Pauses and durations exhibit a serial position effect

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This article reports evidence of two kinds of serial position effects in immediate serial recall: One involves interresponse pauses, and the other response durations. In forward and backward recall, responding was faster at initial and final positions than at center positions, exhibiting a bow-shaped function relative to serial position. These data were obtained in a spoken recall study in which ungrouped lists of four to six words and postcuing of recall direction were used. The pause pattern is consistent with several models of serial memory, including a distinctiveness model (Brown, Neath, & Chater, 2002) and a version of the ACT-R model augmented with a spontaneous grouping strategy (Maybery, Parmentier, & Jones, 2002). The duration pattern suggests that response articulation depends on the processing context, rather than being modular.

Response time (RT) measures have recently gained popularity in serial recall research because they are thought to reveal aspects of retrieval not detected by accuracy measures. One goal of this study was to examine patterns of interresponse pauses as a function of serial position in spoken recall, both forward and backward, and in doing so, to illuminate differences in RT patterns between a previous study from our lab (Thomas, Milner, & Haberlandt, 2003) and a study conducted by Maybery, Parmentier, and Jones (2002). The other goal was to determine whether spoken word durations are influenced by the output context in which the words are articulated.

Interresponse Pauses

In the Maybery et al. (2002) and the Thomas et al. (2003) studies, ungrouped lists of up to six items were used, with typed recall as a response mode. Maybery and colleagues used standard forward recall, with consonants as stimuli. We used forward and backward recall, with words as stimuli. In forward recall, both sets of studies showed an RT peak at output position 1, consistent with the idea that subjects prepare the entire list for output before emitting the first item (Sternberg, Monsell, Knoll, & Wright, 1978). The RT patterns for positions 2–*N* differed across the two studies. We reported flat RTs for these positions, whereas Maybery et al. found a bow-shaped function.

RTs in our previous study (Thomas et al., 2003) were longer in backward recall than in forward recall. They exhibited a bow-shaped function with a slowdown from initial toward center positions, followed by a continuous speedup. We attributed this pattern to a scan-and-drop strategy (Conrad, 1965). Using this strategy, subjects first emit the most recent item and then repeatedly scan to the beginning of the list, advance to the target item, and emit and drop the target item.

In the present study, we used spoken recall, rather than typed recall, and we recorded interresponse pauses and word durations separately. Because speaking is faster than typing, it is considered a more sensitive measure of the temporal dynamics of recall. The dependent variable in our previous study was the aggregate RT for each item. It was not possible to distinguish between the interresponse pause and the duration of typing a word. Thus, the aggregate measure masked the pause between responses, the interval of theoretical interest. Nevertheless, by adding pauses and durations in the present study, we can compare spoken recall times with the typed recall times in our previous study (Thomas et al., 2003).

Examining the pause function in serial recall is important because it advances our knowledge of the processes that occur during the silent interval between responses. The pause is thought to be the locus of retrieval operations in serial recall, including memory search (Cowan, 1992) and lexical access (Hulme, Newton, Cowan, Stuart, & Brown, 1999).

A flat RT function relative to position is predicted by models that assume a serial search involving an equal load per item, including the ACT-R model (Anderson, Bothell, Lebiere, & Matessa, 1998). According to ACT-R, in an ungrouped list, each item is coded according to its serial position. To retrieve items from Position 2 to Position *N*, one retrieval operation, implemented as a pro-

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duction rule, is needed. As a result, pauses should be invariant in terms of serial position and recall direction.

A curvilinear function is predicted, although for different reasons, by several models, including a distinctiveness model (Brown, Neath, & Chater, 2002) and a version of ACT-R augmented by a spontaneous grouping strategy (Maybery et al., 2002). If subjects spontaneously group list items during study, the ACT-R model expects group boundaries at various positions in the center of the list. Retrieving a group involves an additional retrieval step at the position marking the group boundary. Averaging across groups of different sizes would yield a bowed serial RT function. According to the distinctiveness model (Brown et al., 2002), the temporal distinctiveness of items and, presumably, their retrieval speed varies as a function of position. Distinctiveness is greatest at the list boundaries. Therefore, retrieval, as measured by interresponse pauses, is expected to be faster for boundary items than for center items.

Response Durations

Response durations have received less attention than interresponse pauses in research on serial recall. Most of the research on spoken word duration has been motivated by an interest in encoding factors, rather than output factors, in recall. Researchers have sought to evaluate the word length effect, the finding that the memory span is inversely related to the length of the words in the list. As expected, spoken word duration is affected by the length of words (e.g., Cowan et al., 1994; Sternberg et al., 1978).

In terms of output factors in serial recall, it remains unresolved whether response articulation as measured by duration is affected by the position of the item. Articulation in recall may be conceptualized in terms of a modular or a context-dependent view. The modular hypothesis considers search and motor output as fundamentally distinct from one another. Therefore, articulation is not subject to the search processes that occur

during the pause preceding a response. Given the modular view, output durations are based on the characteristics of an item, such as its length (Cowan et al., 1994) and lexicality (Hulme et al., 1999), rather than its position. The duration patterns observed by Cowan (1992) in a memory span task with 4-year-old children as subjects are consistent with the modular hypothesis. Cowan found that position generally did not affect spoken word durations.

The context-dependent view argues that search processes occur even as the person articulates an item (Cowan et al., 1998; Sternberg et al., 1978). Accordingly, output durations should be affected by the same experimental variables as interresponse pauses, including serial position and list length. Sternberg and colleagues varied list length and found that response durations of individual items increased as a function of list length. Similarly, Cowan et al. (1998) found, in a memory span task involving 9-year-old children, that spoken digit duration was affected by span length and, at length 4, by digit position, with durations of 0.52, 0.56, 0.51, and 0.48 sec for the four positions, respectively. On the basis of these data, Cowan et al. (1998) acknowledged that the change in durations reflected the influence of concurrent search processes on articulation.

In sum, the present study focused on output processes in serial recall by examining interresponse pauses and response durations as a function of serial position, list length, and recall direction. The experiment involved an immediate serial recall paradigm using ungrouped lists of four to six words as stimuli, with spoken recall as a response mode. Given our emphasis on output processes, the recall direction was postcued at the end of each list.

METHOD

Subjects

Forty-four undergraduate students participated in the experiment in partial fulfillment of a course requirement.

Figure 1. Probability of correct recall as a function of output position and list length in forward and backward recall.

Table 1
Mean Response Times as a Function of Recall Direction and List Length

	List Length													
	Forward Recall							Backward Recall						
	4		5		6		<i>M</i>	4		5		6		<i>M</i>
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>		<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	
Latencies	0.78	0.06	0.93	0.08	1.09	0.11	0.94	1.89	0.23	1.72	0.24	1.54	0.20	1.72
Pauses	0.11	0.02	0.17	0.02	0.29	0.04	0.19	0.32	0.04	0.49	0.06	0.52	0.07	0.44
Durations	0.50	0.01	0.53	0.03	0.58	0.01	0.54	0.54	0.01	0.57	0.01	0.58	0.01	0.56

Materials

Word lists were composed from a set of 360 familiar one- and two-syllable nouns of up to seven letters.

Design

The experiment involved three within-subjects conditions, one for each list length of 4, 5, and 6. At each list length, the design was a $2 \times N$ factorial with report order (forward or backward) and position (1–4, 1–5, or 1–6) as repeated measures.

Procedure

The subjects were tested individually in a quiet room. The experimental session involved 4 practice trials followed by 72 experimental trials. There were 24 trials at each list length, with 12 requiring forward recall and 12 requiring backward recall. The trial order was uniquely randomized for each subject. Each list included a unique set of words selected randomly from the word pool. On each trial, the list length was announced, and the words were presented sequentially in the center of the screen for 1,500 msec followed by a 500 msec blank interval. The recall prompt was presented at the end of the list for 500 msec, coinciding with a 500-msec tone.

The subjects recalled the word lists by speaking into a microphone. They were asked to say “pass” in place of any words they could not recall. A response was scored as correct when the word was spoken in the appropriate list position. RTs, including start-up latencies, interresponse pauses, and durations, were coded using a sound editor.¹ For each subject and each condition (length $\times$ direction $\times$ position cell), RTs were expressed in terms of medians. The RTs corresponded to correctly recalled words, including words that occurred on trials with error responses. Unless indicated otherwise, the analyses involving RTs were based on the data from 34 subjects who recalled at least one item correctly at each position of each list length. Reflecting the focus on output processes in the present study, we analyzed the response measures in terms of output position.

RESULTS

Figure 1 exhibits percentages of accuracy in both recall directions. These data are similar to those in our earlier study (Thomas et al., 2003), with a primacy effect in forward recall and a recency effect in backward recall. There was a significant direction effect at list lengths 4 and 5 [$F(1,43) = 13.21$ and $F(1,43) = 13.10$],² with greater accuracy in forward than in backward recall. At each list length, there was a significant direction $\times$ position interaction [$F(3,129) = 11.99$, $F(4,172) = 4.44$, and $F(5,215) = 12.13$, respectively], reflecting a more concave shape of the accuracy function in backward recall than in forward recall.

In both recall directions, the start-up latencies prior to the first word were longer than the pauses at other list locations. As Table 1 indicates, latencies increased as a function of list length in forward recall, but not in backward recall. An analysis of variance (ANOVA) revealed a significant effect of direction [$F(1,33) = 20.77$], modified by a direction $\times$ length interaction [$F(2,66) = 6.55$]. A simple effects analysis revealed a significant length effect in forward recall [$F(2,66) = 7.01$], but not in backward recall.

Interresponse Pauses

Figure 2A shows pauses in forward and backward recall for the three list lengths. To analyze the effect of list length, we averaged pauses across position at each length (Table 1). An ANOVA determined that pauses were shorter in forward recall than in backward recall [$F(1,33) = 37.44$], and that they increased as a function of list length [$F(2,66) = 16.77$].

As Figure 2A shows, pauses exhibit a curvilinear function relative to position, with faster responding in the primacy and recency regions than in the center of the list. At each list length, there were significant position and direction effects, as well as significant interactions involving position and direction. The interaction terms for list lengths 4–6 were $F(2,66) = 15.15$, $F(3,99) = 8.77$, and $F(4,132) = 3.55$, respectively. The interactions mirror the greater arch of the pause functions in backward recall than in forward recall. There were significant quadratic trends at each list length in forward recall [$F(1,33) = 9.03$, 8.82 , and 18.16] and in backward recall [$F(1,33) = 18.12$, 31.01 , and 20.57 , respectively].³

Could the bow-shaped pause pattern reflect a dependence of pause durations on response accuracy? It is plausible that an error at position $N-1$ slows the emission of the response at position N , possibly because of competition from the item for which recall failed (Lovatt, Avons, & Masterson, 2002). Because errors are more frequent in the center of the list, pauses might be longer for center than for terminal positions. In order to assess this possibility, we validated the general analysis by conducting two conditionalized analyses. We analyzed pauses at position N given correct recall of the word in position $N-1$, and we analyzed pauses for all-correct trials. These were trials that contained no recall

Figure 2. (A) Interresponse pauses (in seconds) as a function of output position and list length in forward recall and backward recall. (B) Response durations (in seconds) as a function of output position and list length in forward and backward recall. (C) Aggregate response times (RTs, pauses plus durations) for forward and backward recall as a function of list length and output position. Serial position is represented in terms of output position. In forward recall, input and output positions coincide. In backward recall, early output positions represent late input positions, whereas late output positions represent early input positions. The scales in the panels reflect the different response ranges for each measure.

errors.⁴ As is shown in Tables 2A and 2B, both conditionalized pause measures exhibited the serial position effect at each length and direction, as in the general analysis above. The quadratic component was significant in all cases.

Table 3 exhibits pauses for erroneously recalled words at list length 6, the length affording the largest number of observations ($N = 27$).⁵ Pauses were about twice as long for errors as for correct words (see Figure 2A). In terms of output position, in forward recall, pauses for errors were bow-shaped, as evidenced by a significant qua-

dratic component [$F(1,26) = 12.42$]. In backward recall, however, error pauses tended to decrease linearly as a function of output position [$F(1,26) = 9.04$].

Response Durations

Figure 2B displays spoken word durations in forward and backward recall for the three list lengths. The figure indicates that duration was affected systematically by the experimental variables, including length, direction, and position.

Table 2
Conditionalized Pauses

List Length	Forward Recall					Backward Recall				
	2	3	4	5	6	2	3	4	5	6
A. Pauses in Position <i>N</i> Given Correct Recall in Position <i>N</i> – 1										
4	0.10	0.14	0.13			0.44	0.53	0.16		
5	0.11	0.31	0.41	0.29		0.67	0.88	0.90	0.25	
6	0.18	0.50	0.57	0.71	0.47	0.44	1.07	0.93	0.84	0.31
B. Pauses on All-Correct Trials										
4	0.09	0.14	0.12			0.44	0.51	0.16		
5	0.14	0.22	0.18	0.15		0.62	0.70	0.75	0.17	
6	0.05	0.21	0.17	0.31	0.12	0.06	0.51	0.72	0.43	0.31

Note—The number of subjects who exhibited at least two all-correct trials for the three list lengths was 41, 29, and 12, respectively.

To analyze the effects of list length, we averaged median durations across positions at each length (see Table 1). Durations increased as a function of list length [$F(2,66) = 44.31$]. There was an effect of recall direction [$F(1,33) = 16.55$], modified by a length $\times$ direction interaction [$F(2,66) = 9.98$]. The interaction reflects a greater slowdown in spoken duration as a function of list length in forward than in backward recall.

Focusing on the effect of position, we analyzed durations as a function of direction and position separately at each list length in terms of a $2 \times N$ ANOVA. At each length, there were significant effects of position. Similarly, there were significant effects of direction (at length 6, $p < .07$). At lengths 4 and 5, there was a significant direction $\times$ position interaction [$F(3,99) = 10.36$, and $F(4,132) = 10.58$], reflecting a somewhat different shape of the bow in the duration functions in the two recall orders. Trend tests revealed that position was associated with quadratic trends at each list length in both forward recall [$F(1,33) = 8.59, 22.37$, and 38.76] and backward recall [$F(1,33) = 16.24, 34.52$, and 41.10 , see note 3].

Tables 4A and 4B report durations conditionalized on correctly recalled prior words and durations on all-correct trials, respectively. These data exhibit the bow-shaped pattern as a function of position, as does the analysis based on correctly recalled words. For both conditionalized measures, the quadratic component was significant at each direction and list length. Table 3 exhibits durations for erroneously recalled words at list length 6. Unlike pauses, which were about twice as long for errors than for correct words, durations for errors and correct words were comparable. For example, at list length 6 mean error durations and correct durations were 0.565 and 0.574 sec, respectively. In forward recall, the pattern

of durations for errors was curvilinear [$F(1,26) = 20.35$], mirroring the durations for correct words. In backward recall, error durations exhibited a linear trend [$F(1,26) = 34.43$], as well as a quadratic trend [$F(1,26) = 8.15$].

Aggregate Response Times

In our typed recall study (Thomas et al., 2003), we used aggregate RTs as the measure of recall speed. In the present spoken recall study, we estimated aggregate RTs by adding the pause and the spoken word duration for positions 2–*N*. For position 1, we added the preparation latency to the subsequent duration. The resulting aggregate times are plotted in Figure 2C. Comparison of these data with those in our previous study (Thomas et al., 2003, Experiment 2, Figure 2) ⁶ indicates that spoken and typed RTs differed in terms of magnitude. As was expected, RTs were shorter in spoken than in typed recall. The difference amounted to about 1 sec across the board in both forward and backward recall. We attribute this difference to the added motor output processes necessary in typing.

In forward recall, the overall pattern of RTs was similar in typed and spoken recall, with the slowest responding at position 1 and faster responding thereafter. Our original analysis of the typed recall times, based on paired *t* tests, failed to detect differences between positions 2–*N*. In a subsequent analysis of the same data, using the more appropriate trend tests, we found that the quadratic trend approached significance for list lengths 5 and 6 [$F(1,30) = 3.01, p < .10$, and $F(1,22) = 3.43, p < .10$, respectively]. Thus, the reanalysis of our typed recall data and the spoken data call into question the claim of flat RTs in forward recall made in our earlier article (Thomas et al., 2003).

Table 3
Pauses (P) and Durations (D) for Erroneously Recalled Words as a Function of Output Position (Length 6)

	Forward Recall						Backward Recall					
	1	2	3	4	5	6	1	2	3	4	5	6
P		0.48	1.18	1.26	0.89	0.71	1.50	1.69	1.19	1.04	0.65	
D	0.51	0.60	0.59	0.58	0.51	0.51	0.63	0.64	0.62	0.59	0.53	0.48

Table 4
Conditionalized Durations

List Length	Forward Recall						Backward Recall					
	1	2	3	4	5	6	1	2	3	4	5	6
A. Durations in Positions N Given Correct Recall in Position $N-1$												
4	0.51	0.53	0.50	0.49			0.58	0.61	0.52	0.49		
5	0.53	0.55	0.55	0.53	0.48		0.60	0.61	0.62	0.54	0.48	
6	0.54	0.59	0.60	0.60	0.54	0.48	0.59	0.61	0.61	0.61	0.52	0.49
B. Durations on All-Correct Trials												
4	0.50	0.54	0.51	0.48			0.56	0.61	0.51	0.50		
5	0.51	0.54	0.53	0.51	0.50		0.60	0.58	0.62	0.52	0.47	
6	0.47	0.54	0.53	0.54	0.47	0.45	0.53	0.56	0.59	0.61	0.50	0.46

In backward recall, there was a large difference between spoken and typed recall at the first output position. RTs lengthened from the first to the third output position in typed recall (Thomas et al., 2003, Figure 2). In spoken recall, there was the characteristic peak at position 1, with shorter RTs at the second output position. This difference suggests that subjects engage in different processes in typed and spoken backward recall. The RT peak at position 1 confirms the expectation that subjects prepare the list for output (Anderson et al., 1998). We speculate that our typed recall data differ from the expected pattern because the subjects—knowing that typing words would slow them down—might have quickly emitted the final list word and the next to the final word as they were preparing the list for output.

DISCUSSION

Interresponse times and spoken word durations exhibit a serial position effect. Both measures indicate faster processing in the primacy and recency regions of the list than in the center. This finding generalizes the findings of Maybery et al. (2002) from forward to backward recall, from the limited stimulus set of consonants to a much larger stimulus set of words, and from typed recall to spoken recall. The fact that durations were affected by the retrieval context, as pauses were, suggests that response emission is influenced by the processing environment—specifically, by retrieval processes.

Interresponse Pauses

In spoken recall, there was an inverse U-shaped pattern of interresponse pauses in both recall directions, with faster responses for items in initial and final list positions and slower responses in the center. These results confirm the pattern suggested in typed recall studies involving consonants (Maybery et al., 2002) and words, as has been shown by the reanalysis of the Thomas et al. (2003) data. The curvilinear pattern of pauses in serial recall is consistent with several models, including the distinctiveness model (Brown et al., 2002) and the ACT-R model. The latter model assumes that subjects spontaneously create groups involving two or three words

during encoding. This would result in group boundaries at various center positions and, thus, slow responding at these positions. The idea of spontaneous grouping is certainly plausible. However, there is little empirical evidence for such grouping in short lists (e.g., Anders & Lillyquist, 1971).

Backward recall is more difficult than forward recall, because retrieval cues are generally more effective in the forward direction (Kahana & Caplan, 2002; Thomas et al., 2003). In order to report items in the reverse order, subjects are assumed to mentally reconstruct the items in their forward order. They do so using the scan-and-drop strategy (Conrad, 1965). A person presumably implements this strategy after recalling the most recent items, items N and $N-1$. Output of item 1 coincides with list preparation (e.g., Sternberg et al., 1978), slowing responding at the first position. Item $N-1$ is still recent and is recovered relatively quickly. Thereafter, subjects scan to item 1 at the beginning of the list, advancing forward to the current item. Following recall, the item is dropped from the search set, and the process is repeated until item 1 is recalled. Overall, the multiple scans impose an added load that produces longer pauses than those in forward recall.

Response Durations

Spoken word durations exhibited a bow-shaped function that mirrored the pattern of interresponse pauses. This pattern is inconsistent with the modular view of recall output, the notion that production of the recall response is independent of retrieval processes. Rather, the bow-shaped duration functions support the context-dependent position that the output of words in serial recall depends on concurrent cognitive processes. Wright (1990), for example, argued that the spoken duration of a word depends on the recall context. In our task, this means that spoken word durations are subject to the same retrieval processes as those that occur during the silent intervals between words. Apparently, the retrieval of upcoming list items is continued even as the person articulates the current word. Early and late items enjoy an advantage in terms of output speed because retrieval processes are more facile at these positions than at the center of the list.

To our knowledge, this report is the first systematic investigation of spoken word durations in the serial recall paradigm. However, spoken word durations have been investigated in other paradigms, including the lexical decision task (Balota, Boland, & Shields, 1989). Balota et al. found that spoken word durations were shorter for words primed by related words than for those primed by unrelated words. Balota and colleagues interpreted their results in light of an interactive model of speech production where the interaction among linguistic levels, including the phonological level, extends to the output motor codes. The fact that spoken durations show a pattern similar to the pattern of pauses indicates that search processes coincide with articulatory processes. In general, the serial position effects we observed for pauses and durations add to the accumulating evidence on output processes in serial recall (e.g., Cowan, 1992; Hulme et al., 1999).

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NOTES

1. To assess the scoring reliability, the audio protocols of 8 subjects were scored by two independent transcribers. The time measures determined by the two scorers were correlated for each of the subjects. The average of these scores was $M = .88$, reflecting the interscorer reliability.
2. The alpha level was $\alpha = .05$, unless indicated otherwise.
3. There were also significant linear components in selected conditions.
4. The proportions of all-correct trials for list lengths 4, 5, and 6 were .66, .33, and .13, respectively.
5. An analysis of all-error trials was not feasible because of the small number of such trials. The proportions of all-error trials were .02, .03, and .03 for the three lengths.
6. In Experiment 2 of our earlier study (Thomas et al., 2003), list lengths were randomized across trials, as they were in the present study. In Experiment 1, trials were blocked according to list lengths.

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