*Perception & Psychophysics*
*1973, Vol. 13, No. 3, 513-516*

# Searching for many targets: An analysis of speed and accuracy*

ALBERT YONAS and JOHN PITTENGER
*University of Minnesota, Minneapolis, Minnesota 55455*

Three Ss scanned matrices of letters for 40 sessions in a test of Neisser's claim that feature tests in high-speed searches operate independently and in parallel. In the multiple-target condition (MTC), the matrix contained any one of four target letters, while in the four single-target conditions (STC), the S knew which particular target was embedded in the list. In contrast to previous studies, the error rates for individual target letters in the MTC were analyzed separately rather than being pooled. Two Ss made more errors on the hardest target when searched for in the MTC than in the STC. This difference would be masked by pooling error rates. The third S's scanning rate in the MTC was not as rapid as in the STC. Neither a sequential nor a strictly parallel feature processing model can account for these data.

Several studies of visual search suggest that after sufficient practice, Ss can scan as rapidly and accurately for many targets as for one. Neisser has used these findings to support the notion that in the initial stage of perceptual processing the pandemonium model of Selfridge (1966) best characterizes the pattern recognition processes. According to this model, feature analyzers are operationally independent of one another and function in parallel. An alternate model of the pattern recognition process proposed by Feigenbaum and Simon (1963) holds that feature analyzers function sequentially and are hierarchically organized in a tree structure. These models make different predictions in search tasks in which a S is asked to look for any of several targets simultaneously. While both models predict that more feature analyzers will be required in a search for any of several targets than in a search for a single target, they make different predictions about processing time. The sequential ordering of analyzers in the EPAM (Feigenbaum & Simon, 1963) model implies an increase in processing time with an increase in the number of analyzers. Since analyzers in the pandemonium model operate in parallel, processing time should be independent of the number of feature analyzers and thus independent of the number of potential targets. Neisser's list-scanning studies (Neisser, 1963; Neisser, Novick, & Lazar, 1963) purport to demonstrate this independence. The purpose of our study was to test Neisser's hypothesis of simultaneous processing, using a finer grained analysis of scanning speed and error than has been carried out previously.

In Neisser's studies, the S's task was to scan down a matrix of symbols to find a specified target symbol or symbols. In the single-target condition (STC), the S knew that a particular target was embedded in the matrix, while in the multitarget condition (MTC), he knew only that the target would be one symbol selected from a set of 10 possible targets. He did not know which particular member of this set would appear in the list on a given trial. Over 13 days of practice, the initially slow scanning in the 10-target condition increased dramatically and equalled the scanning speed of the STC.

It is important to note that a parallel analyzer model predicts that the speed with which one can scan for a single target would be unchanged by the addition of other equally difficult or less difficult targets. The addition of a more difficult target would, however, require the use of additional and presumably slower analyzers and would be expected to increase processing time. This factor was taken into account in Neisser's studies by the selection of a particularly difficult target from the MTC for use in the STC.

Equality of scanning rates in STC and MTC is not, by itself, sufficient evidence for parallel processing. Error rates must also be considered. A sequential system could, for example, achieve equal scanning rates by performing a superficial search in the MTC. While this search could be as fast as that in the STC, it would result in a higher error rate. Neisser et al (1963) felt this possibility could be ruled out since Ss failed to detect the target slightly more often in looking for the single target than when looking for 10 targets. In their analysis, however, the error rates for all targets in the MTC were pooled. Such pooling leaves open the possibility that the error rate for the target used in the STC did increase when it was scanned for along with other targets.[1]

This possibility becomes more plausible when one considers the amount of time available to the analyzers of easy-to-detect features. If all analyzers continue to function until the slowest analyzer is finished, there will be a relatively long period of time available for the detection of the easy targets. This would lead to a very low error rate on these targets. Thus, if error rates of all targets in the MTC are averaged, low error rates on easy-to-detect targets could mask an increase in the error rate of the difficult target over its error rate in the STC.[2]

*This research was supported in part by grants to the University of Minnesota, Center for Research in Human Learning, and by a Program Project grant (No. 1 P01 HD05027) from the National Institute of Child Health and Human Development to the Institute of Child Development, University of Minnesota.

There are at least two experimental methods of testing for parallel processing which take this problem of difference of detectability into account. The first is the use of equally detectable targets to preclude masking of an increase in the error rate of the difficult target. We first attempted to replicate Neisser's study with equally detectable targets by selecting six letters that were equally confusable for a given background from the Gibson, Osser, Shiff, and Smith (1963) confusion matrix. Although the individual scanning rates for these targets were initially similar, marked differences in scanning rates began to appear after two or three sessions of practice. This method of testing our hypothesis was therefore abandoned. A second method for testing the hypotheses of operationally parallel processing was used. We employed a fine-grained analysis of the speed and error rates of individual targets when searched for singly and simultaneously.

## METHOD

### Stimulus Materials

The method employed in this study was essentially the same as that used by Neisser et al (1963), the primary difference being that the lists were displayed on the cathode ray tube of an IBM 1510 instructional display by an IBM 1130 computer. The lists were 29 rows long, with five letters in each row. The overall dimensions of the list were 1-1/4 x 7-5/8 in. Viewing distance was approximately 15 in. The visual angle of the display varied between 5 x 31 deg and 4 x 26 deg, depending on the posture of the S. The background letters were capital X, F, G, H, K, P, T, and V. Since on each day of testing a S was to search for each target both individually and as part of a multitarget search, the number of targets was limited to four: D, J, O, and U. In the STC, the target was searched for individually, while in the MTC, the target might be, with equal probability, any of those four letters. In every list, the position of the target was chosen randomly and a new random order of background letters was generated.

### Subjects

University of Minnesota undergraduate volunteers, two females and one male, served as Ss. They were paid $1 per session plus a $.50 bonus contingent on an increase in scanning speed from the performance of the previous session; thus, a set for speed rather than accuracy was induced. Although there was no specific cost for errors, a S continued scanning in a condition until the required number of correct trials had been completed. In general, misses increased the time required for the session by about 50%.

### Procedure

At the start of each trial, the target(s) appeared on the left side of the screen. The S looked at a fixation point that appeared at the same location as the center point of the first line of the list and pressed a button, causing the list to appear and signaling the computer to begin measuring the search time. The S immediately began scanning the list. He was instructed to scan the list from top to bottom as rapidly as possible and to expect occasional misses. When the S found the target or reached the bottom of the list without finding it, he pressed the button again and his search time was recorded by the computer. When the button was pressed, a blanking field of white vertical bands, the width of a letter, masked the list and the S then indicated the approximate location of the target with a light pen. If the S reached the bottom of the list without finding the target, the light pen was pressed in a lighted square beside the masking field. This signaled the computer to record a miss. (Search times on miss trials were highly variable and were not used in the analysis.) During each session there were five conditions, four STCs and a MTC. In each of the four STCs, a S scanned at least 10 lists in each session. In the MTC at least 40 lists were scanned, 10 with each of the four letters (D, J, O, U) as targets. If a S failed to detect a target, an additional trial that sampled the same target position was added to the session. The five conditions were presented in counterbalanced order for 40 days. To check that scanning was actually from top to bottom, the S's eye movements were periodically observed by the E. Ss generally scanned smoothly and in order.

## RESULTS

For each S, 10 search times were measured for each of the four targets in the STC and the MTC. These 10 times were combined into a single measure of time per item scanned, using Neisser's method (1963). The search times were plotted against the position of the target, and the slope of that linear function represents the time needed to scan over each noncritical item, independent of response time. These slope estimates and the miss rates served as the basic data of the experiment.

Occasionally a scan was not uniform, and the search time differed substantially from the linear relationship. We used Wattenbarger's (1968) procedure to insure selection of only those trials in which scanning was ordered from top to bottom. Any point that lay more than three standard deviations from the linear regression line was discarded (less than 1% of the points were discarded). The slope, intercept, and r were recalculated. The relationship between position of the target and search time was highly linear, i.e., the mean r was .93.

Table 1 presents the mean time per line and standard deviations for the first, second, third, and fourth blocks of 10 days for each of the letters searched for alone and simultaneously. In addition, overall search times in the STC and MTC were computed by pooling the times of all four letters.

For Ss 1 and 3 in the STC, differences in search rate among the four target letters persisted throughout the experiment. For both Ss, the letter O was the most difficult to detect. Ss 1 and 3 initially searched for O much more slowly in the MTC than in the STC, but after 20 days of practice, this difference was no longer statistically reliable.

For S 2, the search times for the four target letters in the STC on the last block of 10 sessions were not significantly different, making it impossible to establish which target was the most difficult to detect. If the four targets were equally difficult to detect, the search times pooled across all four letters should provide the best comparison of the STC and MTC. When this was done, we found that S 2 searched more rapidly in the STCs than in the MTC ($p < .05$ by a t test for correlated

**Table 1**
**Mean Time Per Line (in Milliseconds) and Standard Deviation for Four Sets of 10 Sessions in STC and MTC**

| Sessions | | Single-Target Condition D | J | O | U | Overall | Multiple-Target Condition D | J | O | U | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Subject 1 | | | | | |
| 1-10 | Mean | 187 | 128 | 201 | 160 | 168 | 255 | 261 | 258 | 248 | 258 |
| | SD | 40 | 37 | 49 | 32 | 28 | 85 | 100 | 99 | 61 | 89 |
| 11-20 | Mean | 143 | 82 | 158 | 109 | 123 | 172 | 170 | 184 | 167 | 172 |
| | SD | 23 | 17 | 28 | 16 | 13 | 36 | 57 | 40 | 41 | 35 |
| 21-30 | Mean | 99 | 66 | 114 | 88 | 91 | 152 | 139 | 141 | 135 | 145 |
| | SD | 21 | 13 | 21 | 21 | 13 | 35 | 23 | 33 | 28 | 29 |
| 31-40 | Mean | 88 | 49 | 106 | 66 | 76 | 114 | 106 | 110 | 103 | 110 |
| | SD | 25 | 18 | 24 | 20 | 15 | 24 | 16 | 26 | 27 | 23 |
| | | | | | | Subject 2 | | | | | |
| 1-10 | Mean | 143 | 99 | 123 | 124 | 121 | 215 | 269 | 223 | 224 | 221 |
| | SD | 48 | 49 | 45 | 31 | 35 | 99 | 153 | 103 | 161 | 102 |
| 11-20 | Mean | 93 | 70 | 90 | 87 | 85 | 129 | 99 | 139 | 117 | 124 |
| | SD | 22 | 11 | 19 | 21 | 11 | 38 | 39 | 38 | 24 | 30 |
| 21-30 | Mean | 66 | 52 | 74 | 62 | 63 | 70 | 70 | 72 | 77 | 72 |
| | SD | 16 | 11 | 23 | 22 | 10 | 27 | 22 | 17 | 25 | 19 |
| 31-40 | Mean | 39 | 35 | 36 | 39 | 37 | 47 | 46 | 48 | 42 | 46 |
| | SD | 12 | 12 | 11 | 6 | 8 | 9 | 17 | 10 | 18 | 11 |
| | | | | | | Subject 3 | | | | | |
| 1-10 | Mean | 268 | 199 | 207 | 180 | 212 | 351 | 249 | 349 | 389 | 267 |
| | SD | 104 | 87 | 64 | 93 | 81 | 169 | 176 | 200 | 250 | 204 |
| 11-20 | Mean | 134 | 79 | 117 | 86 | 103 | 155 | 135 | 154 | 156 | 155 |
| | SD | 36 | 19 | 23 | 29 | 20 | 38 | 50 | 38 | 37 | 33 |
| 21-30 | Mean | 97 | 62 | 100 | 58 | 78 | 111 | 101 | 103 | 112 | 107 |
| | SD | 20 | 19 | 17 | 13 | 10 | 19 | 17 | 26 | 24 | 16 |
| 31-40 | Mean | 74 | 48 | 81 | 37 | 59 | 88 | 91 | 95 | 87 | 89 |
| | SD | 21 | 15 | 23 | 12 | 14 | 23 | 27 | 32 | 18 | 20 |

means). When the search times for the letters O, D, and J are compared, we find that in the final 10 sessions this S searched more rapidly for these letters in the STC than in the MTC ($p < .05$ by a t test for correlated means). When the search times for U were compared, the difference between the STC and MTC was smaller and not statistically significant.

Since the probability that any particular letter in the list will be a target is only 1 out of 145, one would expect the false alarm rate in this task to be very low. In fact, there were only 16 trials during the last 20 days of practice in which Ss were off by more than four lines in indicating the position of the target with the light pen, for a false alarm rate of .0032. These errors were spread equally across conditions and were too few in number for further analysis.

Errors in which the S reached the bottom of the list and indicated that he had not found the target were much more frequent, occurring on approximately one-third of all searches. Miss rates for each session of testing were calculated by dividing the number of trials on which the S failed to detect a particular target by the number of trials in which that target appeared. While search time dropped markedly with practice, the miss rate showed a small increase over sessions. Table 2 presents the mean miss rate for each of the Ss on all conditions averaged over the last 20 days of practice.

For each S the miss rate for the relatively easy-to-detect target, J, was significantly lower when it was searched for in the MTC than when it was searched for alone ($p < .05$, t test for correlated means).

Ss 1 and 3 failed to detect the target letter O more often when it was part of the MTC than when it was searched for alone. For each S, this difference was significant ($p < .025$ by a t test for correlated means).

**Table 2**
**Mean Miss Rates for Each of Four Targets in STC and MTC, Sessions 21-40**

| | Target | Miss Rates: Single-Target Condition | Multiple-Target Condition | Difference* |
|---|---|---|---|---|
| S 1 | O | .33 | .43 | +.10 |
| | D | .28 | .25 | −.03 |
| | J | .21 | .12 | −.09 |
| | U | .26 | .19 | −.07 |
| S 2 | O | .32 | .33 | +.01 |
| | D | .29 | .27 | −.02 |
| | J | .26 | .19 | −.07 |
| | U | .27 | .26 | −.01 |
| S 3 | O | .21 | .32 | +.11 |
| | D | .25 | .18 | −.07 |
| | J | .25 | .08 | −.17 |
| | U | .29 | .19 | −.10 |

*MTC − STC

When error rates in the MTC were pooled, as in Neisser's analysis, S 1 showed an error rate of 28%, S 2, 28%, and S 3, 23%. As may be seen in Table 1, these rates are very much like those of the most difficult letter, O, searched for alone.

Although S 2 failed to show this difference in error rates for the target letter O, the scanning times suggest that he may not have been able to search as rapidly in the MTC as in the STC.

## DISCUSSION

The results of this study give clear support to the conjecture that Ss would not detect the four targets in the MTC with equal accuracy. In the MTC, Ss 1 and 3 failed to detect the "difficult" target, O, almost four times as often as they failed to detect the "easy" target, J. When the error rates for each target in this condition were pooled, the low error rate of the "easy" targets cancelled the high error rate of the difficult target, O, and thereby produced apparently similar error rates for the STC and MTC. By analyzing the error rates separately for each target, we find that, for Ss 1 and 3, the probability of detecting O is decreased by the addition of targets to the search set. While S 2's error rate for O was not significantly increased by the addition of three other targets, his scanning rate in the MTC remained slightly higher than the scanning rates of the single targets. That is, the addition of targets to the search set may either increase error rates or reduce the speed of search. These results suggest that while the processes involved in the detection of a letter are not sequential, they also are not functionally independent.

Neisser (1967) has suggested the preattentive mechanisms that allow equally rapid search for one and many targets are "not built for accuracy." Wattenbarger (1968) provided some support for this contention by repeating the Neisser et al (1963) study with differential stress placed on accuracy. He found that only for the high error rate group was search equally rapid for one and many targets. Kristofferson (1971) has recently found similar results. While it may be that highly accurate performance and parallel processing are incompatible, it seems more likely that a relatively high level of errors is required for the low error rate of easy targets to cancel an increase in error rates for the difficult target.

Several possibilities for further research are suggested by the results of the present study. First, the difference between the single- and multitarget search speeds for S 2 is so small that it seems unlikely that he tested sequentially for each letter in the MTC. Perhaps, as Eleanor Gibson (1969, p. 171) has suggested, the Ss can, with extended practice, develop a small set of features which distinguish the target set from the background set. This set might contain only one or two more features than are required for any individual letter and therefore operates only slightly more slowly than a single-target search. If this were the case, detection of the target would precede recognition and Ss should find it difficult to identify which of the targets was detected on a particular search. This notion could be tested experimentally by using tachistoscopic presentation of the stimuli.

The second possibility is that feature detectors can function in an independent, parallel fashion only up to some threshold of difficulty, beyond which processing becomes sequential. This would suggest that an increase in target set size would not affect either the speed or accuracy of a search if especially easy-to-detect targets were used. This possibility could be investigated by systematic variation of target set size and target difficulty.

In summary, the results of this study suggest that Ss, even when well practiced and operating at a high level of errors, cannot search as accurately and rapidly for a target when other targets are also being searched for simultaneously as they can when that target is searched for alone. In addition, scanning for many targets simultaneously is not a unitary process with a single error rate. Individual analysis of the error rates for each target seems essential for future investigation of searching for many targets simultaneously.

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## NOTES

1. The data required to answer this question from Neisser's (1963) study are not recoverable (Neisser, personal communication).

2. The possibility that errors would not be equal within the MTC was suggested by Hawkins (1967). He noted that in Neisser's 1963 study, Ss scanned more rapidly for two targets than for the more difficult of the two scanned for alone.

(Received for publication December 15, 1972; accepted January 24, 1973.)