Practiced card sorting for multiple targets*

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Ss were given extended practice in card sorting. Each card was inscribed with nine letters; on half the cards one letter was a "target." With practice, the Ss could sort as fast for eight targets at once as for a single difficult target, while maintaining the same overall error rates. However, they did miss the difficult target itself more often when it occurred in the multiple-target condition than when they were searching for it alone.

When practiced Ss search for target letters in a densely packed array, their scan rate is independent of the number of targets for which they are searching (Neisser, Novick, & Lazar, 1963; Wattenbarger, 1968). This effect, which seems to imply that Ss can check for the several targets in parallel, does not appear when the targets are changed on each trial (Kaplan & Carvella, 1965), nor when Ss are set for accuracy (Wattenbarger, 1968; Kristofferson, 1972). It has also been difficult to obtain with small arrays (Burrows & Murdock, 1969), although Ryan (1972) has done so; he argues that the critical variable is not the number of letters in the display itself but the relation between the sizes of the display and the target set. On the other hand, very different results are obtained in the typical Sternberg (1966) paradigm, in which the S must decide whether a *single* presented letter exemplifies any of a set of targets. In that procedure, response time depends regularly on the number of targets he has in mind. Nickerson (1972) provides an elegant review of this literature; a recent experiment by Ross (1970) shows that the number of targets continues to matter in Sternberg's paradigm even after extended practice.

This situation has led many theorists to argue that the results of the practiced search experiments are somehow artifactual and the evidence for "parallel processing" spurious. In some cases these arguments have consisted only of vague assertions about "loose controls" in the original studies (Burrows & Murdock, 1969, p. 237), but other workers have suggested specific counterhypotheses. Sternberg and Scarborough (1969) have proposed an "overlap" theory: instead of testing the first stimulus against Targets A, B, and C, simultaneously, the S tests it against A alone and stores it for future reference; the second stimulus and the stored first stimulus are then both tested against B; the

third stimulus and both stored stimuli are next tested against C; a new test for A is then run on the fourth stimulus together with the (stored) second and third, and so on. This theory would make the search results compatible with Sternberg's sequential-testing model. Yonas and Pittenger (1973) have suggested that a subtle form of speed-accuracy tradeoff may be occurring in the search paradigm, even though overall error rates are roughly the same in multiple-target and single-target searches. Suppose the S sets his time per letter to produce a given error rate when he searches for a single, rather difficult target, say the letter K. When he is searching for any of N targets *including* K, the experimental design usually provides that only 1/N of the lists will actually have K for a target. Thus he can relax his criterion and go faster; the resulting increase in missed Ks will have only a slight effect on the gross error rate because Ks occur so rarely.

Given this profusion of doubts and counterhypotheses, it seemed important to determine whether evidence of parallel processing could be obtained in some paradigm other than straightforward visual search. (Sperling, Budiansky, Spivack, and Johnston, 1971, and Ryan, 1972, present such evidence, but their work was not available when the present research was conducted in 1970.) It would be particularly desirable to employ a method which could test the counterhypothesis of Sternberg and Scarborough and provide evidence related to the suggestion of Yonas and Pittenger. The present study used a card-sorting technique to achieve these aims.

The experimental design was based on a procedure developed by Rabbitt (1967). His Ss sorted cards on which strings of nine letters appeared. Eight of the letters on each card belonged to an irrelevant "background" set; the ninth determined into which pile (of two) the card was to be placed. In one condition, the key letter was either A or B; in another, it could be any letter from A through H, with A, B, C, and D intended for one pile and E, F, G, and H for the other. The Ss sorted decks of such cards as rapidly as they could, with the total sorting time per deck as the dependent variable. These times can be regarded as the sums of the times required for processing and handling the 48 individual

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cards in the deck, perhaps with an additional constant; *differences* between times for two conditions are then due to differences in the processing which the conditions require. In Rabbitt's experiment, the Ss served in a single session in which they sorted 12 decks of each kind. Even on the 12th trial, the multiple sort took appreciably longer than the single sort. (Other findings of Rabbitt's experiment will not be considered here.)

In the present variant of Rabbitt's procedure, cards with *any* of the target letters were sorted into one pile, cards with *no* target into the other. With such a task, each card in the deck represents a "minisearch," since the S must check the "list" of nine letters for the presence of a target. To be sure, he may not scan the card from left to right (evidence to be presented below indicates that he probably does not), but he must test it somehow, and more complex tests or longer sequences of tests should require more time. Even small time differences on individual cards can add up to easily measured differences on whole decks. In the present experiment, Ss were given extended practice in sorting for multiple targets as well as for single targets. There were two main single-target conditions, one involving a difficult letter and one an easy letter. It was hypothesized that the times for the multiple sort and the difficult single-letter sort would converge with practice, just as visual search rates have in earlier studies.¹ (The easy single sort should remain faster than either, since even a parallel process is no faster than its slowest component.) The overlap hypothesis of Sternberg and Scarborough, devised for the visual search paradigm, could not explain such a convergence. A S who scanned a nine-letter card in the manner they suggest, testing only one target at a time and storing previously scanned letters, would often find himself with a lot of processing to do after scanning the last letter; if there were eight targets, he would have seven more of them to test his stored stimulus letters against. A S in a single-letter search would have no such burden and could put the card into the correct pile earlier. Hence total time per deck would have to remain substantially higher for multiple-target conditions.

Card-sorting also permitted a direct test of the hypothesis of Yonas and Pittenger, which predicts that the error rate for a difficult letter should be higher when that letter occurs in the context of a multiple sort than when it is the only target. Since each card represents a separate opportunity to miss a target letter, enough trials for estimates of these error rates could be accumulated. In addition, special sessions at the end of the experiment provided an opportunity to vary the composition of the multiple-target decks with respect to the number of difficult targets which they contained, and thus to explore the possibility that Ss simply hesitate longer before placing individual difficult cards.

The special sessions also permitted a preliminary investigation of another interesting question: do Ss scan each card from left to right and stop when they find the target? Special decks were prepared in which the targets

appeared primarily at the left end of the string and others in which most of them were in the middle or at the right. If a self-terminating left-right scan was being used, the first kind should be sorted more quickly than the others.

METHOD

Stimulus Materials

The experimental materials were decks of specially prepared white cards, $3\frac{1}{2} \times 2\frac{1}{4}$ in., with nine capital letters typed in a row on each card. A "primary school" typeface was used to provide large letters; each letter was approximately $3/16 \times 3/8$ in., and the entire row was $1\frac{1}{2}$ in. long. The cards were coated with plastic after being typed to keep them from becoming worn and dirty. After coating, the cards had somewhat the "heft" and weight of ordinary plastic playing cards, though of course they were smaller.

Each normal deck consisted of 48 cards, of which 24 were defined as "negative" and 24 as "positive." The negative cards always carried a random permutation of the nine background letters R, V, N, Q, Z, O, T, J, and S, which had been used by Rabbitt (1967). The positive cards in the SINGLE conditions were similarly constructed, except that one of the background letters (its position and identity randomly determined) was replaced with a target letter; the same target letter appeared on all 24 positive cards in a deck. The target letters were A, B, C, D, E, F, G, or H, and the corresponding conditions were called A ONLY, B ONLY, . . . , H ONLY. In the MULTIPLE condition, 3 of the positive cards contained an A as target, 3 others contained a B, and so on through H.

In addition to these decks, a small number of others were prepared for a CONTROL condition. In the control decks, the negative cards were inscribed with a series of nine Os and Qs; in the positive cards one of the Os or Qs was replaced by an X. This was intended to provide a particularly easy sorting task as a baseline against which performance with the other decks could be compared.

In the last phase of the experiment, some of the ONLY and MULTIPLE decks were modified in ways which will be described below.

Subjects

The Ss were eight students (four male and four female) enrolled in the Cornell Summer School. They were paid by the hour for their services, which included participation in 24 experimental sessions, usually held on consecutive weekdays. They were run individually by two Es, each of whom worked consistently with four of the Ss.

Procedure

Ss sorted the cards by holding the deck in one hand, face down; taking one card at a time in the other hand, turning it over, glancing at it, placing it on one of two indicated places on the table, taking up the next card, and so on. The E handed the deck to the S; started an electric stopclock as the S turned over the first card; stopped the clock as the S placed the last card; read the clock; examined the two piles for errors and recorded them. The deck was then shuffled for use at a later trial.

Ss always knew what kind of deck they were sorting (i.e., what the targets were). They were instructed to sort as rapidly as possible, even if it meant occasional errors. They knew that the object of the experiment was to determine how fast they could become, with practice. From time to time they were urged to sort faster and reminded that speed was the principal objective of the experiment. They were kept informed about their times and error rates.

Experimental Design

The experiment consisted of three phases. The first 5 days constituted Phase I. On each day, the S sorted 16 ONLY decks:

2 A ONLY, 2 B ONLY, etc. The order of presentation was systematically varied from day to day. The object of Phase I was to determine which target was the easiest (could be sorted most quickly) and which was the hardest. It had been supposed that the hierarchy of difficulty might vary from one S to the next, necessitating individualized conditions in Phase II, but fortunately this did not happen. E was the fastest sort (or nearly) for all Ss and G the slowest. Those two conditions were carried over into the next phase.

Phase II, the main part of the experiment, consisted of four conditions: E ONLY, G ONLY, MULTIPLE, and CONTROL. On the first 5 days of Phase II the Ss sorted two decks of CONTROL and four of each of the others; thereafter they sorted four decks of each type. The CONTROL decks were given first in half of the sessions and last in the other half; the order of the other three conditions was systematically permuted from day to day. Phase II consisted of 15 consecutive days, plus 1 additional day (either Day 17 or 18) interspersed among the sessions of Phase III; it will be called "Day N."

Phase III really consisted of two subexperiments. The purpose of the first, BIASED MULTIPLE, was to see whether the sheer number of Gs would affect the rate of sorting. It took 2 days, on each of which the S sorted 18 decks. Six were normal MULTIPLE (or G-3) decks, with 3 Gs as well as 3 As, 3 Bs, etc. Six others were G-10 decks, with 10 Gs and 2 As, 2 Bs, etc. The remaining 6 were G-17 decks, with 17 Gs and 1 A, 1 B, etc. The other subexperiment, LEFT/RIGHT G, was an attempt to determine whether the Ss were conducting self-terminating scans across the cards. It took 1 day, on which the S sorted 18 specially prepared G decks in which the positions of the target Gs were controlled. In 6 left-loaded decks, the distribution of the 24 targets across the nine positions on each card was

477111111; i.e., 4 targets occurred in the leftmost place, 7 in the second place, etc. In 6 right-loaded decks, the distribution was 111111774; in 6 unloaded decks, 333222333. It was assumed that if the Ss were conducting self-terminating scans across the cards in either direction, they would sort one or the other of the loaded decks more rapidly.

Half the Ss did BIASED MULTIPLE on Days 16 and 17, an additional day of Phase II on Day 18, and LEFT/RIGHT G on Day 19; the other half did LEFT/RIGHT G on Day 16, Day N of Phase II on 17, and BIASED MULTIPLE on 18 and 19. They were not told the special character of the decks involved (except that the day would be "all G" or "all MULTIPLE").

RESULTS

Phase I

Figure 1 shows the sorting times for each letter on each day of Phase I, averaged over the eight Ss. It is clear that E was generally the fastest letter and G, C, D the slowest, although there was some fluctuation in the first few days. On Day 5, E was the fastest sort for six of the Ss and within 1 sec of being the fastest for the other two; accordingly, it was selected to be the easy single letter in Phase II. On the same day G was the slowest sort for only three Ss, but it was within 1 sec of being the slowest sort for four of the others; it was therefore selected as the difficult single letter for Phase II. Sorting times and error rates for each letter are given in Table 1;

Fig. 1. Sorting times and proportions of cards missorted for the various conditions (eight individual letters in Phase I; G ALONE, E ALONE, MULTIPLE, and CONTROL in Phase II) averaged over all eight Ss each day. In Phase I (and for Days 1-5 of Phase II), each point is based on 16 decks; otherwise in Phase II, each is based on 32 decks.

Table 1
Results of Phase I and Selected Miss Rates in Phase II

Target Letter	ALONE Conditions Phase I Days 1-5			MULTIPLE Condition Phase II Days 12-15
	Sorting Rate	Overall Error Rate	Miss Rate	Miss Rate
E	48.6	.04	.04	.05
B	51.2	.05	.05	.13
F	51.3	.06	.06	.09
A	51.9	.06	.06	.10
H	53.2	.08	.07	.16
C	54.6	.09	.11	.24
D	54.8	.10	.13	.27
G	55.3	.11	.13	.28

Note—Letters are arranged in order of difficulty. Sorting times are in seconds per deck, averaged over 80 decks (eight Ss, 10 decks each). Phase I error rates are based on 3840 opportunities (48/deck); miss rates are based on 1920 of the same opportunities (24/deck). Phase II miss rates are based on 384 opportunities (eight Ss, 16 MULTIPLE decks, three targets of each kind per deck). "Overall Error Rate" includes misplaced non-targets in Phase I, but these cannot be assigned to specific target letters in the MULTIPLE condition of Phase II.

it appears that speed and accuracy were almost perfectly correlated across letters.

Phase II

Figure 1 also shows the sorting times for the 16 days of Phase II, averaged over all Ss for the four conditions. It is evident that MULTIPLE was much slower than either single sort at first, but became as fast as G ONLY by Day 11 and ran together with it thereafter. E ONLY was consistently about 4 sec faster than either; the CONTROL condition was slightly but inconsistently faster still.

Over the last 6 days of Phase II, four of the individual Ss displayed roughly equivalent sorting times for MULTIPLE and G ALONE, two seemed consistently faster in MULTIPLE, and two others were consistently

faster in G ALONE. The differences were of the order of 1 or 2 sec per deck. All the Ss were appreciably and consistently faster in E ALONE than in either G ALONE or MULTIPLE; five of them were faster still in CONTROL.

Error rates for each condition and day are also shown in Fig. 1; they were generally between 10% and 20%. The error rate for G ALONE was substantially higher throughout Phase II than in Phase I. Interestingly, the rates for G ALONE and MULTIPLE were no higher at the end of Phase II than at its beginning, despite considerable gains in speed. Very substantial increases in errors occurred for E ALONE and CONTROL, however.

To facilitate the analysis proposed by Yonas and Pittenger (1973), certain times per deck and target miss rates (as distinguished from total error rates) for individual Ss are shown in Table 2, averaged over the period of relatively stable performance, Days 12-15. G ALONE and MULTIPLE had the same average time per deck and about the same average miss rate over this period. (Speeds in these two conditions were correlated, as were miss rates, though the two dependent variables were not correlated with each other.) The data bear out the prediction made by Yonas and Pittenger. Several Ss missed Gs at a much higher rate when they occurred (one-eighth of the time) as targets in MULTIPLE than in Condition G ALONE. For one of them, the miss rates differed by a factor of three. This S was also the one whose performance on MULTIPLE was the fastest relative to G ALONE and the second fastest in absolute terms. In general, there was a rough correlation between how fast Ss went on MULTIPLE relative to G ALONE and how much more prone they were to miss Gs in MULTIPLE than in G ALONE.

In this connection, it is worth noting that G was not the only letter often missed in MULTIPLE sorting. All of the letters which had been difficult ALONE in Phase I remained difficult when they occurred as targets in Phase II. This is evident in the last column of Table 1, which gives the miss rates for the several letters in the MULTIPLE condition. The ordering of the letters is almost identical with that of Phase I.

Table 2
Times and Error Rates for Individual Subjects, Phase II, Days 12-15

	Sorting Time (Sec/Deck)			Miss Rate on Target Gs			Miss Rate on All Targets in MULTIPLE
	G	MULTIPLE	Ratio	Gs in G ALONE	Gs in MULTIPLE	Ratio	
MR	41.8	38.7	0.93	.17	.52	3.06	.16
NG	38.1	37.3	0.98	.17	.29	1.71	.15
BG	40.1	39.8	0.99	.21	.23	1.10	.20
DM	44.3	44.3	1.00	.27	.38	1.41	.24
BS	40.0	40.3	1.01	.20	.23	1.15	.15
DA	42.1	43.1	1.02	.17	.35	2.06	.16
LS	39.0	40.6	1.04	.15	.19	1.27	.15
FS	42.6	44.2	1.04	.11	.08	0.73	.12
Mean	41.0	41.0	1.00	.18	.28	1.56	.17

Note—Sorting times are means of 16 decks; each miss rate is based on 384 targets for Conditions G ALONE and MULTIPLE as wholes and on 48 targets for Gs in MULTIPLE. Ratios of times for MULTIPLE to times for G ALONE and of miss rates for Gs in MULTIPLE to miss rates in G ALONE are also shown.

Phase III

The BIASED MULTIPLE subexperiment of Phase III was intended to determine whether the sheer number of Gs in a multiple deck affected sorting time. On each of 2 days, the Ss sorted 6 ordinary multiple decks with 3 Gs each, 6 others with 10 Gs, and 6 others with 17 Gs. The mean sorting times per deck for these three conditions were: G-3, 40.1 sec; G-10, 40.5 sec; and G-17, 41.0 sec. Each mean was based on 96 sorts (12 decks x 8 Ss). This steady increase was exhibited by each S individually, and is thus reliable, but it is very small; Ss needed about .06 sec longer, on the average, to place a G than to place other cards. If all other factors were unimportant, this would result in G ALONE being about 1-1/3 sec per deck slower than MULTIPLE.

In the other subexperiment of Phase III, Ss sorted G decks in which the targets had been specially placed to occur often at the left end, center, or right end of the string of letters on the cards. Sorting times were 39.9, 40.1, and 39.8 sec, respectively, averaged over 48 decks. Thus, it seems unlikely that Ss were using a self-terminating scan in either direction.

CONCLUSIONS

It is clear that practiced Ss can sort cards for eight alternative targets as quickly as for the single most difficult target of the group. The result obtained by Neisser, Novick, and Lazar (1963) using visual search is replicable with a card-sorting procedure. This finding eliminates the "overlap" hypothesis of Sternberg and Scarborough (1969) as a possible explanation of the speed of multiple searches.

On the other hand, the data clearly support the suggestion of Yonas and Pittenger (1973). When a multiple sorting task includes both easy and difficult targets, Ss miss the hard ones relatively more often in the multiple sort than in the corresponding single sort. This criterion shift is most apparent in the Ss who go fastest on the multiple sort relative to the single sort.

The difficult letter criterion shift must result in some way from the Ss' attempt to cope with the increased load of the multiple task. However, it provides little support for a serial processing theory. Even the most extreme S only missed 52% of the Gs in the MULTIPLE condition, and thus must have continued to test at least half of the 432 (9 x 48) letters in each multiple deck for G. A serial hypothesis would have to assume that the tests for the seven additional letters were carried out sequentially in the time saved by these omitted G tests,

even though some of the additional letters were also difficult and the rest were picked up with very few errors. It is evident that the reorganization of processes and strategies required by the multiple task consists neither of the simple addition of more detectors in parallel, as I once supposed (Neisser, 1967), nor of a longer series of tests in sequence. Yonas and Pittenger are correct in stating that "while the processes involved in the detection of a letter are not sequential, they are also not functionally independent" of the processes involved in detecting other letters (1973, p. 516).

REFERENCES

- Burrows, D., & Murdock, B. B. Effects of extended practice on high-speed scanning. *Journal of Experimental Psychology*, 1962, 82, 231-237.
- Kaplan, I. T., & Carvellas, T. Scanning for multiple targets. *Perceptual & Motor Skills*, 1965, 21, 239-243.
- Kristofferson, M. W. Types and frequency of errors in visual search. *Perception & Psychophysics*, 1972, 11, 325-328.
- Neisser, U., *Cognitive psychology*. New York: Appleton-Century-Crofts, 1967.
- Neisser, U., Novick, R., & Lazar, R. Searching for ten targets simultaneously. *Perceptual & Motor Skills*, 1963, 17, 955-961.
- Nickerson, R. S. Binary-classification reaction time: A review of some studies of human information-processing capabilities. *Psychonomic Monograph Supplements*, 1972, 4(17, Whole No. 65).
- Rabbitt, P. M. A. Learning to ignore irrelevant information. *American Journal of Psychology*, 1967, 80, 1-13.
- Ross, J. Extended practice with a single character classification task. *Perception & Psychophysics*, 1970, 8, 276-278.
- Ryan, C. Parallel and serial processing in search tasks: The memory load-display load ratio and scanning strategy. Research Report No. 3, June 1972, Department of Psychology, University of Western Australia.
- Sperling, G., Budiansky, J., Spivack, J. G., & Johnson, M. C. Extremely rapid visual search: The maximum rate of scanning letters for the presence of a numeral. *Science*, 1971, 174, 307-311.
- Sternberg, J. High-speed scanning in human memory. *Science*, 1966, 153, 652-654.
- Sternberg, S., & Scarborough, D. L. Parallel testing of stimuli in visual search. Paper presented to the International Symposium on Visual Information Processing and Control of Motor Activity, Sofia, Bulgaria, July 1969.
- Wattenbarger, B. L. Speed and accuracy set in visual search performance. Paper presented to the Midwestern Psychological Association, Chicago, 1968.
- Yonas, A., & Pittenger, J. Searching for many targets: An analysis of speed and accuracy. *Perception & Psychophysics*, 1973, 13, 513-516.

NOTE

1. It is sometimes argued (e.g., Sternberg, 1966) that multiple searches should have slower average times than single ones even in parallel processing. The notion is that the duration of each component must have some variability, and more components would provide more opportunity for an unusually long instance to occur. However, this would affect search rate only if the S closely monitored the processes and stopped when all of them were completed. It seems more likely that he allows himself a fixed time per item and continues whether or not all the necessary checking is finished. This would produce some selective rises in error rates, like those observed in the present experiment.

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