Pattern redundancy and detection in very short-term memory*

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A tachistoscopically presented target letter is detected better in a background of redundant items than in nonredundant material. The present experiment extended this finding by showing that detection rate increased systematically across three levels of background letter redundancy. A conclusion based on the earlier findings was that a serial process of letters in memory could not account for the effects of background redundancy on detection accuracy. Contrary to this conclusion, the present analysis showed that detection for semiredundant displays was successfully predicted by two variants of a serial process model. One model assumed that the scan of a letter is faster when the letter is the same as any prior letter scanned in the matrix. The other model assumes that nonredundant letters are processed serially and that redundant letters are processed all at once, i.e., in parallel.

Since Sperling (1960) demonstrated that a relatively complete representation of a visually presented stimulus is maintained for a brief period after stimulus cessation, many investigators have been interested in various aspects of this stage of information processing. Recent investigations of very short-term memory have employed a signal detection paradigm developed by Estes and Taylor (1964). A S is required to identify which of a previously designated pair of letters was present in a matrix display of several different "noise" letters.

McIntyre, Fox, and Neale (1970) found detections to increase when Ss were presented with displays containing redundant noise letters. Within each of three experiments, redundant displays yielded higher detection rates than nonredundant displays. Cross-experimental comparisons suggested that detection increased with increases in noise-letter redundancy. McIntyre et al concluded that the redundancy effects were inconsistent with a serial model of memory search such as that proposed by Estes and Taylor (1964), in which each element of a display is compared to the designated signal elements until a match is found. McIntyre et al suggested that the data indicated that the signal letter was detected by a simultaneous extraction of the features of matrix letters in a parallel process.

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There is, however, a simple modification of the serial process model which will allow the model to predict redundancy data. Before discussing the nature of such modifications, it would be useful to review the assumptions of the original serial process model of Estes and Taylor (1964). These assumptions focus on the process of decay of the very short-term memory trace and on the process of scanning the trace for the signal element.

Decay Process

After a representation of the matrix has been registered in the receptor system, the decay process can be measured off into intervals of Δt size. If the display's trace is still intact at the beginning of any interval, Δt , there is a fixed probability, s , that the trace will decay below a usable level within the Δt interval. Moreover, there is an initial period Δt_0 in which the trace is resistant to decay.

Scanning Process

It is assumed that after the onset of the display, there is a serial scanning process which terminates when the signal element is found. Furthermore, the scanning and processing of an element requires Δt time. In terms of the above decay mechanism, this implies that on each successive scan, there is a probability, s , that the trace will decay below a usable level before the processing of that element is completed. Finally, Estes and Taylor assumed that the time before decay begins, Δt_0 , is equal to the time required to process one element, Δt . The important consequences of this latter assumption are that a S will always process at least one element.¹

From these assumptions, Eq. 1 below is derived for estimating the mean number of elements scanned (k),

where s is the decay parameter defined above and D is the total number of elements in the display.

$$E(k) = \frac{1}{s} [1 - (1 - s)^D] \quad (1)$$

A simple modification of the assumption that a fixed amount of time is required for the scan of an element will permit the serial process model to account for the effects of redundancy on detection. It is possible that the time to scan an element is variable and depends on a factor such as the nature of elements scanned previously. A serial processing model could predict the effects of redundancy if the time required to successively scan redundant elements is less than the time required to scan nonredundant elements. The scanning of redundant items could be expected to require less time due to successful anticipation of processing demands for the next element by S, e.g., maintaining the physical feature analyzer for curved lines in a state of readiness. The effects of expectancy or set on perceptual processes have been well documented in psychology (Boring, 1950; Neisser, 1967). Falmagne (1965) reported successful predictions for choice reaction time data by a model which assumed that reaction time depended on whether the S was in one of two states, that of being prepared and that of being not prepared for the stimulus. In visual scanning of word lists for a target letter, Krueger (1970) found that lists of words were processed more quickly than lists of pseudowords. Krueger concluded that the encoding of a letter was dependent on what was processed on prior encodings.

An implication of Falmagne's (1965) findings is that the time to process elements serially in the very short-term memory trace could be either short or long, depending on the relationship of the current element to be scanned and the recent history of elements scanned. The history of scanned elements could affect ongoing processing in one of two ways. A scan could depend on what was processed on the immediately prior scan (the IPS model) or on what was processed on any prior scan (the APS model). For the IPS model, it is assumed that an element can be processed more quickly when the preceding element scanned was the same alphabetic character. Thus, if the letter K had just been scanned, the time for the scan of a new element will be less if the new element is also the letter K. In the case of the APS model, an element is processed more quickly when it is the same alphabetic character as any element already scanned from the

Table 1
Obtained Detection Rates and Predicted Values for Three Models

Conditions	Percent Correct Detection			
	Observed	Predicted by the Models		
		IPS	APS	AAOS
Redundant	91.9	—	—	92.5
Semiredundant	80.8	73.5*†	83.8*	82.6
Nonredundant	68.0	—	—	—

*Monte Carlo estimate

†Outside 95% confidence intervals of 76.3 to 85.5

matrix. These assumptions constitute modifications of the scanning assumptions of the Estes and Taylor serial process model. Decay assumptions of the Estes and Taylor model remain the same in the IPS and APS models. Formal statement of the IPS and APS scanning assumptions are as follows.

Scanning Process: IPS Model

After the onset of the display, there is a serial scanning process which terminates when the signal element is found. The time to scan an element that is *different* from the immediately prior element scanned (nonredundant transition) is Δt_1 , during which the probability is s_1 that the traces of the display will pass below threshold for correct processing. Conversely, the time to scan an element that is the *same* as the immediately prior element scanned (redundant transition) is Δt_2 , during which the probability is s_2 that the trace of the element will pass below threshold before correct processing can be completed.

Scanning Process: APS Model

After the onset of the display, there is a serial scanning process which terminates when the signal element is found. The time to scan an element that is *different* from any prior element scanned in the matrix is Δt_1 , during which the probability is s_1 that the traces of the display will pass below threshold for correct processing. Conversely, the time to scan any element in a display that is the same as any element scanned previously in the display is Δt_2 , during which the probability is s_2 that the trace of the element will pass below threshold before correct processing can be completed.

The equation estimating the number of elements scanned (k) in a nonredundant display is identical to that predicted by the serial process model for both the IPS and APS models. Thus, the equation is the same as Eq. 1, except that s_1 is substituted for s . In the case of displays with totally redundant noise elements, i.e., all are the same alphabetic character, the assumptions of both the IPS and APS models lead to Eq. 2, below, for estimating k .

$$E(k) = 1 + (1 - s_1) \frac{[1 - (1 - s_2)^{D-1}]}{s_2} \quad (2)$$

Qualitatively, the IPS and APS models predict the effects of redundancy on detection reported by McIntyre et al (1970). Since the models represent only a post hoc analysis of their results, it is necessary to determine if either of these models could predict quantitative features of detection under varied conditions of noise redundancy. For semiredundant displays, the IPS and APS models predict a detection rate which lies between that observed for nonredundant and for redundant displays. Fortunately, they make differential predictions for detection accuracy in semiredundant displays. Because ongoing scanning in the APS model is facilitated by more of the prior history of processing than in the IPS model, the APS model predicts a higher detection rate for semiredundant displays than that predicted by the IPS model. Therefore, the present research had the purpose of determining which of the plausible variants of a serial scanning process, the IPS or the APS model, could predict detection for semiredundant displays.

METHOD

Subjects

Fourteen college and high school students volunteered for the experiment. All had normal or corrected visual acuity.

Apparatus

Stimuli were presented in a three-channel Scientific Prototype tachistoscope (Model GB). The adaptation field and postexposure field were blank white stimuli. The intensity of the adaptation field, stimulus field, and postexposure field was 2.1 fc measured at the eye.

Stimulus Materials

Stimuli were displays of 16 letters printed in a 4 by 4 matrix. Letters were black 36-point Futura Medium decals which were fixed on white cards. A matrix subtended a 4-deg

14-min visual angle along its diagonal. The stimuli varied in the number of different alphabetic characters used to fill the 15 noncritical background cells of the matrix. A single letter was repeated 15 times for redundant matrices, 3 letters were each repeated 5 times for semiredundant matrices, and 15 different letters were used once each for the nonredundant matrices. Twelve different pairs of backgrounds were selected for each condition. Each pair consisted of one matrix with a critical item of B and one matrix with an F. Thus, there were 24 stimulus patterns for each level of redundancy. Across the 24 displays per condition, critical items appeared equally often in all cells of the matrix, except for the four corner cells.

Procedure

The Ss were seated at the viewing aperture of the tachistoscope, with their heads supported in a Bausch & Lomb chinrest. They were light-adapted for 5 min, during which time the experimental instructions were read. Ss were told that either B or F would be present in each stimulus matrix and were instructed to identify which critical letter was present or to guess when uncertain. On each trial, S was told when a stimulus was available for viewing and was then able to trigger the presentation himself. Stimulus duration was 50 msec.

RESULTS AND DISCUSSION

The mean percent correct detection for the 14 Ss under the three conditions of noise-letter redundancy are shown in the first column of Table 1. From inspection of the data, it is clear that increases in the redundancy of background elements facilitated detection of the critical element in the matrix. These differences were significant ($F = 27.3$, $df = 2/26$, $p < .001$). It should be noted that Estes and Taylor (1966) reported a detection rate of 67.3% with displays comparable to those employed in the nonredundant condition of the present experiment. The similarity of that result to the data in the nonredundant condition of the present experiment suggests that the present experiment successfully replicated Estes and Taylor's (1966) experimental conditions. Comparison of the present detection rates to those found by McIntyre et al (1970) cannot be made directly, since they used smaller displays (14 letters) printed in a different style (pica type) and a dark pre-postexposure field. Nevertheless, despite these differences in experimental conditions, the present results reproduce the general findings of McIntyre et al, in that detection rate for redundant displays was greater than that for nonredundant displays.

Predicted detection rate for semiredundant displays was generated by a computer simulation of the scanning processes posited by the IPS model and by the APS model.² The simulations employed decay parameters for the nonredundant (s_1) and redundant (s_2) conditions estimated from the detection rates observed for nonredundant and redundant displays (Estes & Taylor, 1964). For both models, s_1 was estimated to be .161 and s_2 was .002. Inspection of the predictions in Table 1 shows that the APS model provided a satisfactory prediction for detection in semiredundant displays, thereby demonstrating that a serial scanning model can account for the effects of redundancy. The table also shows that the IPS model's prediction fell well outside the 95% confidence interval. The failure of the IPS model in comparison to the success of the APS model could be interpreted as indicating that expectancy effects on processing depended on more than the immediately prior scan.

Since the decay parameter is a function of the time to scan one element, the relative size of the s_1 and s_2 parameters reflect the times required for nonredundant and redundant scans. The s_1 parameter is over 80 times larger than the s_2 parameter. Despite the success of the APS model in predicting the data, the vast difference in s_1 and s_2 suggests that the assumed expectancy mechanism may not provide an adequate representation of the actual short-term memory process. It is difficult to conceive of a mechanism which could produce such an overwhelming change in process time. When confronted with redundant or semiredundant displays, Ss might have been responding to a larger pattern or patterns in the matrix. It may be that when redundant elements are processed, there is a change in the strategy of processing from that employed for nonredundant displays. An alternative to the concept that stimulus redundancy altered expectancy during serial processing is that redundant elements might have been processed all at once, e.g., a parallel analysis of common features (Selfridge, 1959). To test this concept of batch processing of identical elements in a matrix, i.e., all cells containing the same alphabetic character, the all-at-once scan (AAOS) model was formulated.

The AAOS model assumes that once an element has been sampled for scanning, all other identical letters in a display will be processed simultaneously before the scanning progresses serially to a different character. Thus, if the first letter sampled is an M, and there are four

other Ms in the display, all Ms will be processed in parallel before proceeding to sample a new element, such as a G. These assumptions are formally stated below.

Scanning Process: AAOS Model

After the onset of a display, there is a combination of a serial and a parallel scanning process which terminates when the signal element is found. The time to sample a new element and simultaneously scan it and all identical elements in a display is Δt_1 , during which the probability is s_1 that the traces of the display will pass below threshold before parallel processing is complete and prohibit further scanning. Thus, subsets of a display containing identical letters are processed together, but different letter subsets are processed serially. The decay assumptions of the AAOS model are the same as in the APS model.

From these assumptions, the equation for estimating the number of elements scanned in a nonredundant display is identical to Eq. 1 of the serial process model when s_1 is substituted for s . In the case of redundant displays, estimation of the number of elements processed is given by Eq. 3 and for semiredundant displays by Eq. 4.

$$E(k) = 1 + (D - 1)(1 - s_1) \quad (3)$$

$$E(k) = 1 + (D - 1)[1/D - 5](1 - s_1) \\ + (D - 1)[(D - 6)/(D - 5)] \\ [1/(D - 10)](1 - s_1)^2 \\ + (D - 1)[(D - 6)/(D - 5)] \\ [(D - 11)/(D - 10)](1 - s_1)^3 \quad (4)$$

As in the IPS and APS models, the s_1 decay parameter was estimated from the detection rate observed for nonredundant displays. Using the decay parameter in Eq. 3, and making corrections for guessing, the AAOS model predicts a detection rate for redundant displays of 92.5% (see Table 1), which is well within confidence limits around the observed rate of 91.9%. The AAOS prediction for semiredundant displays was also satisfactory, as is shown in Table 1. Thus, a model assuming a combination of serial and parallel processing can also predict the effects of redundancy on detection.

Detection rate for semiredundant displays was successfully predicted by both an expectancy model, APS, and by a batch processing model, AAOS. The AAOS model seems to have an advantage over the APS model in

possessing greater predictive power and for being more parsimonious in using only one decay parameter. Nevertheless, the AAOS model may not be as powerful a predictor as indicated by the present experiment. Employing 14-letter displays comparable to the matrices used in the present experiment, McIntyre et al (1970) observed in their first experiment a detection rate of 78.4% for redundant displays. The s_1 parameter was estimated from their nonredundant condition to be .355, and the predicted detection rate for their displays by the AAOS model was 83.5%. This predicted value falls beyond the upperbound of the 95% confidence interval, 81.6%, for the observed datum. Thus, while the AAOS model can account for the present data, it fails to predict the detection for redundant displays observed by McIntyre et al (1970). In contrast, the APS model might handle these variations in detection rate for redundant displays across the results of the present experiment and those of McIntyre et al due to the s_2 decay parameter.

The difficulty of the present data in allowing a choice between the APS and AAOS models may lie in the high detection rate observed for redundant displays. The s_2 parameter for the APS model is very near zero. If stimulus conditions were altered to lower detection for redundant displays, a larger s_2 value would be obtained and a discrepancy in the predictions for the APS and AAOS models might be more apparent. Thus, a choice between the models may be possible when detection is studied under more difficult stimulus conditions, e.g., a lower exposure duration (Mackworth, 1963).

A serial model, such as the one supported by the present data, has generally received less support than a parallel model in the detection literature (Estes, 1971). What accounts for these discrepancies is not yet known, but one possibility is the degree of practice of Ss (cf. Neisser, 1963). The present experiment used unpracticed Ss, as did other studies which supported a serial process (Estes & Taylor, 1964; Estes & Wessel, 1966), whereas support for a parallel process has come from studies using practiced Ss (Wolford, Wessel, & Estes, 1968; Bjork & Estes, 1971; Estes, 1971). In any case, the present findings indicate that in some conditions, a serial processing model is supported by the data.

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NOTES

1. This assumption was tested by the present authors by letting the number of elements processed (m) before decay sets in be a free parameter. The two free parameters, s and m , were then estimated by a least-squares fit of the model to the data in Estes & Taylor (1966) for varying display sizes. The resulting parameter values were $s = .17$ and $m = .7$, giving empirical support for Estes and Taylor's assumption that $m = 1$.
2. Since the probability of background letter selection for Cell n was not independent of Cell $N - 1$ is semiredundant displays, Monte Carlo procedures were used instead of estimation equations.

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