Associative and serial-order information: Different modes of operation?

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Two versions of a distributed-memory model, one for associative information and one for serial-order information, leave open the question of whether there are two different modes of operation or only one. An analysis of these two versions showed that differential predictions emerge when one considers the role of item information. To test these predictions, a standard item-recognition task (Sternberg, 1966) was embedded in a paired-associate probe-recognition task, a serial-order probe-recognition task, or both. The item-recognition serial-position curves were quite different in the paired-associate and the serial-order conditions, and followed the paired-associate condition when the two were combined. In general, the results were consistent with the predictions of the distributed-memory models, and supported the idea of different modes of operation rather than a single common mode of operation.

When trying to understand memory, it is useful to distinguish between item, associative, and serial-order information. Item information underlies recognition and associative information underlies pairwise associations, whereas serial-order information preserves the sequence of events. Further explanation and evidence in support of these distinctions may be found in Murdock (1974).

Recently, two versions of a distributed memory model have been proposed, one for associative information (Murdock, 1982) and one for serial-order information (Murdock, 1983). Both use convolution and correlation as the storage and retrieval operations, both apply to recall and recognition, and both include item information. In the serial-order model, items and running pairs (A--B, B--C, C--D, ...) are stored, and in the associative model, items and discrete pairs (A--B, C--D, E--F, ...) are stored. In both models, the items (A, B, C, ...) are stored along with the (sequential or simultaneous) pairs.

In both models, information is represented by random vectors. These are vectors whose elements are random variables. All information is stored in a common memory vector, M . In the associative model:

$$M_j = \alpha M_{j-1} + \gamma_1 f_j + \gamma_2 g_j + \gamma_3 (f_j * g_j), \quad (1)$$

where M_j is the memory vector after the j th pair has been stored, f_j and g_j are the items comprising the j th pairs, the asterisk (*) denotes convolution, the pro-

cess or operation by means of which two items are associated, γ_1 and γ_2 are the weighting factors for item information (i.e., the A and B members of the pair), γ_3 is the weighting factor for the associative information, and α is the forgetting factor. Both the weighting factors ($\gamma_1 - \gamma_3$) and the forgetting factor (α) are parameters of the model, and they are assumed to be between 0 and 1. Equation 1 here is the same as Equation 1 in Murdock (1982).

In the serial-order model,

$$M_j = \alpha M_{j-1} + \gamma f_j + \omega (f_j * f_{j-1}), \quad (2)$$

where γ and ω are the weighting factors for item and associative information and the current item (item j) is associated or convolved with the prior item (item $j - 1$). Again, the weighting factors (γ and ω) and the forgetting factor (α) are parameters of the model and are assumed to be between 0 and 1. Equation 2 here is the same as Equation 1 in Murdock (1983). Both models rely on associations or convolution, but what is associated in the two models is different. In the associative model, discrete or successive pairs are convolved, whereas in the serial-order model, chaining is used. The current item is always associated with the prior item.

Given that we must store and retrieve both associative and serial-order information, are there different modes of operation in the two cases or only one? That is, given a single distributed-memory system, can it operate in the same way for associative and serial-order tasks, or does it function differently in the two cases? To analyze this issue, let us first illustrate each mode separately. Table 1 shows the contents of the memory vector after a list of three paired associates has been presented (left-hand column) and after a six-item serial list has been presented (right-hand column). As above, the letters A, B, ..., de-

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Table 1
Memory Vector for Paired-Associates (Left) and Serial List
(Right) After Three Pairs or Six Items Have Been Presented

Paired Associates	Serial List
$\alpha^2 [\gamma_1 A + \gamma_2 B + \gamma_3 (A*B)] +$ $\alpha [\gamma_1 C + \gamma_2 D + \gamma_3 (C*D)] +$ $\gamma_1 E + \gamma_2 F + \gamma_3 (E*F)$	$\alpha^5 (\gamma A) +$ $\alpha^4 [\gamma B + \omega (B*A)] +$ $\alpha^3 [\gamma C + \omega (C*B)] +$ $\alpha^2 [\gamma D + \omega (D*C)] +$ $\alpha [\gamma E + \omega (E*D)] +$ $\gamma F + \omega (F*E)$

note the six items. The memory vector for paired associates is based on Equation 1, and the memory vector for the serial list is based on Equation 2.

Consider item recognition. Recognition is assumed to occur by a comparison of the probe item with the memory vector. The comparison process involves computing the dot product of the two, and over trials there is a distribution of values with an expected value and a variance. There are separate distributions for old and new items, and they determine accuracy and latency of recognition. The coefficients of each item can be considered to be a measure of the strength of each item.

According to the serial-order model and Equation 2, the expected comparison value for an old item probe from Serial Position j is

$$E[f_j \cdot M] = \alpha^{s-j} \gamma, \quad (3)$$

where $f_j \cdot M$ is the dot product of the j^{th} item with the memory vector after a list of s items has been presented. According to the associative model and Equation 1, the expected comparison value for an old item probe from Serial Position j is

$$E[f_j \cdot M] = \alpha^{p-j} \gamma_1 \quad (4)$$

$$E[g_j \cdot M] = \alpha^{p-j} \gamma_2$$

where f_j is an A or left-hand item, g_j is a B or right-hand item, and the list is p pairs long.

If there are different modes of operation, then Equations 3 and 4 indicate what should be expected. For a serial-order task, item recognition should show a monotonic recency effect; the last item should be strongest and the first item should be weakest. (Usually a small primacy effect is obtained; this does not affect the basic argument, and will be discussed later.) For a paired-associates task, an item-recognition test should also show a recency effect, but it should be a zig-zag pattern. Every additional pair will affect the α value, and this is the "zig" within each pair. The relative strengths of the A and B items will depend on γ_1 and γ_2 ; this is the "zag." So, the predicted results are quite clear: if there are different modes of operation, one for associative information and one

for serial-order information, with a paired-associate presentation format, a zig-zag serial-position pattern should be obtained, whereas with a serial-order presentation format, a monotonic serial-position pattern should be obtained.¹

What would be expected if there were only a single mode of operation? Obviously, a single mode of operation must be able to cope with either a serial-order or a paired-associate presentation format. Assume the system has a normal mode of operation which accepts one of the two presentation formats, but adapts to the other if need be. If the normal mode of operation were the associative mode, then it is not clear how the linking associations (B-C; D-E, etc.) would be formed. It seems more reasonable to assume that the serial mode is the preferred mode, but that the linking associations drop out (or are not formed) when an associative mode of operation is appropriate. This possibility is shown in Table 2. Here we have simply repeated the right-hand column of Table 1 but deleted the linking (C-B, E-D) associations.

A glance at Table 2 shows that there is a very clear prediction. The expected results for item information are exactly as given by Equation 3, so we should see the monotonic serial-position recency pattern. The fact that there are "zig-zag" associative components in the memory vector (i.e., first B*A, then nothing, then D*C, then nothing, then F*E) is in fact quite immaterial. Item and associative information are independent (Murdock, 1982), so this factor has no effect whatever on the predicted outcome.

One key question, then, is what pattern item-recognition serial-position latencies show in a paired-associate task. Another key question is what happens when both associative and serial-order information is required. (The details of how this was done will be given in the Method section.) If there are two different modes of operation, then presumably both would be in operation and either one could be used for item recognition. However, if there is only a single mode of operation, then again it would function in the serial-order mode, since both associative and serial-order information could be derived. (Presumably, this time the linking associations would not be deleted, and the results would be the same as those in the right-hand column of Table 1.)

To summarize, if there are two different modes

Table 2
Memory Vector for a Three-Pair List Assuming a Single
Memory System for Associative and Serial-Order Information

$$\begin{aligned} &\alpha^5 (\gamma A) + \\ &\alpha^4 [\gamma B + \omega (B*A)] + \\ &\alpha^3 (\gamma C) + \\ &\alpha^2 [\gamma D + \omega (D*C)] + \\ &\alpha (\gamma E) + \\ &\gamma F + \omega (F*E) \end{aligned}$$

of operation, one for associative information and one for serial-order information, and these work as described in Equations 1 and 2, then monotonic serial-position effects for item recognition should occur in a serial-order task but a zig-zag pattern should occur in a paired-associate task. What should happen in the combined task (when both associative and serial-order information are required) is not clear. On the other hand, if there is only a single mode of operation, then no zig-zag pattern should occur at all. Regardless of whether the task is associative, serial-order, or combined, item-recognition serial-position latency functions should show a monotonic recency gradient.

METHOD

Procedure

There were three conditions: Condition A (for associative), Condition S (for serial order recognition), and Condition AS (for associative and serial order). This was a between-sessions variable. For each of 2 weeks, subjects had two A sessions, two S sessions, and one AS session, making a total of 10 sessions in all. The A sessions took place on Mondays and Wednesdays for half the subjects and on Tuesdays and Thursdays for the other half. The S sessions were the other way around, and the AS session always took place on Fridays. The subjects were fully informed about task requirements in each session before it began. In all sessions, the subjects were instructed to respond as quickly as possible without making any errors. To emphasize the need for accuracy, the subjects were warned that more than 5% response errors in a session would involve repeating the session without increased remuneration. (This threat never had to be carried out, since all subjects maintained a satisfactory level of accuracy.)

Each session in the A and S conditions consisted of 240 trials on three set sizes. The subjects responded to 80 trials at set size 2, 80 trials at set size 4, and 80 trials at set size 6. The trials were blocked by set size, but order of set size was randomized. At each set size, half of the trials (40) were item recognition and the remaining trials were associative recognition (A condition) or serial-order recognition (S condition). We could have used recall to test for associative or serial-order information, but in the models under test associative and serial-order recognition have the same general properties as associative and serial-order recall. Also, we felt it was less disconcerting for the subjects to use recognition tasks throughout. Within each block of 40 trials, half of the probes were positive (a "yes" response was correct) and half of the trials were negative (a "no" response was correct).

For Condition A, items were presented two by two (i.e., in pairs). At the start of each trial, the subjects saw two, four, or six asterisks, centered on the video screen and one row down. Memory-set items were presented in pairs, centered on the screen and two rows down. Each pair was presented for 500 msec with a negligible interpair interval. (A fast presentation was used to discourage rehearsal, which could only have added noise to the data.) When the memory set had been presented, a flashing centered asterisk was presented either three rows down or nine rows down. This asterisk was presented for 1 sec, and indicated to the subject the type of test to follow. If the asterisk was three rows down, the test was item recognition, but if it was nine rows down, it was associative recognition. Then the asterisk was replaced by a probe item or items. The probe(s) remained displayed until the subject responded. Responses were timed from the offset of probe(s) printing. Printing time was negligible.

All trials, whether positive or negative, were assigned a serial-position coding. For item recognition, if the trial was positive (probability = .5), the probe was the item at that serial position in the current memory set. If the trial was negative, a previous

memory set was selected at random and the probe was the item at the assigned serial position in this previous set. In this way, all serial positions were tested equally often on both types of trial, as far as even division made possible. For the item-recognition task, this procedure necessitated a constraint, in that the first trial of any block could not be a negative item-recognition trial. For the associative recognition task, the first item of the pair was coded as the A item and the second item of the pair was coded as the B item. For learning, items were always presented as A-B pairs. At testing, half of the items were presented A-B and half of the items were presented B-A. Positive probes were simply the pair at that serial position in the current memory set. The subjects were instructed to respond "yes" whether the A-B or the B-A combination was shown. For negative trials, the B item was taken from another member of the set (all serial positions with all test positions used equally often) and an A-B' pair constructed. Since half of the time this scrambled pair would be presented A-B' and half of the time it would be presented B'-A, the use of the B item only in the scrambled pairs did not provide the subject with a cue. Set size 2 presented a special problem, since there was only one pair in the list. For this set size, the B item for the negative trials was selected at random from a previous paired-associate trial.

The subject gave his or her responses by pressing a designated key on a key pad. The pad contained three keys and, using his or her dominant hand, the subject placed his or her first and third fingers on the "yes" and "no" keys and his or her second finger on the dummy key. Subjects received feedback after each trial. If the response was correct, the subject was shown his or her response latency in milliseconds. If the response was incorrect, then the word INCORRECT was displayed on the screen (in flashing mode). This type of feedback has been shown to encourage minimal response latencies while maintaining subject response accuracy (Franklin & Okada, 1983). The feedback remained displayed for 2 sec, and then the warning asterisks for the next trial appeared.

For Condition S, items were presented singly for 250 msec, with a negligible interitem interval. Set sizes were 2, 4, or 6, as in the other conditions. At the start of each trial, the subject saw the two, four, or six flashing asterisks centered on the video screen and 1 row down. When the memory set had been presented, a flashing centered asterisk was presented either 3 rows down or 12 rows down. As in Condition A, the asterisk 3 rows down cued the item-recognition task. The other asterisk cued the serial-order task. The item-recognition test was the same in all conditions, both in procedure and location on the screen. For the serial-order test, a column of lines was drawn on the screen starting at line 12. Each line was 12 spaces long, and the number of lines was equal to the set size. For a positive trial, the probe was written over the line that was at the correct serial position in the set of lines. For a negative trial, the probe was written over a line that was not at the correct serial position. For both the correct and the incorrect trials, all serial positions were sampled as equally often as possible. This constraint included consideration of the distance between the correct serial position and the serial position tested in the case of the negative trials. Feedback to the subject was the same across all conditions.

For Condition AS, there were 360 trials in a session. One-third of the trials were item recognition, one-third were associative recognition, and one-third were serial-order recognition. Thus, there were 40 trials of each test type at each set size. On all trials, items were presented in pairs, in the same manner as for Condition A. This was because the serial-order task and item-recognition task could be performed using paired presentation, but the associative task could not be performed using single presentation. Trial order was randomized. When the memory set had been presented, the task type was cued by a flashing asterisk 3 rows down (item recognition), 9 rows down (associative recognition), or 12 rows down (serial-order recognition). Thus, the task cuing in this combined condition was the same as for the separate conditions. The cuing for the item-recognition task did not vary across all three condi-

tions. Similarly, once cued, the three types of tasks proceeded as described for the separate conditions, and feedback on task performance was the same.

It should be mentioned that subjects taking part in this experiment were prescreened. That is, prior to the experiment, subjects took part in a screening session involving only the item-recognition task, and the subjects were warned that to be accepted for the main experiment they had to achieve at least 90% accuracy. One subject was replaced as a result of this session (80% accuracy). Also, on the Friday preceding the 2-week testing sessions, the subjects had a practice session. This session also contained only the item-recognition task. Each set size was tested for 80 trials, and the set sizes were 2, 3, 4, or 5. Presentation was single and at the same rate as in the testing sessions. The purpose of this session was to familiarize the subjects with the equipment and to collect a sample of their item-recognition performance uncomplicated by additional tasks.

Subjects

The subjects were six undergraduates from the University of Guelph. They were obtained by advertisement and paid for their participation. Each subject took part in the practice session and in all 10 experimental sessions. All subjects were tested individually.

Equipment

The experiment was run under the control of an Apple microcomputer. The stimuli were displayed on a Hitachi monitor, and the key pad was interfaced with the microcomputer to record the responses.

Stimulus Materials

All the items for a session were drawn randomly from the Toronto Word Pool (see Friendly, Franklin, Hoffman, & Rubin, 1982). Each subject saw a unique set of stimulus materials (unique across sessions and across subjects). There was no item overlap within a session, but overlap between sessions was unavoidable. There were no constraints upon item selection based upon prior use. Thus, an item could appear in both negative and positive trials in different sessions.

RESULTS

Reaction time data were used as our primary measure because they are very sensitive and can provide strong tests of a theory (e.g., McNicol & Stewart, 1980; Murdock, 1980). Also, after 15 years of work on the Sternberg (1966) paradigm, we know a great deal about what patterns of data to expect. Prior to analysis, each subject's data were trimmed. That is, for each subject, for each set size, a standard deviation was calculated for the latency data (correct responses only). All response latencies within that set that were more than three standard deviations above/below the set size mean were counted as "hesitation" errors and added to the response error rate. The total error rate for each condition and each set size never exceeded 5%.

While there was a tendency for error rate to increase over set size, analysis confirmed that there was no significant effect for set size [$F(2,10) = 3.35$, $MSe = .04$] and no significant effect for type of trial (positive/negative) [$F(1,5) = .617$, $MSe = .01$]. There was no effect for condition [$F(3,15) = 2.33$, $MSe = .03$], and none of the interactions reached significance ($F < 1$). In all analyses, condition, trial type, and set size were

treated as fixed factors and subjects was treated as a random factor. The alpha level was set at .05, and all error data were discarded from further analyses.

The critical reaction time data from the item-recognition task are shown in Figures 1-4. The left panels show the set-size functions for positive and negative probes, and the right-hand panels show the corresponding serial-position data. Taking the figures in order, Figure 1 shows the data from the practice session conducted on the Friday prior to the 2-week testing sessions. The slopes for the best fitting linear functions were 27 msec (positive trials) and 34 msec (negative trials), the intercepts were 444 and 484 msec, respectively, and the r^2 values were both .98. Serial-position curves for these data show a typical recency effect plus a one-item primacy effect.² It would seem that the practice session produced typical Sternberg data to serve as a baseline for the other conditions.

The comparable data for Conditions S (serial-order task) are shown in Figure 2. The slopes of the best fitting set-size functions were 29 and 33 msec/item, the intercepts were 412 and 500 msec, and the r^2 values were .99 and .90 for the positives and negatives, respectively. The serial-position curves are also much like those in Figure 1. Thus, qualitatively and quantitatively, adding the serial-order requirement does not seem to have any noticeable effect on the latencies of item recognition.

Figure 1. Set size and serial-position functions for the practice session.

Figure 2. Set size and serial-position functions for the item-recognition data from Condition S.

Figure 3. Set size and serial-position functions for the item-recognition data from Condition A.

Quite a different picture appears in Figure 3, which shows the data from Condition A. Although the set-size functions are similar to those of Condition S (slopes of 38 and 38 msec/item, intercepts of 385 and 477 msec, and r^2 values of .99 and .92 for positives and negatives, respectively), the serial-position curves are zig-zag, not monotonic. Obviously, latencies for item recognition go pair by pair, and within each pair, primacy dominates recency. The implication is very clear. Item recognition in paired associates is qualitatively different from item recognition in serial lists.

Finally, as Figure 4 shows, Condition AS gives item-recognition results like those of Condition A, the paired-associate session, not like those of Condition S, the serial-order session. For the set-size function, the slopes are 36 and 42 msec/item, the intercepts are 382 and 448 msec, and the r^2 values are .99 and .93 for the positives and negatives, respectively. The serial-position curves show the same zig-zag pattern as in Figure 3, indicating that, when associative and serial-order information are both required, the associative requirement dominates the item information.

For further analysis, the data were transformed into slope and intercept values to better represent

Figure 4. Set size and serial-position functions for the item-recognition data from Condition AS.

the linear set-size factor. This also made it possible to compare the data from the practice session (set sizes 2-5) with the data from the three complex conditions (set sizes 2, 4, and 6). Analysis of the slope data confirmed that there were no differences due to condition [$F(3,15) = .48$, $MSe = 339.49$] or to trial type (Pos/Neg) [$F(1,5) = .18$, $MSe = 123.13$], and no interaction between condition and trial type [$F(5,15) = .30$, $MSe = 160.03$]. As Figures 1-4 (left-hand panels) indicate, the slope values obtained in the complex S, A, and AS conditions are not significantly different from the slope values obtained in the simple practice session. Nor is there any significant difference between the slope values obtained for the positive trials and the slope values obtained for the negative trials. The analysis therefore confirms that all conditions produced similar and typical results for the task.

The complementary analysis of the intercept data shows no effect for condition [$F(3,15) = 2.13$, $MSe = 1628.00$], but does show a main effect for trial type [$F(1,5) = 97.99$, $MSe = 805.08$]. There is no interaction [$F(3,15) = 1.28$, $MSe = 2045.39$]. This analysis confirmed that intercepts in the complex conditions did not differ from intercepts in the practice session. The main effect for trial type can be attributed to subjects' choosing to use their index fingers for "yes" responses and their third fingers for "no" responses. While it would have been cleaner to counterbalance this factor, it was felt that the subjects had enough to contend with in the complex conditions without feeling uncomfortable with the mechanics of their responding. Failure to counterbalance was not seen as critical to the design. The analysis confirms that this factor did not have a differential effect across conditions.

DISCUSSION

The results of all four conditions are quite clear. They may be summarized as follows: (1) The set-size functions for positive and negative probes are parallel linear functions with typical Sternberg parameter values under all conditions. (2) The serial-position curves for an item-recognition task embedded in a probe serial-order task show a typical pattern: monotonic recency effects, with a one-item primacy effect. (3) The serial-position curves for an item-recognition task embedded in a probe paired-associates task show instead a zig-zag pattern; they go pair by pair, with more primacy than recency in each pair. (4) Finally, under the mixed condition (both paired-associate and serial-order recognition required), the data were like those of the paired-associate condition rather than the serial-order condition.

Quite apart from the main issue, it should be noted that the data are very consistent with the distributed memory models under consideration. For the serial-order model, the item-recognition data were just

what would be predicted from Equation 2. Of course, the data here are standard Sternberg findings, so they should be consistent with the model. However, what is new in this regard is that the item-recognition functions are statistically the same whether or not serial-order information is required.

Furthermore, the paired-associate condition yielded data strikingly in accord with the associative version of the distributed memory model (Equation 1). As this equation shows, the "zig" in the serial-position functions is produced by α while the "zag" is produced by the relative magnitudes of γ_1 and γ_2 . For whatever reason, γ_1 must be slightly larger than γ_2 , but the more important point is that, as Equation 1 indicates, this does not interact with serial position.

The main thrust of this paper, however, is directed at the question of whether there are different modes of operation or only one. Consider first the possibility that there are different modes of operation, one described by Equation 1 and the other by Equation 2. Is there any evidence in these data that is inconsistent with this possibility? As far as we can see, no. In fact, as noted above, the data seem amazingly in agreement even down to the fine-grain details. The only point one might quibble about is the small primacy effect obtained under the serial-order condition. This primacy effect is not unreasonable.²

Consider the other possibility, namely, that there is a common mode of operation for both associative and serial-order information. As explained in the introduction, this view predicts monotonic recency gradients for all three conditions. The fact that a zig-zag pattern was obtained in Condition A and in Condition AS strongly argues against this view.

A third possibility would be that there are three different modes of operation: one for item information, one for associative information, and one for serial-order information. An example would be Model 2 in Murdock (1982), which illustrates separate storage for item and associative information. This third possibility seems to be wrong. If there were three different modes of operation, then the item information should be qualitatively the same under all conditions. (Even with a paired-associate format, the two items in a pair of unrelated common words would be processed sequentially, and Equation 1 would apply with γ_3 set to zero.) All item-recognition data should then show monotonic recency effects regardless of condition, and this was clearly not the case.

The data on the associative and serial-order tasks were quite similar to the item-recognition data. The latency data for the associative task under both Conditions A and AS showed a clear recency effect, linear set-size functions, and was essentially the same under both conditions. The latency data for the serial-order task also showed linear set-size effects, but the serial-position functions were more bowed (symmetrical). The overall mean latency was slower under Condi-

tion AS than under Condition S, which also is consistent with the general conclusion.

To check on the generality of the results, we ran a second experiment with two main changes. First, we used a between-subjects design rather than a within-subjects design. Second, the serial-order task used an i-j probe rather than a position probe. Items i and j were always adjacent in presentation, and a forward (ij) order was "yes" while a backward (ji) order was "no." List length was 4, 6, or 8, presentation rate was slightly slower (350 rather than 250 msec/item), and about one subject in four was rejected for failing to meet the high accuracy rate required (95%). The reaction time data for Conditions A and S (we did not run Condition AS) were quite similar to the data in Figure 2-4, so the results do not depend upon the nature of the experimental design or the exact format of the serial-order probe.

In conclusion, we have raised the question of whether associative information and serial-order information require the use of two different modes of operation or whether a single mode of operation can suffice. We have used item recognition as a technique to answer the question, and the data seem to be more consistent with the first alternative (different modes) than with the second (a single mode). What do we mean by different modes of operation? All we mean is the rules that seem to characterize the operation of the system. These rules are the equations, Equation 1 for the associative mode and Equation 2 for the serial-order mode. The task requirements seem to determine which equation (or rule, or mode of operation) applies, and they are different for associative and serial-order tasks. Given these two equations, the tests of the predictions seem quite clear. However, it is quite possible that further theoretical development will come up with a more general formulation that will show these two different modes to be only special cases of a more general common mode of operation.

REFERENCES

- ANDERSON, J. A. (1973). A theory for the recognition of items from short memorized lists. *Psychological Review*, **80**, 417-438.
- FRANKLIN, P. E., & OKADA, R. (1983). The effect of reaction-time feedback on subject performance in the item-recognition task. *American Journal of Psychology*, **96**, 323-336.
- FRIENDLY, M., FRANKLIN, P. E., HOFFMAN, D., & RUBIN, D. C. (1982). Norms for the Toronto Word Pool. *Behavior Research Methods & Instrumentation*, **14**, 375-399.
- McNICOL, D., & STEWART, G. W. (1980). Reaction time and the study of memory. In A. T. Welford (Ed.), *Reaction times* (pp. 253-307). London: Academic Press.
- MURDOCK, B. B., JR. (1974). *Human memory: Theory and data*. Potomac, MD: Erlbaum.
- MURDOCK, B. B., JR. (1980). Short-term recognition memory. In R. S. Nickerson (Ed.), *Attention and performance VII* (pp. 145-194). Hillsdale, NJ: Erlbaum.
- MURDOCK, B. B., JR. (1982). A theory for the storage and retrieval of item and associative information. *Psychological Review*, **89**, 609-626.

- MURDOCK, B. B., JR. (1983). A distributed memory model for serial-order information. *Psychological Review*, **90**, 316-338.
- STERNBERG, S. (1966). High-speed scanning in human memory. *Science*, **153**, 652-654.

probably slight and can be ignored. However, this point warrants further investigation.

2. The one-item primacy effect could be due to the fact that the first item has no prior item. In effect, ω is zero, so perhaps γ is larger than for the subsequent items in which ω is not zero.

NOTES

1. One must also consider the variances. Given reasonable parameter values, differences in variances across serial position are

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ANNOUNCEMENTS

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The 14th annual meeting of the Society for Computers in Psychology will be held on November 7, 1984 (the day before the Psychonomic Society meeting), in San Antonio, Texas. **The deadline for submission of papers, symposia, and posters is July 1, 1984.** Further information may be obtained from and submissions sent to:

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Computer Conference Student Paper Competition

The Society for Computers in Psychology will continue to sponsor an award for the outstanding student paper submitted for presentation at the annual meeting. Although the primary emphasis of the conference is the use of computers in on-line experimental applications, student papers in any area of application of computers to psychology are welcome. Papers may be theoretical, experimental, or applied in approach. Eligibility is open to students currently enrolled in undergraduate or graduate courses, or students who graduated in 1984 and have done the work as part of a course, thesis, or other student research project. All papers submitted for the conference (including those multiply authored) in which the major contribution has been made by a student are eligible for consideration and will be considered for presentation at the conference and subsequent publication. The outstanding student paper will be presented at the 1984 conference and published in the Computer Conference Proceedings. Also, the author will receive a complimentary 1-year membership in the Society for Computers in Psychology, a complimentary 1-year subscription to *Behavior Research Methods, Instruments, & Computers*, and a \$50 cash prize. **The deadline for papers is July 1, 1984.** Eligible papers should be submitted in quadruplicate. A cover sheet should include the author's name, mailing address, telephone number, and academic affiliation, a 50-word abstract, and a note stating that the paper is to be considered for the student award. These materials should be sent to Walter Schneider at the above address.