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Understanding serial position curves in short-term recognition and recall

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Abstract

The experiment analyzed serial position curves in recall, global recognition (comparing probes to whole lists) and local recognition (comparing probes to specific items in a list). Input order, output order, and the spatial order to be memorized were deconfounded by presenting and probing items in random order in different spatial positions. Primacy and recency effects over input position were observed for all three tasks. Only primacy emerged over output position. Spatial position affected only recall and local recognition but not global recognition accuracy. Latency data provided additional information, sometimes deviating from the patterns of accuracy. The results support an attentional gradient as one source of the primacy effect. They are compatible with input and output interference or decay, but are difficult to explain by a temporal distinctiveness account. No support was found for response suppression and edge effects as mechanisms to explain recency.

Keywords: Short-term memory; Serial position curves; Recognition; Recall

One of the most prominent features of performance in short-term memory tasks is its dependency on the serial position of an item in the memory list. The experimental paradigms investigated most, forward serial recall, backward serial recall, and immediate recognition, are each associated with characteristic serial position curves. Forward serial recall generates a large primacy effect, that is, accuracy is high at the beginning of the list and gradually drops towards the end. In addition, there is usually a small recency effect, that is, an upward trend in accuracy on the last or the last few list items (e.g., Jahnke, 1963; Nipher, 1878; for spatial material see Avons, 1998; Smyth & Scholey, 1996). Backward recall, in contrast, is characterized by extended recency and a relatively small primacy effect (e.g., Li & Lewandowsky, 1993, 1995; Madigan, 1971). In the immediate recognition paradigm introduced by Sternberg (1969), one typically observes a large recency effect both for reaction times and for accuracies, often accompanied by a small primacy effect (McElree & Dosher, 1989; Monsell, 1978; Morin, Derosa, & Stultz, 1967). This pattern is also typically observed for accuracies in probed recall tasks (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965).

The goal of the present research was to identify the sources of primacy and recency effects in short-term memory tasks. Several proposals to explain these effects have been made in the literature, some of them in the form of isolated hypotheses, some as part of formal models built to explain a whole array of phenomena associated with one paradigm. My goal here is not to test complete models, but instead to identify which of the hypothesized mechanisms are suitable as part of any model to account for serial position effects.

My working hypothesis is that there are common mechanisms underlying serial position curves in serial

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recall and recognition. This raises the question why the serial position curves associated with these paradigms differ. Serial recall and the Sternberg recognition task differ in at least three respects. One is, of course, the difference in retrieval demands (recall vs. recognition). A second difference is that the Sternberg task requires only item information (i.e., which items were in the list), whereas serial recall also taps order information (i.e., which serial position each item had in the list). Finally, whereas serial recall requires retrieval of all list items, the Sternberg task involves only a single retrieval event. In the experimental paradigm used here, I attempted to deconfound these three aspects.

A second goal was to disentangle three dimensions of serial position that could affect performance in a memory task: (1) The serial order of encoding a list, which I will call encoding position or input position. (2) The serial order of retrieving list elements, named retrieval position or output position. (3) The serial order of items that has to be remembered, called memory position. The standard experimental paradigms discussed above obviously confound these three dimensions of serial position, if they vary them at all. In forward serial recall, encoding and retrieval position are identical, and hence the serial order to be memorized is identical to them as well. In backward serial recall, encoding and retrieval position are negatively correlated, and the order information to be maintained in memory is either the encoding order or its reverse. In the Sternberg task, there is no retrieval order, and no order information has to be remembered. Thus, serial position curves from the Sternberg task can be regarded as coming closest to an unconfounded picture of the input position effect. It is important to know whether the same serial position curve would be obtained for recall tasks as well when input position is disentangled from memory and output position. This is the goal of a new paradigm introduced here.

An experimental paradigm to deconfound serial position effects

Memory items are presented in frames arranged in a row from left to right. They are presented in random order, and retrieval of each item is required in a different random order (Fig. 1). Thus, the temporal order of presentation, the spatial order from left to right, and the temporal order of retrieval are uncorrelated. In tasks that require order information, it is memory for spatial position that must be remembered because items have to be retrieved by their frames. Thus, memory order equals the spatial order from left to right.

This basic paradigm was instantiated with three retrieval demands: Recall cued by spatial position, global recognition, and local recognition. I call global recognition a task where a probe must be compared to the list as a whole, as in the standard Sternberg task. I call local recognition a task where a probe must be compared to the item at a particular list position. In the local recognition task used here, probes were presented in the frames of the list items, indicating the spatial position of the list item they had to be compared with. Thus, local recognition shares with global recognition the type of retrieval demand and with serial and cued recall the requirement to memorize order (or position) information.

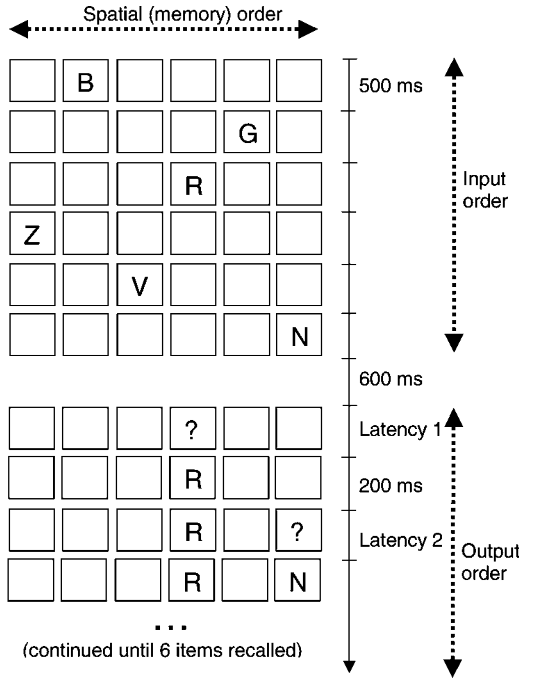

Fig. 1. Display of the sequence of events (subsequent rows of frames from top to bottom) in one trial of the recall task with random presentation order. Letters are presented one by one in random order. Recall is probed by question marks in a different random order.

One previous study deconfounding input and output position was conducted by Cowan, Saults, Elliott, and Moreno (2002). They presented lists of 9 digits and asked participants to recall them in forward order. Depending on a cue presented after the list, recall should begin with the first, the fourth, or the seventh list item. In the partial recall condition, only the next three items, starting with the cued position, were to be recalled. In the full recall condition, all nine items were to be recalled in order, wrapping around at the end of the list back to the beginning. This procedure deconfounded list position (i.e., serial position of encoding) and recall position. Cowan et al. (2002) observed a pronounced recency effect, together with a small primacy effect, when they plotted the first three recalled items over input position—

a pattern quite similar to that usually observed in the Sternberg recognition task. Moreover, with visual presentation of items they obtained a large effect of output position—items later in the output sequence were recalled worse, in particular those in late list positions. This suggests that output interference plays a major role in generating the strong primacy effect in forward serial recall. The present work partially replicates the results of Cowan et al. (2002) with a different paradigm that also allows assessing a third dimension of serial position (i.e., memory position), and it extends them to immediate recognition tasks, as well as to retrieval latencies as a second informative dependent variable.

Sources of serial position effects

Several mechanisms have been discussed in the literature to account for primacy or recency effects in short-term memory tasks, and these mechanisms attribute the effects to different dimensions of serial position. As a result, they predict serial position effects over different dimensions in a paradigm that allows separating these dimensions.

Retroactive interference and decay

One mechanism for generating both primacy and recency effects is *retroactive interference*. Retroactive interference during encoding (input interference) naturally produces a recency effect: The earlier items suffer interference from the later ones in the list. Immediately after presentation, the most recent items should thus be available best. An explanation of recency in terms of interference was proposed for example by Nairne (1988). Input interference arises during encoding and should therefore give rise to a recency effect over input position in the present paradigm. Retroactive interference during a series of outputs (output interference), on the other hand, provides an advantage for items retrieved first, because the early items interfere with the later items in the output sequence. This should generate a primacy effect over output position: Items retrieved earlier interfere with items yet to be retrieved, regardless of input or spatial position. The results from Cowan et al. (2002) mentioned above suggest that output interference contributes to the primacy effect in forward serial recall.

Primacy gradient, response suppression, and chaining

An idea incorporated in many models of serial recall is that of an attentional *primacy gradient* (Brown, Preece, & Hulme, 2000; Farrell & Lewandowsky, 2002; Lewandowsky & Murdock, 1989; Page & Norris, 1998). During encoding of a list, less and less attention is devoted to each additional list item (or to each additional association in TODAM, Lewandowsky & Murdock, 1989), resulting in memory traces of decreasing strength or activation. This naturally generates a primacy effect in forward serial recall.

In the Primacy Model (Page & Norris, 1998) and in SOB (Farrell & Lewandowsky, 2002) the attentional primacy gradient has a functional role—it is used to preserve the order of items. Forward serial recall is accomplished by recalling the most activated item, followed by suppression of the recalled item (response suppression). Based on an activation gradient from the first to the last list item, recall naturally starts with the first item, progresses to the second after suppressing the first, and so on. If an activation gradient is to fulfil the same role in the present paradigm, it should be built up over the spatial serial order (e.g., from left to right). Thus, the idea of a *functional* activation gradient motivates the prediction of a primacy effect over the spatial order—provided that the cognitive system can adapt the gradient flexibly to task demands. Since an activation gradient has no function in a task requiring no order information, no such effect should be expected for global recognition.

A gradual decrease of attention to each additional list element, however, could also arise without purpose from basic attentional mechanisms (e.g., the attentional capture of the list onset, or the distraction of attention from later list elements by the elements already held in memory). Such an *unintentional* attentional gradient would generate a primacy effect over input position. Moreover, it would affect all three paradigms employed here.

Response suppression serves to avoid perseveration by removing the just recalled item from the set of candidates. This is an essential ingredient in models that use an attentional gradient to represent order (Farrell & Lewandowsky, 2002; Page & Norris, 1998), because removal of the strongest items is necessary to make room for later list items to be recalled next. Continuous suppression of recalled items leaves only few items in the candidate set when the end of the list is reached. If recall has gone at least moderately well so far, the remaining items are most likely those that have actually been presented at the end of the list. This increases the probability to recall the final items in the correct list positions, thus generating a recency effect. Since the reduction of recall candidates occurs over successive recall attempts, a recency effect generated by response suppression should emerge over output position in the present paradigm.

One of the early models of serial recall, TODAM (Lewandowsky & Murdock, 1989), was based on a *chaining* mechanism for remembering the serial order of list items. Each new item is associated to its predecessor. This generates a primacy effect in forward serial recall, because items later in the chain depend on accurate recall of earlier items, which can then be used as cues, but earlier items can be recalled correctly without success in later items. The chaining hypothesis makes predictions similar to the attentional gradient account. If the chaining mechanism is under the control of the cognitive system, it should build a chain that preserves the memory order, not necessarily the encoding order. In this case, one could expect a primacy effect over spatial serial position for those paradigms that require order information (i.e., recall and local recognition). If chaining occurs automatically during encoding, regardless of task demand, it would generate little effect in the present paradigm, because it would be largely useless for a task where retrieval order does not match encoding order. Successful retrieval would then have to rely on other cues.

Distinctiveness and edge effects

Serial position effects can also arise from the differential *distinctiveness* or discriminability of list items in memory. For present purposes, we must distinguish two versions of the distinctiveness account. One is based on temporal distinctiveness, the other is a more general distinctiveness approach. The idea of *temporal* distinctiveness theories (Brown et al., 2000; Burgess & Hitch, 1999; Glenberg, Bradley, Kraus, & Renzaglia, 1983) is that successive events are associated with a continually changing context representation. An attempt to recall an event (e.g., a list item) uses a reconstruction of the context representation as cue. The distinctiveness of a list item decreases when the interval between encoding and retrieval increases, because the temporal context at encoding and the one at the time of recall have less and less in common, making it increasingly difficult to reconstruct the encoding context. In a more recent distinctiveness model called SIMPLE (Brown, Neath, & Chater, 2002), distinctiveness decreases over time because the cognitive time dimension is logarithmically compressed, thus compressing the psychological distance between events as they recede in time. The temporal distinctiveness hypothesis predicts a recency effect over input position, because items presented more recently will be more distinctive on average. In addition, distinctiveness decreases over the time of recall, generating an advantage for items recalled first, that is, a primacy effect over output position.

For the present paradigm, a temporal distinctiveness account for primacy and recency effect would have to face one problem: In the random presentation condition temporal context is not a useful cue to distinguish items within a list; participants have to rely on spatial cues instead. So if distinctiveness is assumed to rest on the temporal discriminability of context cues for recall, distinctiveness of items within lists would not be expected to matter.

A temporal distinctiveness account could still be based on *between-list* discriminability: Items at the end of the input sequence are farther removed from the previous lists and thereby less likely to be confused across lists, thus generating a recency advantage. The delay over successive outputs also reduces discriminability between lists, thereby generating a primacy gradient over output position. Discrimination between lists, however, should affect only memory for items (i.e., which items were in the current list), not memory for order (i.e., at which position an items was within the list). The predictions from temporal discriminability therefore are confined to memory for items.

A second category of distinctiveness models is based on the discriminability of items on dimensions that are not necessarily linked to time. One such model is the Start–End Model proposed by Henson (1998b). He assumes that each list item is associated to a context formed by a vector of two context units: a start unit with activation decreasing from the beginning towards the end of a list, and an end unit with activation decreasing from the end towards the beginning of the list. Items close to the start and the end of the list have more distinctive context vectors, because the activation gradients of the units decline sharply towards the middle and then gradually level off. SIMPLE (Brown et al., 2002) also incorporates other dimensions besides time to calculate overall discriminability.

For a model such as the Start–End Model one should assume that the context representation would be arranged to capture the memory order, not necessarily the input order. For instance, when a task requires memory for spatial position instead of input order, the start- and end-markers would be set on the left and the right end of the row, respectively. This should generate primacy and recency effects over the spatial dimension. In fact, U-shaped serial position curves over spatial position have been reported for the accuracy of recalling the spatial position of a given item (R. E. Anderson, 1976; Healy, 1975a; for delayed recall see Nairne & Dutta, 1992), though not consistently (Healy, 1975b).

Primacy and recency effects can also arise simply from the differential probability of transposition errors. Transpositions (i.e., recall of correct items at wrong positions) typically arise from positional confusions among neighboring items in a list, with migrations to positions farther away being increasingly rare (e.g., Healy, 1974; Henson, Norris, Page, & Baddeley, 1996). This pattern can arise from a lack of distinctiveness of positional cues during recall, as discussed above, but also from random noise in the activation levels of items ordered by a primacy gradient (Page & Norris, 1998) or from perturbations between neighboring items in the retention phase (Estes, 1972).

Since the first and the last list item have only one neighbor, they have less chance to be confused. The same effect holds, though to a lesser degree, for items in the second and next to last position with regard to confusions over two positions. This results in fewer transposition errors for items close to the beginning and end of a list, compared to those in the middle. These *edge effects* have been discussed as contributing to primacy as well as recency effects (Brown et al., 2002; Estes, 1972; Lewandowsky, 1999). Because positional confusions count as errors only when they concern an item's position on the memory order dimension, in the present paradigm edge effects should appear as "primacy" and "recency" over the spatial dimension.

Table 1 summarizes the mechanisms potentially responsible for primacy and recency effects in short-term memory tasks, together with the dimension of serial order for which they predict effects in the random presentation condition of the present paradigm, separate for tasks that require order information (recall and local recognition) and the task that does not (global recognition). The last column of the table summarizes the degree of support for these mechanisms gained from the present data, as explained in the Discussion.

Method

Participants

Three groups of participants were tested with the basic paradigm outlined above, one with recall, one with global recognition, and one with local recognition. They were psychology undergraduates at the University of Potsdam who took part in one-hour sessions in partial fulfillment of requirements for an experimental lab course (recall and global recognition) or were reimbursed by 5€ (local recognition). There were 20 participants in the recall and the local recognition group, and 23 in the global recognition group.

Design

Each task was implemented in two conditions, varied within subjects. In the randomized condition, items were presented and retrieved in random orders, as described above, thus deconfounding the three dimensions of serial order. In the serial presentation condition, items were displayed from left to right, and retrieval also proceeded from left to right. Thus, all three serial orders were perfectly correlated. With recall this comes down to a version of forward serial recall where successive items are displayed in a left-to-right order; with local recognition, we obtain a recognition task that is parallel to serial recall in all procedural aspects—the task requires order as well as item information, and all items are to be retrieved in order of their presentation.

Each participant worked through 13 test blocks of 12 trials, alternating between the conditions from block to block (the odd number of blocks was due to a program error). Each condition was the starting condition for half of the participants. The test blocks were preceded by 2 practice blocks, one for each condition, with 6 trials each.

Materials and procedure

Each trial began with the presentation of a row of six square frames (2.3 cm^2, separated by 5 mm) in the middle of a computer screen in white color on a black background. After 500 ms, six consonants were presented in white color, one in each frame, with a

Table 1
Hypothetical mechanisms and their predictions for separate dimensions of serial order

	Relevant dimension (recall, local recognition)	Relevant dimension (global recognition)	Evidence?
Mechanisms for primacy			
Output interference/decay	Output	Output	+
Attentional gradient (automatic)	Input	Input	++
Attentional gradient (functional)	Memory	(None)	+
Chaining (automatic)	(None)	(None)	–
Chaining (functional)	Memory	(None)	+
Distinctiveness (temporal context)	Output[a]	Output	–
Edge effects	Memory	(None)	–
Mechanisms for recency			
Input Interference/decay	Input	Input	+
Distinctiveness (temporal context)	Input[a]	Input	–
Distinctiveness (arbitrary context)	Memory	(None)	–
Response suppression	Output	(None)	–
Edge effects	Memory	(None)	–

[a] The effect of temporal distinctiveness should be limited to memory for items.

presentation time of 400 ms followed by an ISI of 100 ms for each letter. In the serial condition, the consonants were presented from left to right; in the randomized condition, their presentation order was determined at random for each trial and participant. Lists were built by randomly selecting from the 20 consonants (excluding 'Y') without repetitions.

Six hundred ms after the offset of the last list element, retrieval was initiated depending on the demands of each task. In the recall task, a red question mark appeared in one frame, and the participant had to enter the letter presented in that frame through the keyboard. In the global recognition task, a probe consonant was presented in a red frame in the lower third of the screen, and participants had to decide whether this letter had been in the list by pressing the left or the right arrow key. The assignment of "yes" and "no" to the two arrow keys was determined by the participant at the beginning of the experiment. In the local recognition task, a probe was presented in one of the frames of the row, and the participant had to decide whether the letter had been presented in that frame, again by pressing the left or right arrow key.

In all three tasks, six successive retrieval requests followed each list presentation, with each new question mark or probe following 200 ms after the previous response. In the recognition tasks, half the probes were positive (i.e., they required a "yes" response), and the algorithm producing the items took care that they were evenly distributed over the six input positions throughout the experiment for each participant. For the global recognition task, negative probes were sampled at random from the consonants not presented in the list. For local recognition, the negative probes were all items from the list, but presented in the wrong frames. This made sure that participants had to use memory for position in order to discriminate between positive and negative probes. In both recognition tasks, no probe was used twice during the sequence of six probes in each trial.

In the serial condition, the question marks and the probes of the local recognition task proceeded from left to right. The probes of the global recognition task were always presented in the same red frame, but the positive probes (i.e., those that had been in the list) were presented in their correct temporal serial positions (e.g., the third probe, if it was a positive probe, matched the letter at temporal and spatial position three). In the randomized condition, in contrast, the order of the retrieval requests was determined at random for each trial. Latencies were recorded from the onset of each retrieval probe (question mark or consonant) until the next key press. The computer accepted only consonant keys in the recall task, and only left or right arrow keys in the recognition tasks. At the end of each trial, participants received a feedback display of the form "x out of 6 correct" and started the next trial by pressing the space bar.

Results

The analysis mainly focuses on accuracy, because this is the dependent variable that best allows for comparisons between recall and recognition. From the recognition tasks only responses to positive probes were used because negative probes have no serial position on the input and the memory dimension. Short-term recognition has more often been evaluated by response times, but latencies have rarely been investigated for serial recall, and the few studies there are suggest that they do not reflect the same serial position effects as accuracy data (J. R. Anderson & Matessa, 1997; Maybery, Parmentier, & Jones, 2002). Nonetheless, the latencies provided additional interesting information, which will be presented in a later section. An alpha level of .05 was adopted for all inference statistics.

Overall accuracy

The proportion of items recalled or recognized correctly in each task and condition is displayed in the first two columns of Table 2. Recall and the two recognition tasks are not directly comparable because the chance of guessing correctly is much higher for recognition. I therefore computed scores corrected for guessing by the formula

$$p_c = (p - g)/(1 - g),$$

where p stands for the uncorrected proportion of correct responses, p_c for the corrected proportion, and g for the guessing probability, which was set to 1/20 for recall and

Table 2
Mean proportion correct by task and presentation condition

	Serial	Random	Serial (corrected)	Random (corrected)
Recall	.80	.49	.78	.46
Local recognition	.85	.74	.71	.48
Global recognition	.87	.83	.75	.67

Legend: Serial, serial presentation condition; random, random presentation condition, corrected, corrected for guessing.

1/2 for recognition. The corrected performance scores are summarized in the right two columns of Table 2.

A mixed-model ANOVA with task (3) and presentation condition (2) as factors and the corrected accuracies as dependent variable revealed main effects of task, $F(2,60) = 5.85, MSE = .025$, and of condition, $F(1,60) = 141.4, MSE = .01$, as well as an interaction, $F(2,60) = 16.1, MSE = .01$. Separate ANOVAs by presentation condition showed that the three tasks did not differ significantly with serial presentation condition ($F = 1.9$), but they differed with random presentation condition, $F(2,60) = 14.1, MSE = .019$. This difference reflects the requirement for order information, which is necessary for the recall and the local recognition task, but not for global recognition. The differential role of position memory seems to matter only when presentation order is random.

Separate t tests for each task showed that the serial presentation order was superior to the random order for all three tasks, $t(19) = 14.4$ for recall, $t(19) = 5.3$ for local recognition, and $t(22) = 3.4$ for global recognition. This difference is particularly remarkable for the global recognition task, because here presentation and retrieval order are irrelevant for the formal task demands—all a participant has to do is remember which items were in the list and respond to each probe accordingly.

Serial position effects on accuracy

Serial presentation

The serial presentation condition mainly served to compare serial position effects in recall and recognition under equivalent testing conditions (i.e., testing of all items in their order of presentation). Fig. 2 shows the serial position curves of the three tasks. The recall data replicated the typical forward serial recall curves with large primacy and small recency. The recognition data mirrored this pattern, and thereby differed from the typical curves obtained with the Sternberg paradigm, probably due to the alignment of the test procedure with serial recall. A mixed model ANOVA with task as between-subjects factor and serial position as within-subjects factor revealed significant linear [$F(1,60) = 204.9, MSE = .01$] and quadratic [$F(1,60) = 34.1, MSE = .005$] trends over serial position. Higher order polynomial contrasts were also significant, but are difficult to interpret and will therefore generally not be reported in this article. The main effect of task was significant as well, $F(2,60) = 5.8, MSE = .036$. The linear contrast interacted with task, $F(2,60) = 9.2, MSE = .01$, which was due to a steeper primacy gradient in the recall compared to the recognition data.

The overall difference between recall and recognition accuracy, as well as the steeper decline over serial positions 1–5, could be due to the much higher chance of guessing correctly in the recognition tasks. When the same ANOVA was conducted with the corrected accuracies, the main effect of task ($F = 1.9$) and the interaction with serial position ($F = 1.5$) were no longer significant. To summarize: When all six elements of a list had to be retrieved in the same order as they were presented, the serial position curves for accuracy did not differ substantially between recall, local recognition, and global recognition. This is compatible with the assumption that the same mechanisms are responsible for serial position effects in recall, local recognition, and global recognition.

Random presentation

The top panel of Fig. 3 shows the accuracies from the three tasks plotted over input position, averaged across output and spatial positions. All three serial position curves displayed clear primacy and recency effects.

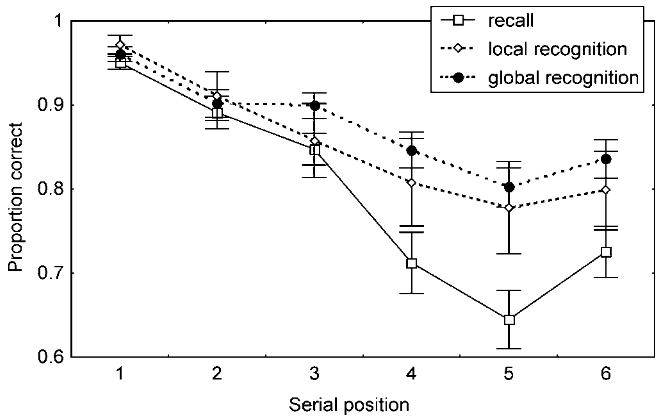

Fig. 2. Accuracies of recall, global recognition, and local recognition by serial position in the serial presentation condition. Error bars reflect one standard error for between-subject comparisons.

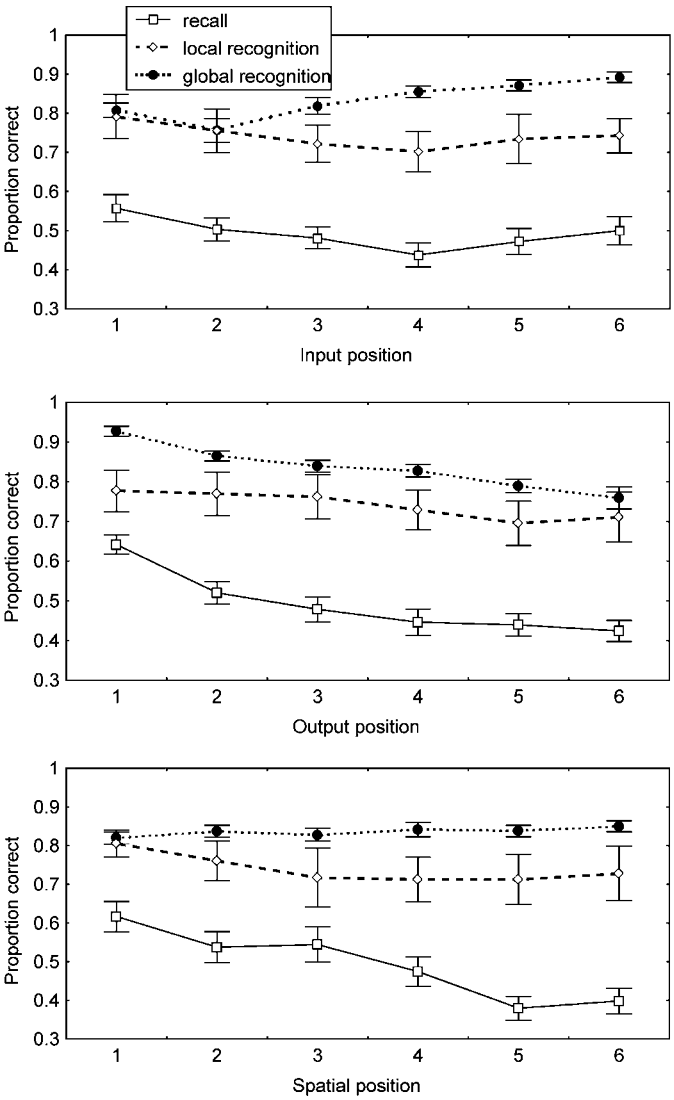

Fig. 3. Accuracies of recall, global recognition, and local recognition in the random presentation condition, plotted by input position (top panel), by output position (middle panel), and by spatial position (bottom panel). Error bars reflect one standard error for between-subject comparisons.

This was supported by a significant quadratic trend, $F(1,60) = 26.2, MSE = .005$. The linear trend over serial positions was not significant overall ($F < 1$), but it interacted with task, $F(2,60) = 7.0, MSE = .02$. When tested within each task separately, the linear trend was significant only for global recognition, $F(1,22) = 15.7$, $MSE = .014$. Thus, the serial position curves over the input dimension were symmetrical for the two tasks that required order information—recall and local recognition—but there was a predominance of recency in the global recognition data. The global recognition data match the pattern usually observed with the Sternberg task, consistent with the assumption that a single probe, as well as the average of a series of probes, provides a good estimate of the pure effect of input position on global recognition.[1]

[1] Cowan et al. (2002) reported an interaction of input and output position, such that for the first three output positions there was a large recency effect over input order, which largely disappeared for later output positions. I attempted to replicate this finding by analyzing input serial position curves separately for output positions 1–3 and output positions 4–6. A plot of the data suggested that for both recall and local recognition, the recency effect over input position was pronounced for output positions 1–3, but much reduced for output positions 4–6, just as reported by Cowan et al. (2002). The interaction, however, was not significant for the whole sample, nor for the recall task alone.

The serial position curves of the output dimension are plotted in the middle panel of Fig. 3. All three tasks exhibited a marked decline of accuracy over output position, with no sign of a recency effect. This was confirmed by a significant linear contrast, $F(1,60) = 76.7, MSE = .012$. The quadratic contrast also became significant, $F(1,60) = 7.8, MSE = .006$. The linear trend interacted with task, $F(1,60) = 3.7$, $MSE = .012$, as did the quadratic trend, $F(1,60) = 4.6$, $MSE = .006$. The quadratic trend reflected the gradual flattening of the recall curve, which was not observed with the recognition data. When the recall task was removed from the analysis, the quadratic trend disappeared ($F < 1$).

The accuracies plotted over the spatial position (from left to right) are shown in the bottom panel of Fig. 3. There was a significant linear contrast, $F(1,60) = 20.3, MSE = .02$, which interacted with task, $F(2,60) = 12.7, MSE = .018$. Separate ANOVAs confirmed a marked decline of accuracy from left to right in the recall data, $F(1,19) = 18.4, MSE = .04$, and a weaker similar trend in local recognition, $F(1,19) = 4.6, MSE = .017$, whereas no such tendency was apparent with global recognition.

As a test of the between-list distinctiveness account, I also investigated serial position effects in the recall task separately for order memory. Order memory was defined as the conditional probability of recalling a list item in its correct spatial position, given it was recalled at all anywhere. If the recency effect over input position and the primacy effect over output position are due to between-list discriminability alone, there should be no such effects on order memory. However, there was a reliable recency effect over input position, $F(1,19) = 18.3, MSE = .005$ for the quadratic contrast, and $F(1,19) = 7.3, MSE = .009$, for the linear increase over the last three positions (conditional probability increased from .61 to .69). Likewise, there was a reliable primacy effect over output position on order memory, $F(1,19) = 9.1, MSE = .006$, for the linear contrast. Thus, the serial position effects over input and output position are not limited to item memory, as the temporal distinctiveness account would have to predict. This conclusion is also supported by the local recognition data: Local recognition exclusively tests for memory of position, since all probes were contained in the list.

Response latencies

For recognition data, I followed standard procedure by eliminating all response times associated with errors, as well as those in excess of 5 s. For serial recall latencies, however, no standard treatment has been established yet. Therefore, I analyzed latencies for both correct and incorrect responses separately without removing any data.

Serial presentation

Fig. 4 (top panel) shows the recall latencies for the serial presentation condition, separate for correct and wrong responses. A clear grouping pattern is apparent, with longer latencies at the start of each group of three items. This pattern is reminiscent of the data by Anderson and Matessa (1997) and Maybery et al. (2002), although in the present experiment there was no experimental induction of grouping. An ANOVA with response status (correct vs. incorrect) and serial position as factors showed that error latencies were larger than latencies for correct responses, $F(1,17) = 25.5, MSE = 230,423$, and there was a significant effect of serial position, $F(5,85) = 21.2, MSE = 172,856$, but no interaction, confirming the visual impression that the two curves were largely parallel.

The serial position curves of latencies from the two recognition tasks are displayed in the bottom panel of Fig. 4. A 2 (task) × 6 (serial position) ANOVA showed no main effect of task ($F = 2.6$), but a significant cubic trend over serial position, $F(1,41) = 35.2, MSE = 961,432$, which was slightly more pronounced with local than with global recognition, $F(1,41) = 6.2$ for the interaction with task. These curves differ markedly from serial position curves usually obtained in the Sternberg task, because they reflect not just input position, but also output position in a sequence of probes. The curves are similar to those from serial recall, suggesting that the same grouping structure might underlie a sequence of recognition attempts when the sequence of probes matches the presentation order of the list. An alternative interpretation is that the recognition curves display primacy and recency effects, on top of which the first latency contains the extra time to switch from encoding to retrieval.

Random presentation

Latencies from the random presentation condition were analyzed by input position, output position, and spatial position, analogous to the accuracy data. Serial position curves over input position are displayed in Fig. 5 (top panel). The latency data from all three tasks showed a small primacy effect over input position, but no measurable recency effect. This was statistically confirmed by significant quadratic contrasts, $F(1,19) = 15.9, MSE = 61,723$, for the recall data, and $F(1,41) = 7.06$, $MSE = 38,012$, for the recognition data. When the first position was taken out of the analysis, no serial position effect became significant in both the recall and the recognition data.

The middle panel of Fig. 5 plots latencies of the three tasks over output position. There was a pronounced decline of recall times over output position. This was reflected by a linear trend, $F(1,19) = 156.7, MSE = 137,348$, which interacted with response status, $F(1,19) = 6.4, MSE = 36,791$, although the same overall form was apparent for both correct and error responses. There was also a linear trend in the recognition data, $F(1,41) = 40.1, MSE = 33,376$, which inter-

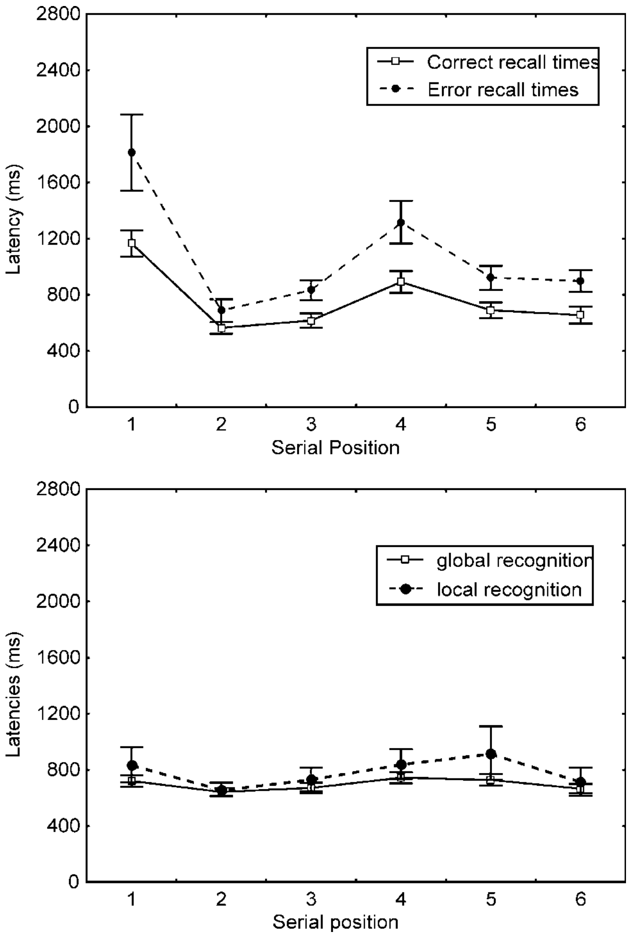

Fig. 4. Response latencies in the serial presentation condition for recall (top panel) and the two recognition tasks (bottom panel). Error bars reflect one standard error for between-subject comparisons.

acted with task (local vs. global), $F(1,41) = 29.1$. When tested separately, the linear contrast was significant only for local recognition, $F(1,19) = 33.7, MSE = 63,728$, but not for global recognition ($F = 2.2$). Global recognition was characterized by a quadratic trend, $F(1,22) = 15.0, MSE = 85,156$. When the first output position was removed from the analysis, there was a linear *increase* in global recognition times over positions 2–5, which just failed to be significant, $F(1,22) = 4.3, MSE = 6,866$, $p = .051$. To summarize, there was a strong and steady decline in latencies over output position in the two tasks requiring memory for position. In the global recognition task, in contrast, latencies were largely constant or even increasing from the second to the last output position; the longer time at the first output position could reflect the time to switch from encoding to retrieval (c.f. Murdock & Anderson, 1975).

When analyzed by spatial position, the recall latencies showed an interaction between response correctness and serial position, which was captured by the quadratic contrast, $F(1,19) = 11.2, MSE = 39,389$. The latencies of correct responses were slower for middle positions than for end positions; no such trend was apparent for the incorrect responses (see Fig. 5, bottom panel). The advantage of correct recall at the two ends of the spatial row could be interpreted as an indication of edge effects, but the evidence is not particularly conclusive. The recognition data showed a slight increase in latencies from left to right positions, $F(1,41) = 4.8, MSE = 42,241$, which was carried exclusively by the local recognition data, although the interaction with task was not significant ($F = 2.5$). This effect mirrors the left–right gradient observed in the accuracy data.

Discussion

The goal of the experiments presented here was to analyze serial position effects in short-term recall and recognition. To this end I designed recognition tasks

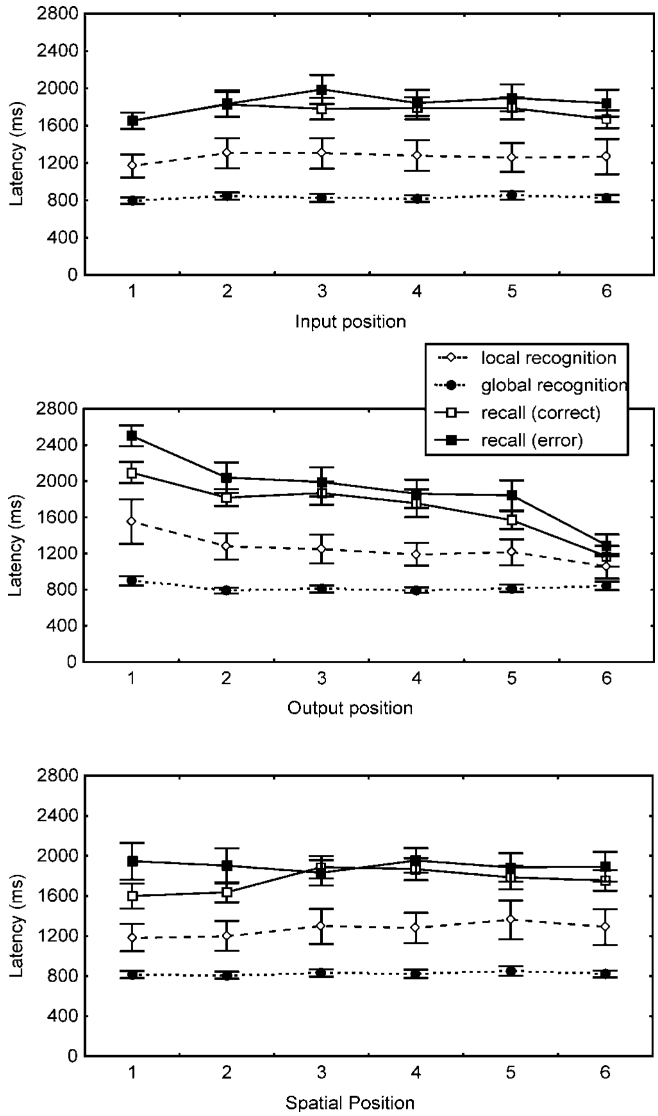

Fig. 5. Response latencies in the random presentation condition plotted over input position (top panel), output position (middle panel), and spatial position (bottom panel). Error bars reflect one standard error for between-subject comparisons.

that matched the serial recall paradigm with regard to the sequence of retrieval attempts (both recognition tasks) and the requirement for positional information (local recognition). The accuracy data from the serial presentation conditions showed remarkably similar serial position functions for all three tasks, with extended primacy and small recency effects. After correction for guessing, even the overall accuracy levels were comparable. This implies that the different serial position curves observed in forward serial recall and the Sternberg task have nothing to do with the difference between recall and recognition per se. They are most likely due to the fact that the Sternberg task involves only one retrieval attempt, whereas serial recall involves a sequence of retrieval attempts.

To my knowledge, the only other series of experiments comparing serial recall and serial recognition of items at individual positions was done by Avons (1998; Avons & Mason, 1999). These experiments used matrix patterns as items and tested each serial position by a forced-choice recognition task in forward serial order. In contrast to a serial recall task, no serial position effects were observed in the recognition task. Either the different kind of materials or the fact that forced-choice recognition was used could be responsible for the difference between Avons' and my results.

The random presentation condition provided a separation of serial position effects over the input, output, and memory dimension. This allows differentiating between several mechanisms proposed as explanations of position curves. In what follows, I first discuss how well these mechanisms can account for the accuracy data. The rightmost column of Table 1 summarizes for which mechanism the present experiments, taken together, provided supporting evidence (++) or evidence at least consistent with the mechanism (+). Following this, I will briefly discuss the latency results, and finally try to put the dissected sources of serial position effects back together to explain standard serial recall and recognition data.

Serial position effects on accuracy

The recency effects over input position in all three tasks can be explained by either input interference or decay. Both would be expected to affect earlier list items more than later ones and thereby generate a recency advantage. A distinctiveness account based on temporal context cues would also predict a recency effect over input position, but limited to memory for items. The recall and local recognition data, however, showed that the effect was also present in memory for the correct (spatial) position.

The primacy effect over input position can be explained by an automatic attentional gradient during encoding: Items presented first receive more attention and therefore are encoded better, even when presentation order is irrelevant for retrieval. No other mechanism discussed here provides a straightforward explanation for the primacy effect over input position, so the evidence for an attentional gradient must be regarded as quite compelling.

There was a strong primacy gradient over output position for all three tasks. It can be explained by either output interference or decay. A decrease of temporal distinctiveness over the time of output would predict a primacy effect over output order confined to item memory. In the recall task, as in local recognition, the effect was observed for order memory as well, creating a difficulty for a distinctiveness account.

There was little evidence for a recency effect over output position. This poses a problem for models incorporating response suppression, because this mechanism should generate a small advantage for items retrieved last. One reason for the absence of this recency effect could be that in my experiment a relatively large pool of items (20 consonants) was used, and overall performance was relatively low. The recency effect generated by response suppression relies on a gradual reduction of the candidate set for recall over successive outputs, such that toward the end of recall the remaining items in the set are the ones to be recalled in the remaining positions. If recall is not successful at the beginning of the output sequence, the candidate set will not be narrowed down to the correct rest, and if the pool of items is larger than the list, extralist items might easily intrude into the candidate set. Simulations will be needed to determine whether response suppression would still predict a recency effect under these conditions. Lewandowsky (1999) showed that it does not when lists are very long and performance comes close to floor level.

When looking at the position curves over the memory dimension (i.e., the spatial dimension), a first surprising observation is the complete absence of "recency" effects, that is, elevated accuracy at the right end of the row. Both a distinctiveness mechanism based on a non-temporal context vector and every mechanism generating edge effects would predict higher accuracy at both ends for recall and local recognition, because these tasks rest on accurate memory for spatial position. This pattern was indeed observed by several authors (Anderson, 1976; Healy, 1975a; Nairne & Dutta, 1992). A reason why it was absent here could be that the increase of performance toward the right side was masked by the overall trend of decreasing accuracy from left to right. The present data, therefore, do not rule out edge effects or non-temporal context vectors, but if they were effective, the serial position effects they generated must have been relatively weak.

The most conspicuous aspect of these data is the large "primacy" effect over spatial position that was confined to the two tasks requiring memory for position. The idea of an attentional gradient or an associative chain set up intentionally from left to right could provide an explanation for this pattern. Direct evidence for intentional control over the primacy gradient comes from a study by Duncan and Murdock (2000) who showed that the primacy effect in forward serial recall is reduced when participants expect a (global) recognition instead of a recall task during list encoding. Furthermore, a study by Glanzer and Dolinsky (1965) showed that the primacy effect can be manipulated by instructions about the locus of the start point in a cyclically presented list.

One way to intentionally set up a spatial primacy gradient would be to rehearse items from left to right as soon as they have been presented, thus setting up a rehearsal loop that captures the spatial order of items in its temporal order. Alternatively, one could rehearse items selectively during presentation only if no position to the left of them is still empty. Thus, the left-most item will be rehearsed immediately after being presented, whereas items farther to the right will have to wait until the slots to their left are filled. This strategy would give items on the left side more rehearsal on average, and if each rehearsal increases an item's activation, this would set up an activation gradient from left to right.

The recall latencies, however, qualify this interpretation. If participants somehow set up an association chain or an activation gradient from left to right to encode spatial order, they would have to go through the sequence from left to right to recall any particular item. Thus, recall latencies should increase from left to right. This was obviously not the case for the recall data (see Fig. 5, bottom panel). It might still be that participants set up an attentional gradient from left to right during encoding, but they apparently did not use it to reconstruct the left–right order during recall in a way akin to the Primacy Model (Page & Norris, 1998).

Serial position effects on latencies

If recall latencies reflect the same parameter as accuracy (say, an item's "strength" or its accessibility in a given retrieval context), one would expect the two to go hand in hand. In several analyses, however, latencies and accuracies diverged (compare Figs. 3 and 5). As just mentioned above, the marked drop in performance from left to right in recall accuracy was not matched by the corresponding latencies. The divergence of accuracy and latency was even more dramatic over the output dimension. Accuracy dropped over output position, whereas speed of recall and of local recognition increased.

A related observation was reported by Murdock and Anderson (1975, Exp. VI) in a global recognition experiment using several consecutive probes. Latencies decreased over output position for memory lists of four words, but increased over output position for lists with eight words or more. The present experiment used a list length intermediate between four and eight, and the latency data showed a pattern similar to the short lists of Murdock and Anderson (1975) when local recognition was required, but an "intermediate" pattern, with possibly a trend for latencies to increase over output position, for global recognition. Following Murdock and Anderson (1975), we could assume that decreasing latencies over output position reflect retrieval from active or working memory, whereas increasing latencies over output position reflect retrieval from long-term memory. The present data then would imply that local recognition, and probably also recall, rely more on working memory, whereas global recognition relies more on long-term memory.

This interpretation fits well into the dual-process view of short-term recognition, proposed elsewhere (Oberauer, 2001): Local recognition has to rely on explicit recollection of the occurrence of an item at a specific location, which rests on working memory representations of the current items at each spatial position. With each output position, one such representation can be removed from working memory, thereby reducing the load on its limited capacity and increasing the speed of further retrievals. Global recognition, on the other hand, can rely largely on the activation of representations of list elements in long-term memory. If activation declines over time, this would lead to an increase of latencies over output positions, because the activation difference between list items and foils declines as well, making it harder to distinguish them.

Such an interpretation, however, is highly speculative, and there is a certain tension between the idea that already tested memory representations can quickly be removed from working memory on the one hand, and the lack of evidence for response suppression in the accuracy data noted above, on the other hand. This tension is probably one specific manifestation of the discrepancy between latency and accuracy data observed here and elsewhere, which certainly deserves more attention in future research.

Re-integrating serial position curves

The present paradigm with randomized input and output order provides a tool to dissect serial position effects. It deviates considerably from standard short-term memory tasks, however, and it is not granted that the mechanisms generating serial position effects in my experimental paradigm would operate in the same way in a task with traditional procedures. In this section I explore to what degree the sources of serial position curves identified in the experiment help understanding the serial position curves typically found in recognition, serial recall, and probed recall.

Recognition in the Sternberg paradigm and probed recall typically show large recency and small primacy effects. The recency effect can be explained by retroactive interference or decay during encoding. The primacy effect could be due to an automatic attentional gradient providing increased activation to the first item presented. Output interference plays no role in these paradigms, because there is typically only one recall attempt for each list.

Serial recall in forward order shows a large primacy effect and relatively small recency. The larger primacy effect compared to the other paradigms can be attributed to two sources. One is output interference—the items at the end of the list are recalled last and therefore suffer interference (or decay) during output. The other is due to an encoding strategy that introduces an intentional primacy gradient (in addition to the automatic gradient) or chaining to represent the order information required in this paradigm.

Backward serial recall shows larger, recency and smaller primacy than recall in forward order. This difference can in part be attributed to output interference—now the primacy items are those output last and suffering most interference from output. Encoding strategies, however, also seem to play a role because the shift from primacy to recency with backward recall sometimes disappears when recall direction is cued only after list presentation (Neath & Crowder, 1996; but see Li & Lewandowsky, 1993). This suggests that the intentional primacy gradient is implemented only when participants expect forward recall, because it is much less helpful for backward recall.

The recency effect in forward serial recall is still difficult to explain. If retroactive interference is equally strong during input and output, the recency advantage generated by input interference should be neutralized by output interference, because the number of items intervening between encoding and recall is constant for all serial positions. One could explain recency as a net effect of retroactive interference if encoding produces more interference than recall. This is a plausible assumption given that participants will try to actively encode presented items but not items they produced during recall. In the present data, however, the effect presumably reflecting output interference—the primacy effect over output position—is remarkably strong, whereas the effect attributed to input interference—the recency effect over input position—is comparatively weak (compare the top and middle panels of Fig. 3). An account based on temporal decay or temporal distinctiveness faces a similar problem. These accounts can predict a residual recency effect if recall proceeds faster than encoding, because in this case the temporal distance between encoding and recall is shorter for the last list item than for earlier list items. In the present data, however, presentation of six items took 3 s, whereas recall of the first five items already took about 5 s in the serial presentation condition (see Fig. 4, top panel). Thus, the temporal distance between encoding and recall was largest for the last item, which would thereby have suffered the largest amount of decay and the largest decline in distinctiveness.

Another potential explanation for recency could be response suppression. The present data, however, contain no evidence for response suppression, so its contribution must be doubted at least for the conditions realized here. We might speculate, however, that response suppression plays a role nonetheless, but this role is limited to conditions allowing retrieval in forward serial order (i.e., the serial presentation order in my experiment).

In fact, several pieces of evidence in the present data suggest that there is a special mechanism for the short-term retention of forward serial order, at least for verbal material. First, overall recall accuracy was much better with serial than with random presentation order. A general mechanism to form associations between items and their positions (e.g., item-context associations as in Burgess & Hitch, 1999, or the perturbation model of Estes, 1972) would not predict this, because it should not matter whether items are associated with temporal or with spatial positions. Second, two mechanisms for which the data provided evidence—the attentional gradient set up during encoding, and chaining of successively presented items—are suited to remember the serial order of presentation but not any arbitrary order information such as spatial order. These mechanisms apparently operate to some degree even when they are not functional, since a primacy gradient over input position was observed even in global recognition.

Specialized mechanisms such as chaining or an automatic activation gradient could work in addition to a more general, but less powerful mechanism that records item-context links for arbitrary contextual representations (e.g., spatial positions). If response suppression is part of the specific mechanism for remembering input serial order, it might operate in forward serial recall tasks but not in the random presentation condition. One prediction of this speculation is that another empirical signature of response suppression—the failure to recall repeated items in a list (Henson, 1998a)—would also be absent in a random presentation condition.

Taken together, the present results clearly support the hypothesis of an attentional gradient as one source of the primacy effect in serial recall. A second factor is responsible for both primacy and recency effects in recall as well as recognition; most likely this factor is retroactive interference or decay during input and output. Temporal distinctiveness accounts have difficulties to explain primacy and recency effects on memory for order in the present paradigm. No support was found for response suppression as an explanation of recency, and there was also little evidence for a contribution of non-temporal distinctiveness and of edge effects to serial position curves.

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