for Condition 4A.

The experimental program was organized by 48-trial blocks. Each block was assigned to a particular combination of the D, A, and background variables, and within the block, all four values of N occurred equally often in a random sequence. Maximal control was thus obtained for comparisons among different numbers of redundant signals per display. It seemed desirable to obtain extremely reliable determinations of functions relating response measures to N, since results involving this variable have raised particularly acute problems for current models.

Procedure

Experimental sessions normally comprised six blocks of 48 trials, three under each of two display sizes, the three values of the A variable being randomly assigned to the three blocks at each value of D. With these restrictions, the order of conditions was randomized over the experiment as thoroughly as idiosyncrasies of scheduling permitted. At least the first full session, and for some Ss, the first two, was treated as a practice series, the data being discarded and those blocks rerun later. The criterion of readiness for data collection was a performance level at which nearly all latencies were below 1 sec.

The Ss were fully informed about the nature of the experiment and were instructed to respond as quickly as possible while maintaining accuracy. They received no information concerning correctness of their responses on individual trials, but were frequently informed between blocks concerning their overall accuracy and were permitted to look at their latency records after any session.

The experimental room was darkened, but prior to each 48-trial block, the door was opened, admitting enough illumination so that the S could read a card, placed beside the response box, on which were displayed the two sets of signal letters.

A trial began with a 2-sec exposure of a predisplay mask, consisting in a 5 x 6 dot matrix in the position of each letter to be presented in the display. Then the display appeared for 100 msec. In Condition NC, the appropriate predisplay matrices were displaced by instances of the signal letter or noise matrices prescribed for the trial[1], and in Condition C, all of the matrices were replaced by signal or noise letters. After the display, the mask reappeared and remained until the S operated a response switch, when the screen went blank. Within 48-trial blocks, there was a 1-sec intertrial interval. Between blocks, there was a rest interval of about 2 min while the next input tape was read into the computer.

By means of the real-time clock in the computer, latencies from display onset to closing of a response switch were measured, accurate to .001 sec, and both latencies and choices were typed out on a Teletype in the adjoining control room. Of the 8,640 data collection trials, 5 were discarded owing to disturbances which produced latencies far outside the normal range.

RESULTS

Frequency Data

Proportions of correct detection responses for each S, categorized by display size, number of alternative signals, and background condition, are presented in Table 1.

A strong interaction between display size and background is apparent, group mean proportions correct running .94, .89, and .86 for D values of 4, 6, and 8, respectively, in the C and .98, .98, and .98 in the NC condition. This interaction obtains for all individual Ss and is similar for the group within all values of A. A similar but weaker interaction is manifest between size of the memory set and background condition. Mean proportions correct are .90, .90, and .87 for 2, 4, and 8 alternatives, respectively, in the C and .98, .98, and .98 in the NC background. The decrease in detection accuracy with increasing number of alternatives in the C background is slightly accentuated at D = 8, where the proportions correct are .87, .87, and .83. The decrease, though small in absolute amount, occurs for all five Ss.

Functions relating proportions of correct detections to number of redundant signal elements within each combination of display size and background are presented in Fig. 1. In the varied background, the curves are similar to those observed in preceding studies (Estes & Taylor, 1966; Wolford, Wessel, & Estes, 1968), but, as with the D and A variables, the main effect virtually disappears in the constant background.

Latency Data

Mean latencies of correct responses in milliseconds are presented by values of D, A, and background in Table 2. Owing to the low error frequencies under most conditions, error latencies are reasonably stable only when data are pooled over the rows or columns of Table 2; the marginal means will be included in the figures illustrating the principal interactions.

The interactions of display size with background are exhibited for correct and error latencies in the left and right panels of Fig. 2, respectively. Latencies are substantially and uniformly shorter in the nonconfusable background, and interactions correspond in direction to those for response frequencies. The function for correct latencies in the confusable background is shallower than might have been anticipated, and the trend is of marginal reliability. The latter aspect doubtless is due to the fact that display size was not as well controlled across sessions as were the other variables.

Interactions of number of alternatives with background are similarly depicted in Fig. 3. The increasing trend for correct latency in the nonconfusable background, though small, may be reliable, since it

Table 1
Proportions of Correct Detections for Individual Ss

Number of Alternative Signals	S	Confusable Background			Nonconfusable Background		
		Display Size					
		4	6	8	4	6	8
2	1	.94	.92	.81	1.00	.98	1.00
	2	.95	.95	.92	.99	1.00	1.00
	3	.93	.75	.81	.98	.95	.96
	4	.98	.97	.88	1.00	1.00	1.00
	5	.94	.83	.93	.96	.96	.99
4	1	.94	.90	.88	.98	.99	.99
	2	.94	.92	.92	.99	.96	1.00
	3	.90	.86	.73	.92	.95	.94
	4	.98	.97	.93	.99	1.00	.99
	5	.94	.88	.90	.98	.99	.98
8	1	.94	.91	.79	1.00	.98	.98
	2	.93	.94	.92	1.00	.99	1.00
	3	.82	.74	.72	.91	.94	.93
	4	.96	.92	.86	.99	1.00	.99
	5	.97	.85	.86	.97	1.00	.99

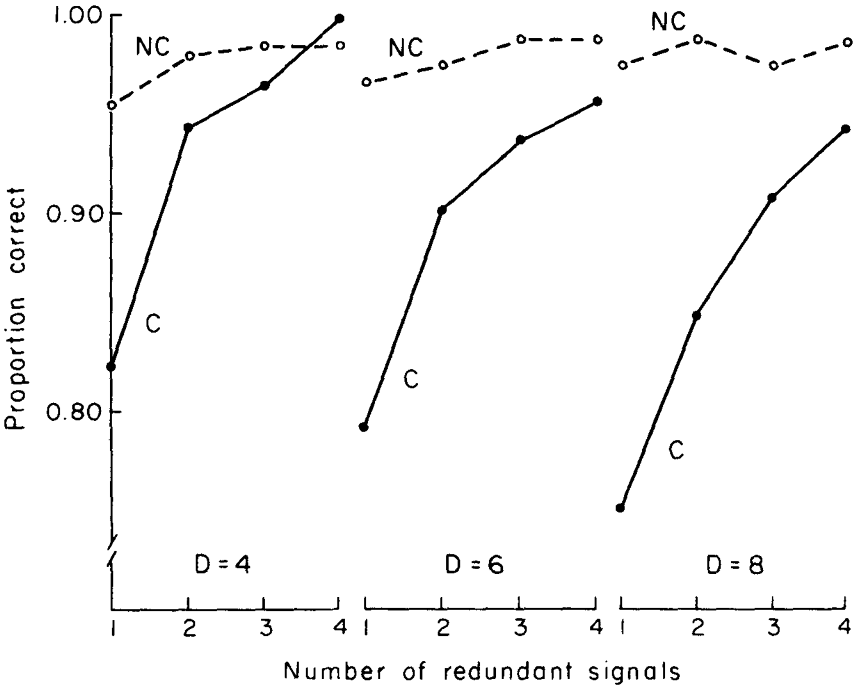

Fig. 1. Proportion of correct detections vs number of redundant signal characters, with confusable (C) vs nonconfusable (NC) background condition and display size (D) as parameters.

Table 2
Mean Correct Response Latencies by Display Size, Number of Alternatives, and Background

Number of Alternatives	Confusable Background			Nonconfusable Background		
	Display Size					
	4	6	8	4	6	8
2	442	506	461	351	381	374
4	491	526	543	385	419	408
8	555	515	619	406	388	416
Mean	496	516	541	381	396	399

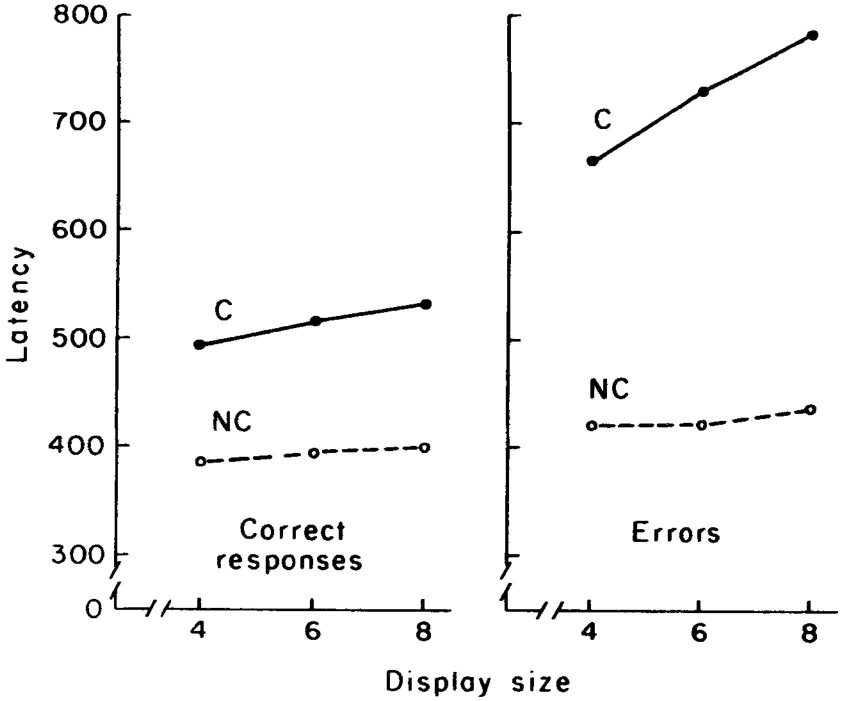

Fig. 2. Mean latency of correct responses and errors in milliseconds as a function of display size, with background condition as a parameter.

obtains for all individual Ss (though monotonically for only one). The monotone trend for correct latency in the confusable background is representative of all Ss and is undoubtedly reliable.

Functions relating correct latency to number of redundant signals are presented for each combination of display size and background in Fig. 4. Mean error latencies for the C background, with data pooled over display sizes to obtain reasonable stability, are 793, 724, 514, and 459 for N = 1, 2, 3, and 4, respectively. All of the functions for correct latencies and that for error latencies in the C background are representative of all individual Ss.

In the NC background, errors are too sparse to determine individual functions. Overall means are 480, 368, 368, and 507 for N = 1, 2, 3, and 4, respectively, the last value dropping to 407 if one atypically large value is excluded. We can be sure only that there is no significant positive or negative trend over number of redundant signals.

Unlike preceding studies (e.g., Estes & Wessel, 1966), a correction for guessing does not eliminate the relationship between correct latency and number of redundant signals, estimated true detection latencies being 572, 513, 462, and 441 for N = 1, 2, 3, and 4, respectively. Even in the NC background, a slight trend remains in the corrected latencies: 410, 389, 396, and 379 for N = 1, 2, 3, and 4, respectively.

Additional Results on Size of the Memory Set

During the exploratory phase of this study, when parameter values for the main experiment were being determined, a fairly substantial body of data, which provides some useful additional information concerning the functions for number of alternatives in a less experienced group of Ss than those of the main experiment, was collected for the confusable background condition. Six Ss completed from six to nine 48-trial blocks each, without preliminary practice, with the three values of A, 2, 4, and 8, equally represented at each display size. In the pooled data for the total of 42 blocks of trials obtained with these Ss, there was again strikingly little variation in the proportion of correct detections as a function of number of alternatives—.91, .90, and .90 for 2, 4, and 8 alternatives, respectively. The functions for latencies are similar in form to those shown in Fig. 3 for the more experienced Ss, except that the slopes are distinctly steeper. For correct latencies, the means were 585, 723, and 796 for 2, 4, and 8 alternatives, respectively, and the error latencies 1,045, 1,389, and 1,496. It seems clear that, with a confusable background, the functions for both

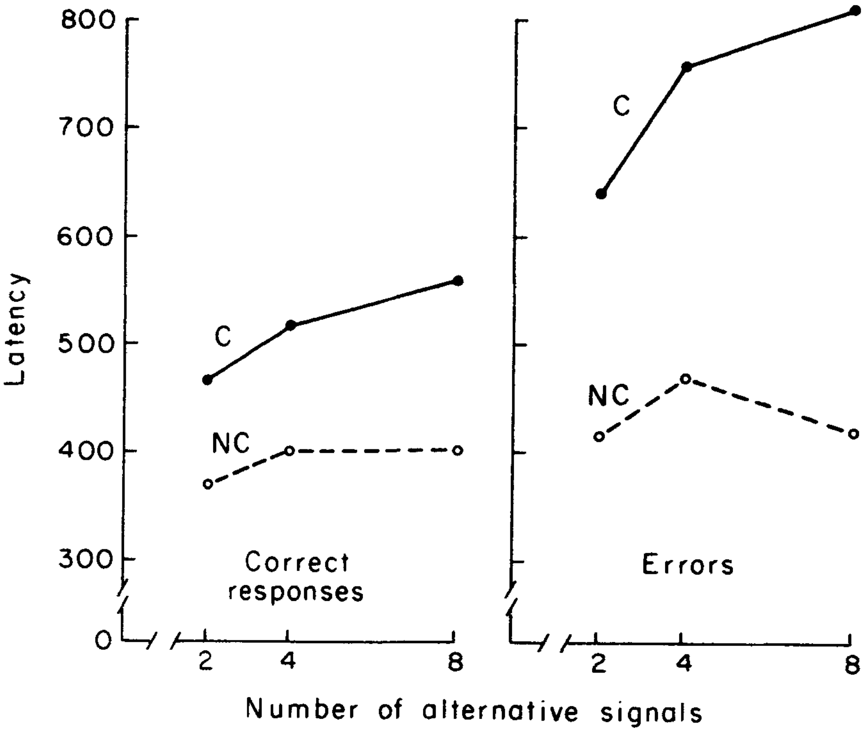

Fig. 3. Mean latency of correct responses and errors in milliseconds as a function of number of alternative signals, with background condition as a parameter.

correct and error latencies as a function of number of alternatives are negatively accelerated in form, with the slope for error latencies roughly twice that for correct response latencies.

It seemed desirable also to check further on the apparent increase in correct response latency with number of alternatives in the nonconfusable background. Therefore, data were collected from an additional 22 Ss, each run for one 48-trial block under each value of A in the nonconfusable background after 144 practice trials. Proportions of correct detections were .99, .95, and .96, respectively, for 2, 4, and 8 alternatives. Mean correct latencies, in the same order, were 486, 554, and 574 msec. The form of the latency function nicely replicates that observed for practiced Ss (Fig. 3); the increase in correct latency from 2 to 4 alternatives is significant at the .01 level by a sign test, but the change from 4 to 8 alternatives does not approach significance.

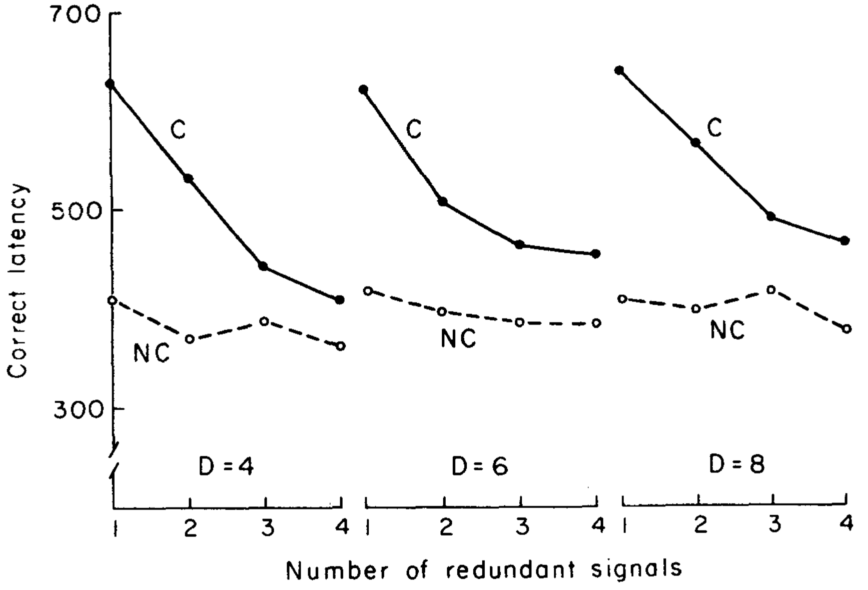

Fig. 4. Mean latency of correct responses in milliseconds as a function of number of redundant signal characters, with display size (D) and background condition as parameters.

DISCUSSION

Review of Principal Findings

Before we examine in detail the effects of the various individual variables, it may be useful to summarize the general results which seem most pertinent to theoretical issues.

(1) For both frequency and latency measures, all independent variables interact strongly with background condition and all independent variables affect error latencies more strongly than correct response latencies.

(2) In the nonconfusable background condition, error frequencies are extremely low and latencies of both correct and incorrect responses are low and virtually constant over values of the other variables. Taking these data together with comments by Ss, it appears that in nearly all instances, errors made under the NC background condition are "mistakes" in the sense that they do not reflect incomplete or inaccurate processing of display information, but rather represent momentary lapses in the Ss' attention to the response assignments. For brevity, I shall refer to these as *response errors.*

(3) Uniformly, the proportion of correct detections decreases and both correct and error latency increase as a function of the number of confusable characters with which the S must deal on any trial.

(4) When the number of confusable characters is modified by means of a display property, i.e., display size or number of redundant signals, probability of correct detections and latency vary inversely. When the number of confusable letters is varied by modifying the memory load, accomplished in this study by varying the number of alternative signals, latency increases substantially as a function of number of possible confusions, whereas detection accuracy is virtually constant.

Evidence on the Role of Confusability

In planning the experiment, it was intended that the only property common to the four independent variables should be that each exerts a measure of control over the number of opportunities for confusions between signal and noise characters. Thus, the data seem to provide rather compelling evidence for a major role of intercharacter confusions.

Nonetheless, alternative interpretations must be considered. When display size increases in the confusable background, the number of confusable noise elements increases, but so also does the average distance of signal elements from the fixation point. However, data from the nonconfusable background condition show the latter variable to have virtually no effect within the limits of the present experiment.

With the procedure used in this study, both display characteristics and overt response requirements are constant as the number of alternative signals varies. One might still point out that as the number of alternatives increases, so also does the amount of information which must be handled by the S in reaching a decision. However, changing from C to NC background leaves the latter aspect unaffected but virtually eliminates the correlations between response measures and number of alternatives. Number of possible intercharacter confusions remains as the evidently relevant factor.

Under all conditions, variation in the number of redundant signals per display entails corresponding changes in the probability that a signal element will appear near the fixation point; but only in the C background does this variation modify also the number of signal-noise confusions (because each additional signal element in a display of a given size displaces a noise element). Since detection probabilities and latencies vary systematically with N in the C background but not in the NC background, the number of possible confusions is again implicated as a responsible factor.

However, the reduction in latency by the addition of redundant signals is much too great to be accounted for simply by the reduction in total number of noise letters by each additional signal. Variation in number of redundant signals simultaneously modifies the probability that a signal will fall near the fovea and the number of confusable noise elements surrounding any signal. Clearly, the interaction of these two variables is of major importance.

Theoretical Interpretation

As a first step toward overcoming the deficiencies of the models mentioned in the introduction, it will be useful to examine the extent to which the present data, together with those of related studies, serve to elucidate the functioning of the principal independent variables.

Number of redundant signals. As observed above, the effects of adding redundant signals both on probability of correct detection and on latency of both correct detections and errors are much too great to be accounted for merely as a by-product of the obvious fact that each added redundant signal displaces a noise element. Further, it has been established in previous studies (e.g., Estes & Taylor, 1966) that redundant signals act as independent events in determining the probability of correct detections. Thus, it is clear that each added redundant signal provides an additional opportunity for some event which is favorable to correct detection.

A favorable event whose probability is certainly directly related to number of redundant signals is the appearance of an instance of the signal near the fixation point of the display. But why should this variable be effective only in the confusable noise condition? A clue is to be found in a recent study of Estes and Wolford (1971). These investigators obtained a very shallow function relating reportability of a letter to distance from the fixation point if the letter was not surrounded by adjacent characters, but a very steep function if the letter was surrounded by adjacent characters.

Further, although latency of correct detection is always found to vary inversely with number of redundant signals, Wolford, Wessel, and Estes (1968) found that this trend disappeared in data restricted to correct detections which were given high confidence ratings by the Ss. Similarly, Bjork and Estes (1971) obtained constant low mean latencies in data restricted to trials on which the Ss not only gave correct detections, but could correctly report the location of the signal element.

It appears that whenever an instance of a signal occurs within a critical distance from the foveal region of maximal discriminability, this critical distance depending upon the characteristics of the noise background, it evokes a detection response of a constant low latency independent of other characteristics of the display. I shall term this short latency response to a fully identifiable signal as a *primary detection response.* The requirement of a high confidence judgment and that of a correct report of location are alternative ways of restricting data to trials on which primary detection responses occur.

When conditions on a particular trial do not permit a primary detection response, then a long latency response occurs which may be correct or incorrect. Postponing consideration of the question of whether the long-latency responses are necessarily random guesses in the usual sense or whether they may be based on partial information, I shall refer to them by the noncommittal term *secondary responses.*

In these terms, I suggest that correct responses are a mixture of primary detections and secondary responses and that errors are a mixture of response errors and secondary responses. The decreasing functions relating both correct and error latencies to number of redundant signals arise, in terms of this analysis, from shifting mixtures of the two types of responses in each case. Since primary detection responses are always correct, and since their probability is an increasing function of number of redundant signals, it follows that the larger the number of redundant signals, the larger will be the proportion of primary detection responses in the distribution of correct responses and therefore the lower the latency. Further, since primary detection responses and secondary responses are incompatible, the latter necessarily decrease in frequency with increasing number of redundant signals. Therefore, for larger values of N, there must be smaller relative proportions of secondary responses in the distributions of errors and, consequently, lower mean latencies.

Display size function. A satisfactory interpretation of the relation between accuracy of detection and display size requires the collation of a variety of facts. However, the effort seems worthwhile in view of the central importance of this function in tachistoscopic research since the appearance of Sperling's partial report study (1960). The smoothly declining function relating probability of correct detection to display size is so similar in form in experiments of widely varying procedures that one might be tempted (and indeed many investigators have been tempted) to infer that it represents some unitary process. However, it is becoming clear that at least three factors which covary with display size are implicated in the display size function.

Firstly, when a single signal element, or any fixed number of signal elements, is imbedded in a linear array of characters with constant spacing, as in the study of Estes and Taylor (1964), the average distance of a signal from the fovea increases directly with display size. It appears from the results of Estes and Wolford (1971) that under the conditions of most tachistoscopic experiments, this distance per se is not a strong determiner of detectability, but that it becomes so when there are confusable noise elements adjacent to the signal.

Secondly, in the matrix displays used by Estes and Taylor (1966) and in the circular displays used in many other studies, the average distance of the signal from the fovea is constant, but the average number of noise characters adjacent to a signal increases with display size. Taking the present data, together with other results summarized by Eriksen and Rohrbaugh (1970), I think we may conclude that (1) the detrimental effect of a confusable noise character on detectability of a signal varies inversely with distance, even at separations great enough to preclude retinal contour interaction, and (2) at any given separation, the effect increases with distance from the fovea.

A common consequence of the operation of these two factors is that the probability of the combination of conditions required for a primary detection response varies inversely with display size under all of the standard procedures of tachistoscopic experiments. Only when there are no confusable noise elements present, as in the NC background condition of the present study, and when the combination of display area and figure-ground contrast is such that the role of distance from the fovea per se is negligible does the display size function flatten out.

But the story is not yet complete. We must conclude also from results of Eriksen and Rohrbaugh (1970), Eriksen and Spencer (1969), Estes and Wolford (1971), and Gardner (1973) that the presence of confusable noise elements in a display detracts from detectability of the signal even when they are not adjacent to it. It appears that on trials when there is no signal in a position to evoke a primary detection response (and, in particular, on trials when there is no signal element in the display at all, as occurred under some conditions in the study of Eriksen and Spencer), each noise element present in the display which shares features with a possible signal has some probability of evoking the corresponding detection response, i.e., a "false positive."

All of the available results on detection latencies in relation to display size seem interpretable on the assumption that there are only two latency distributions involved: (1) that of the short-latency primary detections and response errors, and (2) that of the long-latency secondary responses (guesses and confusion errors). As in the case of number of redundant elements, the functions relating both correct and error latencies to display size may be accounted for in terms of shifting mixtures of responses from the two distributions—primary detections and secondary responses in the case of correct responses and response errors and secondary responses in the case of incorrect responses.

Size of the memory set. The exceedingly slight variation in probability of correct detections with number of alternative signals suggests that, within the limits of this study, this variable does not influence the probability of a primary detection response. What then is the basis for the variation in correct response latency with number of alternatives? A suggestion as to the answer comes from the observation that, quite unlike the situation with the variables having to do with display properties, correct latency appears to increase with number of alternatives even in the nonconfusable noise condition, and, further, the combination of correct and error latency functions fits the pattern characteristic of a self-terminating search process. That is, in each case, latency increases with number of alternatives and the slope of the error function is approximately twice that of the correct latency function. Thus, although this idea is rather more speculative than those previously advanced, I am led to suggest that, on trials when no primary detection response is evoked, the processing of the decaying traces of the various elements in the visual system continues and a secondary response is generated via a process which will be described in the following section.

Preview of a model. It seems clear that none of the models hitherto proposed for visual detection is adequate to interpret the effects of the main independent variables reviewed above. Serial scanning models, and perhaps also concurrent Poisson models, do not account adequately for the effects of redundant signals upon processing time; neither type, as presently formulated, makes any explicit provision for the interactions of other variables with signal-noise confusability. Parallel, unlimited capacity models take account of confusability but not of the important effects of variation in the positions of signal and noise elements in the visual field.

I am by no means ready to set down a mathematical model which will handle the complex assemblage of empirical relationships reviewed above. Still, it is interesting to ask whether we can yet envisage any reasonably simple mechanism which accounts qualitatively for all of the well-established phenomena in hand and which might provide a basis for development of an adequate model. I think that perhaps we can.

Firstly, the extremely important role demonstrated for confusability of signal and noise elements suggests a feature extraction rather than a template matching process. In particular, there seems much to be said for the idea of Rumelhart (1970), that representations of the letters of the alphabet in the perceptual and short-term memory systems are generated by combining in various ways subsets of a reasonably small master set of critical features.

Thus, we are led to assume as one basic concept in a model a set of feature detectors. Let us imagine further that corresponding to each feature detector there is a set of input channels distributed over the visual field, with density decreasing from the fovea outward in all directions. When a character containing a given feature appears at a particular location in a display, it may excite an input channel, and, if so, the central processing mechanism registers this event and tags the location of the feature relative to other currently active channels.

The likelihood that an input channel will be excited by an incoming stimulus arriving at an appropriate location must depend on a number of factors. Firstly, even when external conditions are constant, the excitability of a channel, that is, its readiness to transmit information, must vary randomly around some mean value. Secondly, in order to take account of the S's preparatory set, it seems desirable to assume that, as a result of instructions and experimental context, the input channels to detectors associated with the characters of the memory set involved in a particular experiment are put into a state of heightened excitability.

But the most important effects on excitability within a trial must come from events originating in the visual display. It is clear from various lines of evidence presented in preceding sections that the probability that an input channel is excited by a stimulus must depend upon activity at other loci in the visual field. Thus, we are led to assume that excitation of any particular input channel exerts inhibitory effects on other channels going to the same or other feature detectors, the amount of inhibitory effect decreasing with distance in the visual field. Although available facts from tachistoscopic studies are not definitive, it seems likely that the quantitative properties of these inhibitory interactions may be similar to those involved at other levels of sensory processing (Ratliff, 1965; von Békésy, 1967).

It should be noted that stimuli other than confusable characters ma enter into inhibitory interaction However, these interactions will occu with lower probability than thos arising from confusable character The reason for the difference is tha input channels utilized by extraneou stimuli will not have been sent int states of increased excitability b instructions or experimental contex hence, they will be less likely to b excited and thus to exert inhibitor effects than will channels associate with characters that share featur with characters of the memory set.

As a consequence of the decreasin density of input channels for an detector from the foveal region to th periphery of the visual field, th likelihood that stimulation from target character will find a chann ready to transmit to an appropria detector likewise will decrease fro center to periphery. As a consequenc probability of detection will decrea and latency of response will increase the location of a target charact moves from the center to th periphery of the visual field. Th variation in both probability an latency with location will accentuated if there are confusab characters in the vicinity of the targ character; since there are few channels to a detector from peripheral than from a centra location, the likelihood is greater tha inhibitory effects from adjacen characters will leave no free channe ready to transmit from a targe character in a peripheral location t one of the essential feature detector

In a detection experiment with restricted set of possible signals, let assume that at the beginning of an trial, a representation of eac permissible signal character is in active state in immediate memory an that the connections of each to th response mechanism are in a read state requiring only summation fro the appropriate combination c feature detectors to trigger an ove response. Upon exposure of a displa of characters, the following sequenc of events is then presumed to occu Firstly, the characters in the displa activate their input channels to th feature detectors, quite possibly by process of the kind conceived i Rumelhart's (1970) model, and th results of this processing are registere essentially in the form of a listing c the inputs received from each displa location. If the set of detecto activated by inputs from any on display position exactly matches on of the representations in memory c an admissible signal, a primar detection response is evoked an processing stops. [If we let ou imagination range even more widel for a moment, we shall have to wonde whether these primary detection responses might prove to be the same as Bamber's (1969) fast "same" responses.]

If no primary detection response occurs on a trial, the feature extraction process continues until truncated by a postexposure mask or until a temporal decay process has run its course. At this point, in general, inputs from a number of display locations will have activated constellations of features which in differing degrees resemble those belonging to admissible characters. These may activate character names by associations in long-term memory [the "naming" stage in Posner's (1969) conceptualization of the recognition process]. The resultant coded, and not necessarily accurate, representation of the display is then scanned, each entry being compared with the representations in memory of the various possible signal characters. If a match is found, a response is made and the process stops. If no match is found, a response is made at random after the scan is completed. In either event, reaction time will be greater than on trials when primary detection responses occur. The substantially greater variation of correct latency with size of the memory set than with display size is predictable, in the interactive channels model, as a consequence of the diminishing returns function relating the number of characters activated by a display to display size.

There remain a couple of loose ends with regard to the relation between correct latency and number of alternatives. The function is clearly nonlinear, and it has significantly greater than zero slope even in the NC condition. An interpretation which may merit consideration is that with the larger memory sets, not all of the members can simultaneously be maintained in the active state which is requisite for primary detection responses. In order to overcome this limitation, Ss may undertake some recoding of the memory set—the efficiency of this recoding increasing and therefore the slope of the latency function decreasing with practice (cf. Garner, 1962, pp. 48-49).

What of "attention"? It appears that an interactive channels model can provide a coherent account of the effects of display size, redundant signals, spatial location and separation of characters, and the interactions of all of these factors with signal-noise confusability. Some of these effects have been interpreted by other investigators in terms of shifting or focusing of attention (Eriksen & Rohrbaugh, 1970; Rumelhart, 1970). But it is not easy to say just what is at issue. If the concept of attention is extended to any selective process, then we cannot hope to differentiate attentional and nonattentional theories in any general way.

But suppose we restrict the term "attention," in conformity with my impression of general usage, to voluntary processes, normally initiated prior to onset of a stimulus display, that modify what is perceived. ("Selective attention may be conceived as the programming by the O of which stimuli will be processed or encoded and in what order this will occur [Eriksen & Hoffman, 1972].") In a number of recent studies, effects of spatial and temporal relations among displayed characters have proven strikingly resistant to modification by measures which would be expected to be effective on the basis of an attentional theory (Shaw, 1969; Shiffrin & Gardner, 1972). Most strikingly, Townsend, Taylor, and Brown (1971) have shown that, so long as eye movements are precluded, Ss are unable to overcome the effects of varying spatial locations and separation of characters, even with unlimited viewing time.

Thus, the weight of the evidence appears to be against a theory assuming variation in focus or spread of attention within a single visual fixation. Nonetheless, selective attention in the restricted sense does play a role in tachistoscopic experiments. In particular, pretrial information concerning positions or other properties of stimuli to be displayed or concerning indicators which may appear at some point before, during, or after stimulus exposure are known to be important. How can these effects be interpreted within the present framework?

As I have indicated above, I believe there is substantial reason to assume that instructions or contextual factors can increase the excitability of a set of feature detectors prior to a display, thus increasing the probability of some perceptual events over others. However, I suggest that pretrial information concerning indicators or positions of stimuli to be displayed does not affect the processing of sensory information up to the point of feature detection (provided that fixation is controlled).

A principal function of information regarding position, including intraexposure and postexposure indicators, may be control of the order of encoding and naming operations. Such control of the readout order would indirectly determine which stimuli in a display would be favored with respect to short-term retention loss. This suggestion does no more than structure the problem, of course, for the specific control processes involved remain to be ascertained.

REFERENCES

BAMBER, D. Reaction times and error rates for "same-different" judgments of multidimensional stimuli. Perception & Psychophysics, 1969, 6, 169-174.

BJORK, E. L., & ESTES, W. K. Detection and placement of redundant signal elements in tachistoscopic displays of letters. Perception & Psychophysics, 1971, 9, 439-442.

ERIKSEN, C. W., & HOFFMAN, J. E. Some characteristics of selective attention in visual perception determined by vocal reaction time. Perception & Psychophysics, 1972, 11, 169-171.

ERIKSEN, C. W., & ROHRBAUGH, J. W. Some factors determining efficiency of selective attention. American Journal of Psychology, 1970, 83, 330-342.

ERIKSEN, C. W., & SPENCER, T. Rate of information processing in visual perception: Some results and methodological considerations. Journal of Experimental Psychology Monograph, 1969, 79, No. 2.

ESTES, W. K., & TAYLOR, H. A. A detection method and probabilistic models for assessing information processing from brief visual displays. Proceedings of the National Academy of Science, 1964, 52, No. 2, 446-454.

ESTES, W. K., & TAYLOR, H. A. Visual detection in relation to display size and redundancy of critical elements. Perception & Psychophysics, 1966, 1, 9-16.

ESTES, W. K., & WESSEL, D. L. Reaction time in relation to display size and correctness of response in forced-choice visual signal detection. Perception & Psychophysics, 1966, 1, 369-373.

ESTES, W. K., & WOLFORD, G. L. Effects of spaces on report from tachistoscopically presented letter strings. Psychonomic Science, 1971, 25, 77-80.

GARDNER, G. T. Evidence for independent parallel channels in tachistoscopic perception. Cognitive Psychology, 1973, 4, in press.

GARNER, W. R. *Uncertainty and structure as psychological concepts.* New York: Wiley, 1962.

McINTYRE, C., FOX, R., & NEALE, J. Effects of noise similarity and redundancy on the information processed from brief visual displays. Perception & Psychophysics, 1970, 7, 328-332.

POSNER, M. I. Abstraction and the process of recognition. In G. H. Bower and J. T. Spence (Eds.), *The psychology of learning and motivation.* Vol. 3. New York: Academic Press, 1969. Pp. 44-100.

RATLIFF, F. *Mach bands: Quantitative studies on neural networks in the retina.* San Francisco: Holden-Day, 1965.

RUMELHART, D. E. A multicomponent theory of the perception of briefly presented displays. Journal of Mathematical Psychology, 1970, 7, 191-218.

SHAW, P. Processing of tachistoscopic displays with controlled order of characters and spaces. Perception & Psychophysics, 1969, 6, 257-266.

SHIFFRIN, R. M., & GARDNER, G. T. Visual processing capacity and attentional control. Journal of Experimental Psychology, 1972, 93, 72-82.

SPERLING, G. The information in brief visual presentations. Psychological Monographs, 1960, 74, No. 498, 1-29.

SPERLING, G. A model for visual memory tasks. Human Factors, 1963, 5, 19-31.

STERNBERG, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

TOWNSEND, J. T., TAYLOR, S. G., &

BROWN, D. R. Lateral masking for letters with unlimited viewing time. Perception & Psychophysics, 1971, 10, 375-378.

von BÉKÉSY, G. *Sensory inhibition.* Princeton, N.J: Princeton University Press, 1967.

WOLFORD, G. L., WESSEL, D. L., & ESTES, W. K. Further evidence concerning scanning and sampling assumptions of visual detection models. Perception & Psychophysics, 1968, 3, 439-444.

NOTE

1. Predisplay and noise matrices were identical in form, and at any given position superposed exactly. However, there was a perceptible flicker at the moment of transition when a noise matrix replaced a predisplay matrix.

(Accepted for publication June 5, 1972.)