Search processes for detecting repeated items in a visual display*

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Evidence for successive serial exhaustive searches was found in a task requiring detection of repeated letters in visually presented lists of varying length. The time per comparison was 25 msec. Important differences in processing appeared between instances of adjacent repeated letters and instances of nonadjacent repeated letters.

Sternberg (1966) has proposed a model of high-speed short-term memory (STM) search composed of additive components: (1) encoding of a test item, (2) an exhaustive serial comparison of the test item against each item in STM, and (3) a response, "positive" if a match occurred, "negative" if not. The latency of this response is predicted to be a linear function of the number of items in STM, and the slope of the function relating target set size to latency is the time per comparison. This model has successfully fit a variety of memory search tasks, and the comparison time has taken on the properties of an invariant information processing parameter (20-40 msec/item).

The inverse of Sternberg's task has been investigated by Chase and Posner (1965) and by Atkinson, Holmgren, and Juola (1969). A visually presented display was searched for a previously memorized test item. Both of these studies found evidence for a serial exhaustive search with a comparison time comparable to that found for memory search.

The present study attempted to extend this line of investigation to a more complex task in which Ss detected repeated items in a visually displayed horizontal list of letters. This task did not involve prior material in STM; our hypothesis, nevertheless, was that the serial exhaustive search would remain the basis of processing even under the more complex requirements of this task.

Specifically, a succession of serial exhaustive scans is postulated to detect a repeated item in such a task. The first scan compares the leftmost item in the list in left-to-right order against the n − 1 remaining items. If a match occurs, a positive response is initiated after completion of the scan. If no match is found, the second item on the left is then compared in left-to-right order against the n − 2 items to its right. This scanning process continues until a match has been detected or until all n − 1 scans have been completed—a negative response is initiated in the latter case, a positive in the former.

This model predicts that latency is a linear function of the number of comparisons. For negative instances, every comparision must be made, requiring, therefore, n(n − 1)/2 comparisons for a list of n items. For lists with repeated items, the number of comparisons depends both upon p, the position of the first repeated item, and n, the list length:

Number of comparisons

$$= \sum_{k=n-1}^{n-p} k = p(2n - p - 1)/2.$$

Response latencies for negative and positive instances are therefore given by the following expressions:

$$RT^{-} = a^{-} + n\frac{(n-1)}{2}b \quad (1)$$

$$RT^{+} = a^{+} + p\frac{(2n-p-1)}{2}b \quad (2)$$

Here a^{-} and a^{+} are the negative and

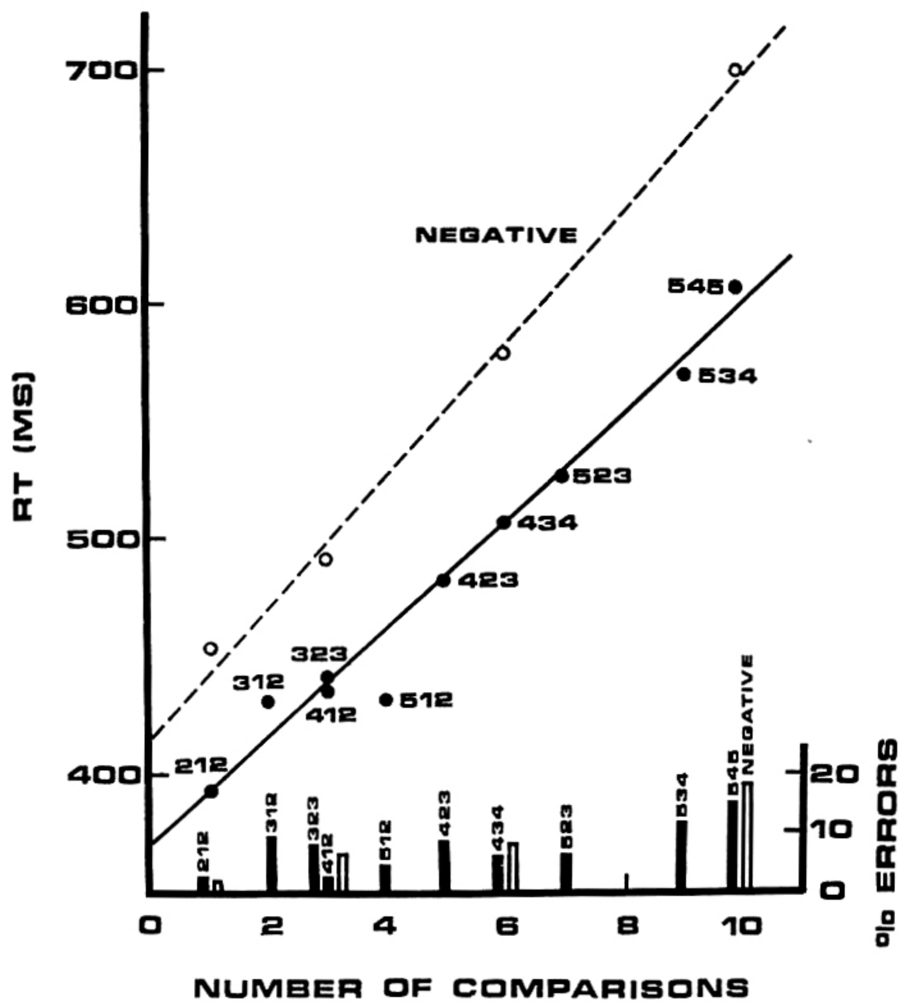

Fig. 1. Reaction time and error rate as a function of the predicted number of comparisons for negative and positive adjacent conditions. The three-digit number codes describe the list configurations of positive adjacent instances as follows: list length; position of first repeated letter; position of second repeated letter.

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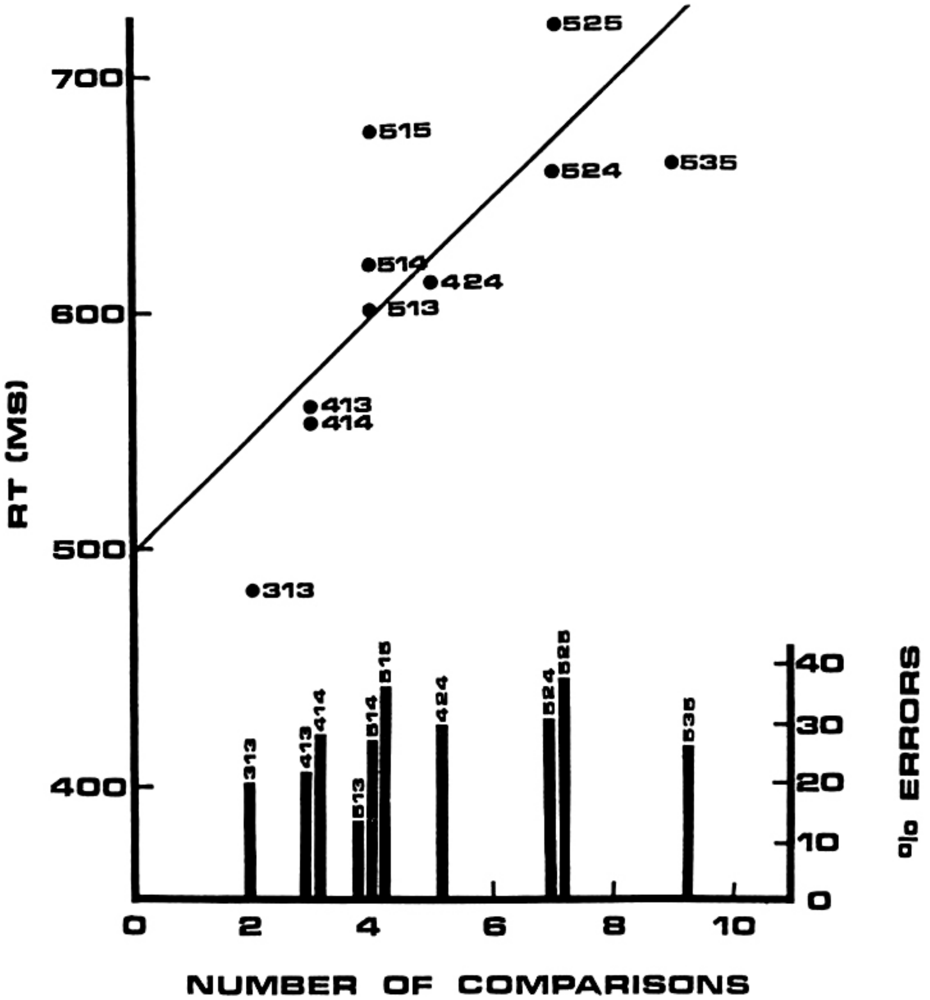

Fig. 2. Reaction time and error rate as a function of the predicted number of comparisons for the positive nonadjacent condition. The number codes describe the list configurations as follows; list length; position of first repeated letter; position of second repeated letter.

positive intercepts, and b is the time per comparison.

METHOD

Subjects

Four right-handed college students, two males and two females, were paid for participation in eight sessions each.

Material and Apparatus

Lists of from two to five letters drawn randomly from the alphabet were displayed horizontally on a video monitor with presentations controlled by a DDP-116 real-time digital computer. List length was varied randomly from two to five letters, and letters were assigned randomly to lists, with lists containing repeated letters and lists with no repeated letters both being equiprobable. No more than one pair of repeated letters appeared within a given list. The lists were presented centered on the monitor's screen and consisted of block capital letters subtending .5 deg of visual angle with a center-to-center spacing of 1.0 deg. Responses were made by pressing one of two buttons located approximately 50 cm in front of the screen. The hand of the positive and negative response buttons was counterbalanced across Ss. Latencies were timed and recorded by the computer to the nearest .001 sec from the time the list was sent to the monitor until button contact was made.

Design and Procedure

The Ss were run one session per day for 8 consecutive weekdays. Each session consisted of 320 trials, with the first session considered as practice. Within each trial, the procedure was as follows: (1) the message "READY?" appeared on the screen until S pressed a response button; (2) after a 1-sec interval, the list appeared and remained until S responded; (3) the S's latency was displayed for 1 sec following a correct response, but only "INCORRECT" appeared otherwise. Ss were instructed to respond "as quickly and as accurately as possible." Individual sessions required an average of approximately 20 min for completion.

Table 1
Intercepts, Slopes, R^2 Values and Error Rates for Individual Ss

Subject	Instance	Intercept (Msec)	Slope (Msec/Item)	R^2	Error Rate (Percent)
	Positive Adjacent	358.8	26.2	.949	5.0
S 1	Negative	436.2	29.0	.999	7.8
	Positive Nonadjacent	568.1	16.4	.105	32.5
	Positive Adjacent	376.4	22.6	.944	6.6
S 2	Negative	414.3	33.6	.982	9.2
	Positive Nonadjacent	589.0	19.7	.283	34.1
	Positive Adjacent	391.4	26.3	.938	9.2
S 3	Negative	453.9	24.0	.991	9.0
	Positive Nonadjacent	424.0	35.9	.929	22.8
	Positive Adjacent	361.6	12.8	.824	6.7
S 4	Negative	356.6	25.4	.986	8.7
	Positive Nonadjacent	410.7	27.0	.682	20.9
	Positive Adjacent	370.8	22.1	.972	6.9
Pooled	Negative	416.5	27.8	.995	8.7
	Positive Nonadjacent	498.0	24.7	.608	27.5

RESULTS

A preliminary analysis of the positive responses indicated a substantial difference in error rates for those repeated items which were adjacent in the list (6.9%) and those which were nonadjacent (27.5%). The data were therefore analyzed separately for negatives (which had 8.7% errors), positive adjacent, and positive nonadjacent items.

Figure 1 shows error rates and latencies as a function of the number of comparisons predicted by the model for negative and adjacent positive instances and the linear regressions for these two conditions. Figure 2 shows the fit for nonadjacent positives. These results show several important features.

(1) The model fits quite well for the negatives (99.5% of the variance) and positive adjacent items (97.2%), and the slopes of 27.8 and 22.1 msec per comparison, respectively, are in good

agreement with previous visual and memory search rates (e.g., Atkinson et al, found slopes of 26.2 and 23.8 sec per comparison for negative and positive responses, respectively). The difference in intercepts between positives and negatives of 45.7 msec is also in good agreement with the previous research. (An intercept difference of 30 msec was reported by Atkinson et al.)

(2) The largest deviations in the positive adjacent items are for lists with repeated items in Positions 1 and 2.

(3) The model fits poorly for nonadjacent positives (60.8% of the variance), but the slope of 24.7 msec per comparison is the right magnitude for the model. The intercept of 498.0 msec is 117.2 msec higher than for adjacent positives and 81.5 msec higher than for negatives.

Table 1 shows least-squares slopes and intercepts, R^2 values and error rates for individual Ss. These data are generally in accord with the overall results.

DISCUSSION

The most important finding is that the negative and adjacent positive data are well described by successive serial exhaustive searches. Further, the magnitude of the comparison time agrees with previous estimates from visual and memory search tasks.[1]

The deviations from the model suggest some interesting possibilities, however. First, the fastest times in the experiment were for repeated items in the first two positions on the left. Latencies were basically constant in these cases for List Lengths 3, 4, and 5. It may be that in this configuration the visual search can self-terminate.

Second, the high intercept, the high error rate, and wide variability for nonadjacent positives suggests that these conditions are much more difficult. It may be that Ss notice a match in these cases, but then have to recheck items to verify a detection. This additional noticing process may then vary between particular list configurations as well as between individual Ss. Further, the comparison process for nonadjacent repetitions may be based on a more abstract code, whereas adjacent same-different judgments can be made on the basis of physical features (Hochberg, 1968; Posner & Mitchell, 1967).

The support the model did receive gives evidence that high-speed mental processing is capable of a relatively high degree of complexity; specifically, in the current task, the ability to start successive scans at progressively rightward positions.

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NOTE

1. An analysis of a more complex model was performed to evaluate the hypothesis that the item to be searched for on a particular scan was first encoded into STM. Comparisons are then performed between the target representation in STM and the list items in the visual display to the right of the target item position.

One encoding is required for each successive scan until either all comparisons are completed or a repeated item is found. In the former case, $n-1$ encodings are required; in the latter, the scans terminate after the first repeated item is processed, requiring, therefore, p encodings (where p is the position of the first repeated item). Latencies are then predicted by the following equations:

$$RT^{-} = a^{-} + n\frac{(n-1)}{2}b_1 + (n-1)b_2 \quad (3)$$

$$RT^{+} = a^{+} + p\frac{(2n-p-1)}{2}b_1 + pb_2 \quad (4)$$

Here a^{-} and a^{+} are the negative and positive intercepts, respectively, b_1 is the time per comparison, and b_2 is the time per encoding. We felt that this encoding should be equivalent to that investigated by Sperling (1960).

This model with four parameters—a^{-}, a^{+}, b_1, and b_2—was fit to the negative and positive adjacent data using stepwise linear regression. The RSMD was 12.0 msec with 10 deg of freedom. The parameter values were 425.5 and 356.2 msec for negative and positive intercepts, respectively, 21.0 msec per comparison, and 10.1 msec per encoding. This encoding time is in good agreement with the 10-msec rate found by Sperling (1960).

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