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Output order in immediate serial recall

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Abstract

Two experiments examined the effect of output order in immediate serial recall (ISR). In Experiment 1, three groups of participants saw lists of 8 words and wrote down the words in the rows corresponding to their serial positions in an 8-row response grid. One group was pre-cued to respond in forwards order, a second group was pre-cued to respond in any order, and a third group was post-cued for response order. There were significant effects of output order but not of cue type. Relative to the forwards output order, the free output order led to enhanced recency and diminished primacy, with superior performance for words output early in recall. These results were replicated in Experiment 2 using 6-item lists, which further suggests that output order plays an important role in the primacy effect in ISR, and that the recency items are most highly accessible at recall.

146 words 877 characters

In the immediate serial recall (ISR) task, participants are presented with sequences of digits, letters or words and immediately after the last item has been presented, must try to recall as many of the items as possible in the correct serial order. With very short lists, performance on the task is near-perfect, but as the list length is increased so performance breaks down in a characteristic manner: there are extended primacy effects (superior recall of early items) and limited recency effects (superior recall of terminal items). These large primacy effects are rather distinctive because performance in many other immediate memory tasks (such as sequential probed recall and cued recall) typically lead to recency-dominated serial position curves. The resulting serial position curve in ISR has become a fundamental empirical finding that must be explained by all models of ISR.

Primacy effects have been modelled in a number of different ways. Many models assume that the encoding or activation strength of successive list items decreases over serial positions, such that items in early input positions have greater activations than subsequent items. In some models, this is the primary cause of primacy effects (e.g., Farrell & Lewandowsky, 2002; Lewandowsky, 1999; Page & Norris, 1998). For example, in Page and Norris's (1998) primacy model, the result of the greater activation of the earlier items is a primacy gradient. During recall, the most active item, usually the first presented item, is first chosen for recall and then suppressed. Following this, the item with the next highest activation is recalled and suppressed, and so on. The primacy gradient decays exponentially over time, and at recall this produces a steep primacy effect.

In other models, item selection at recall is not based directly on the items' activation strengths, but indirectly through positional, temporal or contextual markers (e.g., Brown, Preece & Hulme, 2000; Burgess & Hitch, 1999; Henson, 1998). Nevertheless, many of these models similarly incorporate some form of primacy gradient. In Henson's (1998) Start-End Model (SEM), for example, each item is stored in memory as a token containing information about the item's position relative to the start and end of a list. During retrieval, items are cued by reinstating the positional markers for each item and comparing the overlap in positional information between the cue and the tokens in memory. Primacy and recency effects are produced mainly because the positional markers have a greater positional distinctiveness at the start and end of a list. In addition, the start marker is more distinctive than the end marker, leading to a larger primacy than recency effect.

A third class of short-term memory model is based on the idea of the temporal or contextual distinctiveness of list items (Brown, Neath & Chater, 2002; Glenberg & Swanson, 1986). In these models, items in memory are thought to be situated along a temporal or contextual continuum, and recall is considered to be a process of discrimination along this continuum. The discriminability, and hence retrievability, of these items is a function of the inter-item interval and the retention interval. According to one such implementation, the scale-invariant memory, perception and learning (SIMPLE) model (Brown et al., 2002), the primacy effect in ISR is mainly the result of the shifting temporal perspective which occurs during recall. This changing perspective leads to a greater effective retention interval for the recency items compared to the primacy items, and hence an extended primacy effect.

An alternative (or in some cases, additional) source of primacy is produced through output interference. According to one interpretation of output interference, the recall of an item in a list has a negative effect on the recall of the other list items. However, other interpretations exist. For example, the feature model (Nairne, 1988, 1990) assumes that recall involves the sampling and recovery of items in memory, and that the probability of recovering a sampled item decreases as the number of prior recoveries increases. Recall in ISR tasks typically occurs in forwards serial order, such that the early items are subject to less output interference than the later items, and this leads to a primacy effect. Although this is called “output interference” in these accounts, it could arguably be thought of as a form of response suppression. In the oscillator-based associative recall (OSCAR) model of Brown et al. (2000), primacy effects can potentially arise as a result of both output interference as well as the decrease in encoding strength across list items.

There is some empirical evidence that the primacy effect in ISR may in fact largely be due to output interference (Cowan, Saults & Brown, 2004; Cowan, Saults, Elliott & Moreno, 2002). Cowan et al. (2002) pointed out that in the typical ISR task, three factors are confounded: input serial position, output position, and response set size. They therefore developed a technique aimed at deconfounding these factors. In their method, lists of nine digits were presented and recall began at input serial position 1, 4 or 7. On the partial-report trials, participants had to stop after recalling three digits, whereas on the whole-report trials, participants had to cycle back to the beginning of the list and continue until all nine responses had been made. Cowan et al. (2002) found that when input serial position and output position were deconfounded in this way, the input serial position curves obtained showed larger recency effects than primacy effects. In an investigation of the modality effect in ISR, Beaman (2002) also manipulated the order in which participants were required to output items at test. Some participants had to perform standard forwards serial recall, beginning recall from the start of the list, whilst others were required to begin recalling (in forwards serial order) the second half of the list before the first half of the list. A much larger primacy effect was obtained with forwards serial recall from the beginning of the list, whereas beginning recall from the second half of the list led to a much more extensive recency effect. A similar manipulation of recall order by Posner (1964) also resulted in greater recency than primacy effects. Finally, Oberauer (2003) demonstrated that when the effects of input order, output order and spatial order were examined separately, a large primacy effect was obtained only when recall performance was plotted by output position. These studies suggest that output interference may indeed be responsible for the extensive primacy effects and relatively modest recency effects normally found in ISR.

There are, however, a number of potential problems with these experiments. Firstly, the requirement to start recalling from different serial positions may lead to participants using different strategies from those normally occurring in “standard” ISR. Furthermore, different encoding strategies may also be used depending on the particular portion of the list from which participants are required to start recalling. Secondly, even when the starting point is post-cued such that encoding strategies are likely to be similar across different output conditions (as in the Cowan et al., 2002 study), no direct comparison is usually made with performance in a standard pre-cued ISR condition in which participants always recall in standard forwards order (although see Beaman (2002) for an exception). Finally, by assigning participants with a start position, it is impossible to tell from which point participants would choose to output if they were not so constrained. These latter data might provide an insight as to which items are most accessible or discriminable at time of test.

The present experiments sought to investigate these issues further by using both standard forwards output ISR, as well as the free position recall technique used by Crowder (1969). In our technique, participants are free to write down the list items in any order they choose at test, as long as their ultimate written position corresponds with the order in which the items were presented. Using this technique, it is possible to gain an insight as to which items are the most easily accessible at time of test. If the extended primacy effects typically observed in standard ISR reflect the greater accessibility of early list items at test, then participants in the free output order might continue to output the early items first, and the serial position curve under free output conditions may be relatively unaffected. If, however, the recency items are the most highly accessible at test, then when participants are free to choose their order of output at recall, they might be expected to output the recency items before the primacy items, and this might lead to serial position curves with larger recency than primacy effects. In addition, the present experiment uses a pre-cue and post-cue technique, in which participants are told to begin recall in strict forwards order, or in any order, either before the start of the list (pre-cue) or only at the end of the list (post-cue). The reason for using a pre-cue/post-cue technique was to determine whether any differences in the serial position curves which might be found in the two output order conditions were due to strategic factors occurring at encoding. If any differences in the serial position curves in the two output order tasks for the pre-cue condition are maintained in the post-cue condition, it suggests that these differences could not be due to differences occurring at encoding, because the curves are unaffected by whether participants know in advance which output order will be required. Rather, any differences in the serial position curves are likely to be due to differences occurring at retrieval (such as differences in output strategies) between the two output order tasks.

Experiment 1

In Experiment 1, three groups of participants viewed 32 lists of 8 words for tests of immediate serial memory. One group knew in advance that they would always perform standard ISR with forwards output: they saw 8 words, one at a time, and at the end of the list had to write down the words in strict forwards order in an 8-row response grid. A second group knew in advance that they would always perform ISR with free output; that is, they viewed the words as before, but at the end of the list they had to write down the words in their correct serial position in the 8-row response grid, but were free to write down their responses in any order. A third group viewed the lists in the same way as the two other groups, but during the encoding of each trial they did not know which of the two output order conditions they would be tested with. On a random half of the trials, the participants were post-cued to respond in strict forwards order (as in group 1), whereas on the remaining trials participants were post-cued to respond freely (as in group 2) in any order in the response grid.

Method

Participants. Forty-eight students from the University of Essex participated in this experiment.

Materials. The materials were selected from the Toronto Word Pool (Friendly, Franklin, Hoffman & Rubin, 1982) and consisted of 272 nouns with frequencies of occurrence of 10-50 per million based on the Kucera & Francis (1967) norms. From this word pool, 32 experimental lists of 8 words per list were constructed. Participants in each of the two pre-cue conditions received 32 lists, either for forwards or free output. Participants in the post-cue condition received 16 lists for forwards output and 16 lists for free output. Words were randomly selected for each participant. Two additional practice lists of 8 words were similarly generated. No participant received the same word twice during the experiment. The materials were presented using the application Supercard on an Apple Macintosh computer.

Design. The experiment used a mixed design. Serial position was always a within-subjects factor (8 levels: serial positions 1-8). Cue type (2 levels: pre-cued and post-cued) was a between-subjects factor. Output order (forwards or free) was manipulated both within- and between-subjects.

Procedure. Participants were randomly divided into 3 groups of 16 and were tested individually. The 3 groups were the pre-cued forwards output order group, the pre-cued free output order group, and the post-cued group, who received both forwards and free output orders.

In all four conditions, each list began with a warning tone and a visual pre-list cue, followed after 3 seconds by a series of 8 words presented visually one at a time in the centre of the computer screen at a rate of 2 seconds per word (1 second on, 1 second off). Participants were instructed to read aloud each word as it was presented. A series of beeps and a visual post-list cue signalled the beginning of the recall period. Participants were given 30 seconds to write down their responses on a numbered response grid. They were not required to indicate blanks for items they could not recall. They were also told to vocalise their responses as they wrote them down. These were tape recorded for subsequent analysis.

The pre-list and post-list cues in the pre-cued forwards output condition were the words “Same order”, indicating that participants were to write down the words in the same order in which they had been presented. (Participants were allowed to begin recalling from any serial position as long as recall was performed in strict forwards order, i.e., they were not allowed to go back to fill in previous blanks in the response grid.) The pre-list and post-list cues in the pre-cued free output condition were the words “Any order”, indicating that participants could write down the words in any order, as long as each word was written in the same position in which it had been presented, i.e. the first word presented was to be written on line 1 of the numbered response grid, etc. In the post-cued condition, the pre-list cue was the string “?????????”, and the post-list cue was either “Same order” or “Any order” depending on the relevant output condition, which was randomly determined.

Results

On a small minority of trials (between 0.8% and 2%, depending on condition), participants failed to obey instructions by either not following a strict forwards order output strategy (in the forwards output order conditions), or not verbalising all their responses, such that the output order of the recalled words could not be determined (in the free output order conditions). These trials were eliminated from subsequent analyses.

An item was scored as correct only if it was written in the correct position in the 8-row response grid. The mean proportion of correct responses for each condition are plotted in Figures 1A and 1B, and are replotted in Figures 1C and 1D to aid comparison.

Effect of Output Order

Pre-cued conditions. The proportions of items recalled at each serial position for the pre-cued forwards and free output orders are shown in Figure 1A. A 2 (Output order: forwards or free) x 8 (Serial positions: 1 to 8) between-subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(7, 210) = 33.59$, $MSE = .576$, $p < .0001$, and a significant interaction between output order and serial position, $F(7, 210) = 38.69$, $MSE = .664$, $p < .01$. Simple main effects revealed a significant effect of output order at serial positions 1, 2 and 6-8 (all *p*s < .0001). Inspection of Figure 1A shows a larger primacy effect in the forwards output order condition and a larger recency effect in the free output order condition. There was a significant primacy effect in the forwards output condition, and significant primacy and recency effects in the free output condition. Tukey's honestly significant difference (HSD) pairwise comparisons revealed that in the forwards output condition, there were significant differences between serial position 1 and all other serial positions (all *p*s < .001), between serial position 2 and serial positions 4-8 (all *p*s < .05) and between serial position 3 and serial position 6 ($p < .05$). In the free output condition, there were significant differences between serial position 1 and serial positions 3 and 4 ($p < .05$), between serial positions 2-4 and serial position 6 (all *p*s < .05) and between serial positions 1-6 and serial positions 7 and 8 (all *p*s < .001).

--Figure 1 about here--

<u>Post-cued conditions.</u> The proportion of items recalled at each serial position for the post-cued forwards and free output orders is shown in Figure 1B. A 2 (Output order: forwards or free) x 8 (Serial positions: 1 to 8) within-subjects ANOVA was performed. This revealed a significant main effect of output order, $F(1, 15) = 69.13$, $MSE = .551$, $p < .0001$, and serial position, $F(7, 105) = 18.63$, $MSE = .703$, $p < .0001$. The interaction between output order and serial position was also

significant, $F(7, 105) = 22.07$, $MSE = .303$, $p < .0001$. Simple main effects revealed a significant effect of output order at serial positions 1 and 6-8 (all *p*s < .05). Inspection of Figure 1B shows that, as in the pre-cued conditions, there is greater primacy in the forwards output order condition and greater recency in the free output order condition. There was a significant primacy effect in the forwards output condition, and significant primacy and recency effects in the free output condition. Tukey's HSD revealed that in the forwards output condition, there were significant differences between serial position 1 and all other serial positions (all *p*s < .05), and between serial position 2 and serial position 7 ($p < .05$). In the free output condition, there were significant differences between serial position 1 and serial positions 3-6 (all *p*s < .01) and 8 ($p < .05$), between serial position 7 and serial positions 3-6 (all *p*s < .05), and between serial position 8 and all other serial positions (all *p*s < .05).

Effect of Cue Type

Forwards output order. The proportion of items recalled at each serial position for the forwards output order conditions are replotted in Figure 1C for ease of comparison. A 2 (Cue type: pre-cued or post-cued) x 8 (Serial positions: 1 to 8) between subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(7, 210) = 39.04$, $MSE = .834$, $p < .0001$, but not of cue type ($p > .05$). Tukey's HSD tests revealed significant differences between serial position 1 and all other serial positions (all *p*s < .001), between serial position 2 and all other serial positions (all *p*s < .05), between serial positions 3 and 6 ($p < .05$), and between serial position 8 and serial positions 6 ($p < .01$) and 7 ($p < .05$). The cue type *x* serial position interaction was not significant ($F < 1$).

Free output order. The proportion of items recalled at each serial position for the free output order conditions are also replotted in Figure 1D. A 2 (Cue type: pre-cued or post-cued) x 8 (Serial positions: 1 to 8) between subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(7, 210) = 61.21$, $MSE = 1.319$, $p < .0001$, and a significant interaction between cue type and serial position, $F(7, 210) = 3.90$, $MSE = .084$, $p < .001$. Simple main effects revealed a significant effect of cue type at serial positions 6 and 7 (*p*s < .01). Tukey's HSD revealed that in the pre-cued condition, there were significant differences between serial position 1 and serial positions 3, 4, 7 and 8 (all *p*s < .01), between serial positions 3 and 4 and serial position 6 (*p*s < .01), and between serial positions 7 and 8 and all other serial positions (all *p*s < .001). In the post-cued condition, there were significant differences between serial position 1 and serial positions 2-6 and 8 (all *p*s < .05), between serial position 2 and serial positions 4 ($p < .05$) and 8 ($p < .001$), between serial position 7 and serial positions 3-6 (all *p*s < .001), and between serial position 8 and all other serial positions (all *p*s < .001). Inspection of Figure 1D indicates a somewhat larger recency effect in the pre-cued condition compared to the post-cued condition.

Analysis of Output Order

The number of correct responses for each serial position and output order condition are shown in Tables 1 (forwards output) and 2 (free output). Inspection of the tables indicates that the free output and forwards output conditions differ in the order in which items are output. In the free output conditions, participants are most likely to start recalling from the later serial positions, whereas in the forwards output conditions, participants are most likely to start recalling from the early serial positions. This provides evidence that the differences found in the serial position curves across the two output order conditions are indeed due to differences in the order in which list items are output. Items that are output early are associated with higher recall probabilities than items that are output later.

--Table 1 about here--

--Table 2 about here--

Further analyses were performed to examine the most common sequences of responses. We report the two most common correct starting sequences up to a maximum sequence length of 4. In the pre-cued forwards condition, these output sequences were 1234 and 1 (21% and 20% of all correct sequences respectively). In the pre-cued free output condition, these were 5678 and 8 (12% and 9% of all correct sequences respectively). In the post-cued forwards condition, these sequences were 1 and 12 (21% and 14% of all correct sequences respectively). Finally, in the post-cued free condition, the most common sequences came from both the end and the beginning of the list, and were 8 and 1234 (13% and 7% of all correct sequences respectively).

--Figure 2 about here--

Figure 2 plots, for each condition, the number of correct responses at each output position as a proportion of the total number of correct responses for that condition. This was done in order to examine the effect of output position whilst controlling for the absolute level of recall across conditions. The figure shows that this proportion decreases steadily as output position increases, and that the rate of decrease is approximately similar across all conditions: between 80% to 86% of all correct responses are made within the first four output positions.

Analysis of Errors

Following Maylor, Vousden and Brown (1999), errors were classified into 3 categories: movements, omissions or intrusions. A movement error was recorded whenever a list item was recalled in an incorrect position in the 8-row response grid. An omission error was recorded whenever a line on the response grid was left blank. An intrusion error was recorded whenever an extra-list item was recalled. Intrusion errors constituted a very small percentage (between 1.7% and 2.5%) of the total responses and we will therefore concentrate on the movement and omission errors.

The movement and omission errors were analysed as proportions of the total number of responses at each serial position, and are shown for each serial position for the forwards output order conditions (Figure 3A) and for the free output order conditions (Figure 3B).

--Figure 3 about here--

Movement errors

Forwards output order. A 2 (Cue type: pre-cued or post-cued) x 8 (Serial position: 1 to 8) ANOVA was conducted. There was a significant main effect of serial position, $F(7, 210) = 32.34$, $MSE = .233$, $p < .0001$, but the effect of cue type and the cue-type *x* serial position interaction were not significant ($F < 1$). Tukey's HSD pairwise comparisons on the main effect of serial position revealed significant differences between serial position 1 and serial positions 3-8 (all *p*s < .01), between serial position 2 and serial positions 4-8 (all *p*s < .001), between serial position 3 and serial positions 5-8 (all *p*s < .05), and between serial position 4 and serial positions 5 and 6 (*p*s < .05). Figure 3A shows a steady increase in the proportion of movement errors up to serial position 5. Appendix A1 details the full distribution of responses across all serial positions for both the forwards and free output order conditions.

Free output order. A 2 (Cue type: pre-cued or post-cued) x 8 (Serial position: 1 to 8) ANOVA was conducted. There was a significant main effect of serial position, *F*(7, 210) = 17.36, *MSE* = .125, $p < .0001$, but the effect of cue type and the cue-type *x* serial position interaction were not significant ($F < 1$). Tukey's HSD tests on the main effect of serial position revealed significant differences between serial position 1 and serial positions 3-7 (all *p*s < .05), between serial position 2 and serial positions 4-6 (all *p*s < .001), between serial position 3 and serial position 6 ($p < .001$), between serial positions 6 and 7 ($p < .001$), and between serial position 8 and serial positions 3-6 (all *p*s < .05). Figure 3B shows an increase in the proportion of movement errors up to serial position 6, followed by a decrease at serial positions 7 and 8.

<u>Omission errors</u>

<u>Forwards output order</u>. A 2 (Cue type: pre-cued or post-cued) x 8 (Serial position: 1 to 8) ANOVA was conducted. There was a main effect of cue type, *F*(1, 30) = 4.43, *MSE* = .390, $p < .05$, due to a slightly greater proportion of omissions in the post-cued condition than the pre-cued condition and a significant main effect of serial position, *F*(7, 210) = 12.46, *MSE* = .290, $p < .0001$, but the cue-type *x* serial position interaction was not significant ($F < 1$). Figure 3A shows that omissions increase up to serial position 4 and remain relatively constant thereafter. Tukey's HSD pairwise comparisons on the main effect of serial position revealed a significant difference between serial position 1 and all other serial positions ($p < .001$), and between serial positions 4 and 8 ($p < .05$).

<u>Free output order.</u> A 2 (Cue type: pre-cued or post-cued) x 8 (Serial position: 1 to 8) ANOVA was conducted. There was a non-significant main effect of cue type ($p > .05$), a significant main effect of serial position, *F*(7, 210) = 48.77, *MSE* = 1.01, $p < .0001$, and the cue-type *x* serial position interaction was also significant,

F(7, 210) = 4.27, *MSE* = .088, $p < .001$. Simple main effects revealed a significant effect of serial position at serial positions 5-7 (all *p*s < .05). Tukey's HSD revealed that in the pre-cued condition, there were significant differences between serial position 6 and all other serial positions (all *p*s < .05), and between serial positions 7 and 8 and serial positions 1-6 (all *p*s < .05). In the post-cued condition, there were significant differences between serial position 1 and serial positions 3-5 and 8 (all *p*s < .05), between serial position 4 and serial position 6 ($p < .05$), between serial position 7 and serial positions 2-5 and 8 (all *p*s < .01), and between serial position 8 and all other serial positions (all *p*s < .01). Figure 3B shows a large decrease in omissions across serial positions 5-8.

Discussion

There are three primary findings from Experiment 1. First, when participants are given the choice of which items to output at the point of recall, the majority of their initial responses come from items from the later input serial positions. It is argued that this differential output strategy has an effect on the shape of the serial position curve, with reduced primacy and increased recency effects in the free output order conditions. Second, the fact that similar patterns of recall were obtained in both the pre- and post-cued conditions suggests that participants used similar, or at least compatible, strategies at encoding for the two output order conditions. There was, however, some difference in the most common initial output sequences between the pre- and post-cued free output conditions. Finally, the proportion of the total number of correct responses was found to decrease steadily with output position (Figure 2), with little differences in the slope and shape of this function across all four conditions. This further points to the importance of a word's output position during recall.

Secondary analyses on the patterns of errors (Figure 3) revealed that across all four conditions, movement errors increased with serial position, reaching a maximum of approximately 20% at serial position 6, and then decreasing thereafter (with this decrease being more pronounced in the free than the forwards output order conditions). Omission errors were more frequent than movement errors, reaching a maximum of approximately 50-60% at serial position 4. In contrast to the similarities in the patterns of movement errors, there were large differences in the patterns of omissions across the forwards and free output conditions. In the forwards output condition, omissions generally increased over the first four serial positions and then remained at a relatively high level thereafter. However, omission errors in the free output condition showed only a slight increase over the first four serial positions, and decreased markedly towards the end of the list.

When the error patterns in Figure 3 are considered in conjunction with the recall patterns in Figures 1C and 1D, it can be seen that the decrease in recall over the early serial positions present in all the curves reflects an increase in both movement and omission errors over the first four serial positions. By contrast, the differences in the magnitude of the recency effects across the four conditions in Figures 1C and 1D largely reflects differences in the levels of omission errors over the later serial positions.

Experiment 2

One possible limitation of Experiment 1 was that the 8-item lists that we used were relatively long. Some researchers have claimed that data generated using longer lists might not generalise to that generated using shorter lists, since only data collected with shorter lists (typically 5 or 6 items) might make use of specialised short-term or working memory mechanisms (e.g., Baddeley, 2000; Baddeley & Larsen, 2003; Hanley & Bakopolou, 2003; Larsen & Baddeley, 2003; Page & Norris, 1998). Hence, it was decided to replicate Experiment 1 with shorter lists of 6 items.

Method

Participants. Forty-eight students from the University of Essex participated in this experiment. None had taken part in Experiment 1.

Materials. The materials were identical to those used in Experiment 1, except that lists of 6 words (instead of 8) were constructed for each participant.

Design. The experiment used a mixed design. Serial position was always a within-subjects factor (6 levels: serial positions 1-6). Cue type (2 levels: pre-cued and post-cued) was a between-subjects factor. Output order (forwards or free) was manipulated both within- and between-subjects.

Procedure. The procedure was identical to that of Experiment 1, with the sole exception that participants were presented with lists of 6 words.

Results

As in Experiment 1, a small number of trials (between 0.2% and 1.2%) were eliminated from subsequent analyses because participants failed to comply with instructions.

An item was scored as correct only if it was written in the correct position in the 6-row response grid. The mean proportion of correct responses for each condition are plotted in Figures 4A and 4B, and are replotted in Figures 4C and 4D to aid comparison.

Effect of Output Order

Pre-cued conditions. The proportion of items recalled at each serial position for the pre-cued forwards and free output orders are shown in Figure 4A. A 2 (Output order: forwards or free) x 6 (Serial positions: 1 to 6) between-subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(5, 150) = 15.60$, $MSE = .297$, $p < .0001$, and a significant interaction between output order and serial position, $F(5, 150) = 14.30$, $MSE = .272$, $p < .0001$. Simple main effects revealed a significant effect of output order at serial positions 1 and 4-6 (all *p*s < .05). Inspection of Figure 4A shows a larger primacy effect in the forwards output order condition and a larger recency effect in the free output order condition. Tukey's HSD revealed that in the forwards output condition, there were significant differences between serial position 1 and all other serial positions (all *p*s < .05) and between serial position 2 and serial positions 4-6 (all *p*s < .05). Significant primacy and recency effects were found in the free output condition. There were significant differences between serial position 1 and 3 ($p < .01$), between serial positions 3 and 5 ($p < .01$), and between serial position 6 and serial positions 2-4 (all *p*s < .001).

--Figure 4 about here--

Post-cued conditions. The proportion of items recalled at each serial position for the post-cued forwards and free output orders is shown in Figure 4B. A 2 (Output order: forwards or free) x 6 (Serial positions: 1 to 6) within-subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(5, 75) = 18.00$, $MSE = .523$, $p < .0001$. The interaction between output order and serial position was also significant, $F(5, 75) = 10.72$, $MSE = .193$, $p < .0001$. Simple main effects revealed a significant effect of output order at serial position 6 ($p < .01$). Inspection of Figure 4B shows that, as in the pre-cued conditions, there is greater primacy in the forwards output order condition (although this difference is not statistically significant, $F < 1$) and greater recency in the free output order condition. Tukey’s HSD revealed that in the forwards output condition, there were significant differences between serial position 1 and serial positions 3-6 (all *p*s < .001) and between serial position 2 and serial positions 4-6 (all *p*s < .05). Significant primacy and recency effects were found in the free output condition. There were significant differences between serial position 1 and serial positions 3 and 4 (ps < .01), and between serial position 6 and serial positions 3-5 (all ps < .01).

Effect of Cue Type

Forwards output order. The proportion of items recalled at each serial position for the forwards output order conditions are replotted in Figure 4C for ease of comparison. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial positions: 1 to 6) between subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(5, 150) = 46.26$, $MSE = .837$, $p < .0001$, but not of cue type ($F < 1$). The cue type *x* serial position interaction was also not significant ($F < 1$). There was an extended primacy effect and a one-item recency effect. Tukey's HSD pairwise comparisons on the main effect of serial position revealed significant differences between serial position 1 and all other serial positions (all ps < .001), between serial position 2 and all other serial positions (all ps < .001), between serial position 3 and serial positions 4 and 5 (ps < .05), and between serial position 5 and serial position 6 ($p < .05$).

Free output order. The proportion of items recalled at each serial position for the free output order conditions are also replotted in Figure 4D. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial positions: 1 to 6) between subjects ANOVA was performed. This revealed a significant main effect of serial position, $F(5, 150) = 16.14$, $MSE = .395$, $p < .0001$. There was no main effect of cue type and the cue type *x* serial position interaction was non-significant (both ps > .05). There were significant primacy and recency effects. Tukey's HSD tests on the main effect of serial position revealed significant differences between serial position 1 and serial positions 2-4 (all *p*s < .05), between serial position 3 and 4 and serial position 5 (*p*s < .05), and between serial position 6 and serial positions 2-5 (all *p*s < .01).

Analysis of Output Order

The number of correct responses for each serial position and output order condition are shown in Tables 3 (forwards output) and 4 (free output). As expected for the forwards output conditions, most of the initial output responses were of items from the early serial positions. In addition, in the free output conditions, as found in Experiment 1, the majority of initial output responses were from the later serial positions (e.g., in output position 1 of the pre-cued condition, there were 188 words from serial position 1 compared to a total of 270 words from serial positions 4-6). However, one noticeable difference is that in Experiment 2, there appears to be a sizeable increase in the proportion of recalls beginning from the early serial positions. For example, in Experiment 1, out of the total number of responses in output position 1, a proportion of between 0.09 (45 out of 476 responses) for the pre-cued condition and 0.31 (71 out of 227 responses) for the post-cued condition were made from serial position 1. In Experiment 2, these proportions have increased to between 0.39 (188 out of 481 responses) for the pre-cued condition and 0.45 (109 out of 243 responses) for the post-cued condition. Hence, while there is a similar tendency in Experiment 2 for participants in the free output conditions to start recalling from the later serial positions, this tendency is somewhat reduced.

Experiment 2 further provides evidence that differences found in the serial position curves across the two output order conditions are due to differences in the output order of list items. Items which are output early have higher recall probabilities than items which are output later.

--Table 3 about here--

--Table 4 about here--

As in Experiment 1, further analyses were performed to examine the most common sequences of responses. We report the two most common correct starting sequences up to a maximum sequence length of 4. In the pre-cued forwards condition, these output sequences were 1234 and 1 (33% and 14% of all correct sequences respectively). In the pre-cued free output condition, these were 1234 and 4561 (17% and 9% of all correct sequences respectively). In the post-cued forwards condition, these sequences were 1234 and 12 (37% and 13% of all correct sequences respectively). Finally, in the post-cued free condition, they were 1234 and 4561 (19% and 6% of all correct sequences respectively).

--Figure 5 about here--

Figure 5 plots, for each condition, the number of correct responses at each output position as a proportion of the total number of correct responses for that condition. The figure shows that, as in Experiment 1, this proportion decreases steadily as output position increases, and that the rate of decrease is approximately similar across all conditions.

Analysis of Errors

The proportions of responses that were movement errors, omission errors or intrusion errors in Experiment 2 were calculated in the same way as before. Intrusion errors similarly constituted a very small percentage of the responses (between 1.8% and 2.8%) and will not be discussed further. The movement errors and the omission errors are shown for each serial position for the forwards output conditions (Figure 6A) and for the free output conditions (Figure 6B).

--Figure 6 about here--

Movements

Forwards output order. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial position: 1 to 6) ANOVA was conducted. There was a significant main effect of serial position, $F(5, 150) = 30.58$, $MSE = .149$, $p < .0001$, but the effect of cue type and the cue-type *x* serial position interaction were not significant ($p > .05$). Tukey's HSD on the main effect of serial position revealed significant differences between serial position 1 and serial positions 3-6 (all *p*s < .001), between serial position 2 and serial positions 3-5 (all *p*s < .01), between serial position 3 and serial positions 4 and 5 (*p*s < .05), and between serial position 6 and serial positions 4 and 5 (*p*s < .01). Figure 6A shows a steady increase in the proportion of movement errors up to serial position 5, followed by a decrease at serial position 6. Appendix A2 details the full distribution of responses across all serial positions for both the forwards and free output order conditions.

Free output order. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial position: 1 to 6) ANOVA was conducted. There was a significant main effect of serial position, $F(5, 150) = 20.23$, $MSE = .144$, $p < .0001$, but the effect of cue type and the cue-type *x* serial position interaction were not significant ($p > .05$). Tukey's HSD on the main effect of serial position revealed significant differences between serial position 1 and serial positions 2-5 (all *p*s < .05), between serial position 2 and serial positions 3 and 4 (*p*s < .05), between serial position 4 and serial position 5 ($p < .05$), and between serial position 6 and serial positions 2-5 (all *p*s < .01). Figure 6B shows that movement errors increased up to serial position 4 and then decreased across serial positions 5 and 6.

Omissions

Forwards output order. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial position: 1 to 6) ANOVA was conducted. There was a significant main effect of serial position, $F(5, 150) = 19.11$, $MSE = .303$, $p < .0001$. The effect of cue type and the cue-type *x* serial position interaction were not significant ($F < 1$). Figure 6A shows a general increase in omission errors with serial position. Tukey's HSD revealed a significant difference between serial position 1 and all other serial positions, and between serial positions 2 and serial positions 4-6 (all *p*s < .05).

Free output order. A 2 (Cue type: pre-cued or post-cued) x 6 (Serial position: 1 to 6) ANOVA was conducted. There was a significant main effect of serial position, $F(5, 150) = 6.52$, $MSE = .119$, $p < .0001$. The effect of cue type and the cue-type *x* serial position interaction were not significant ($p > .05$). Figure 6B shows that omissions increased up to serial position 3 and decreased thereafter. Tukey's HSD tests revealed a significant difference between serial positions 1 and 3 ($p < .05$) and between serial position 6 and serial positions 2-4 (all *p*s < .01).

Discussion

Experiment 2 confirms the main findings of Experiment 1 – when participants are free to output items in any order (whilst ensuring items are in their correct input serial positions), they choose to start recalling from the later serial positions, and this results in increased recency effects and somewhat reduced primacy effects for the free output condition relative to the forwards output condition (Figure 4). In addition, there was little or no effect of cue type in Experiment 2, and there were no differences in the most common initial output sequences between the pre- and post-cued free output conditions. These findings suggest that the differences in the serial position curves for the forwards and free output conditions cannot be due to strategic differences at encoding. Finally, as in Experiment 1, there was a steep decline in performance with increasing output position (Figure 5).

The patterns of errors in the forwards output and free output conditions were also similar to those in Experiment 1. Movement errors were rather similar across the four conditions, increasing up to serial positions 4-5 and decreasing thereafter (particularly in the free output conditions). There were also more omission errors than movement errors in Experiment 2, and greater differences in the patterns of omissions than movement errors across the two output order conditions. Omissions were greatest at later serial positions for the forwards output conditions but were reduced at the corresponding serial positions for the free output conditions. The fact that similar serial position curves, output patterns and error patterns are obtained even when the list length has been reduced to 6 items suggests that similar processes are occuring in the recall of these shorter lists.

There is, however, one significant difference between Experiments 1 and 2. In Experiment 2, there is a noticeable increase in the extent to which participants choose to output the first item first in the free output conditions. Although participants still choose to start their output more often with later serial positions than early serial positions, there is nevertheless a marked increase in participants starting their responses with serial position 1. This difference is also apparent in the most common initial output sequences in the pre-cued free output conditions of Experiments 1 and 2. This increased tendency to start in a forwards order in the free output conditions may also be reflected in the differences between the serial position curves obtained in Experiments 1 and 2: in Experiment 2, the differences between the primacy and recency effects in the forwards and free output order conditions are somewhat smaller than the corresponding differences in Experiment 1.

General Discussion

The two experiments reported here show that output order is an important factor in determining the shape of the standard serial position curve. In a typical ISR task, participants are made to output list items in a strictly forwards order, that is, beginning with the first presented item and ending with the last presented item, and their performance decreases with serial position (with the exception of a 1-item recency effect). The decline in performance with increasing serial position is therefore usually confounded with a corresponding increase in output order. The present study provides a method in which output order and serial position may be deconfounded. In the free output order conditions, participants are free to choose the order in which items are output. The experiments show that when given the choice, they tend to begin their recall protocols with items occurring in later serial positions before moving on to items occurring in early serial positions. This pattern of output was present in both the pre-cued (Tables 1 and 3) and post-cued (Tables 2 and 4) conditions, and we believe that it is largely responsible for the different patterns of recall performance reflected in the serial position curves for the two output order conditions (Figures 1 and 4). Under forwards output conditions, the large primacy effect and somewhat smaller recency effect that are characteristic of recall performance in ISR are obtained. However, under free output conditions, a significantly smaller primacy effect and larger recency effect are obtained. The effects of output order are most clearly shown in Figures 2 and 5. We believe that these findings are consistent with those of Beaman (2002) and Posner (1964), who directly manipulated participants' recall order of items, and also of Crowder (1969) and Wood and Hinrichs (1971), who similarly used a free output order methodology and obtained serial position curves with more extensive recency than primacy effects.

A second aspect of our findings concerns the effect of cue type on recall. The results obtained suggest that there are no substantial effects of cue type on recall. While there was some evidence that pre-cuing led to a slightly higher proportion of recall than post-cuing (Figures 1C and 1D) in Experiment 1, the effects were small and inconsistent (non-significant with forwards output and only at serial positions 6 and 7 with free output) and were not present in Experiment 2 (Figures 4C and 4D). This provides further evidence that the differences found in the serial position curves under the free and forwards output conditions are due to differences in output order at retrieval (rather than strategic differences at encoding).

A third finding concerns the patterns of errors in Experiments 1 and 2. These suggest that the differences in serial position curves under the forwards output and the free output conditions are largely (but not exclusively) due to differences in the pattern of omission errors (Figures 3 and 6). Although participants often do not recall all the items, the post-cued conditions demonstrate that at test, more items are accessible to participants than they ultimately are able to report. As more words are output, so accessibility to subsequent words decreases. We note that the rates of omission errors are high in our experiments (and that our rates of movement errors low) compared to the data from some other studies of ISR (e.g., Maylor et al., 1999). We attribute this to our use of an open set of words, which reduces the opportunities to guess or generate candidate list items at recall. When a small, closed set of words is used (such as when using digits, consonants, or words from a restricted word pool), participants might use knowledge of the word set to cue their responses. This may lead to a decrease in omission errors and a corresponding increase in accuracy, movement errors (items from within the same list) or intrusion errors (items from the restricted set that were presented on earlier lists). This difficulty in attributing the exact cause of different types of errors in ISR and other immediate memory tasks is well known and trade-offs between different types of errors through the use of list structure and sophisticated guessing has been suggested, for example, by Farrell and Lewandowsky (2003).

We believe our findings are entirely consistent with previous research that shows detrimental effects of output upon ISR performance (Cowan et al., 2002; Cowan et al., 2004; Nairne, 1988, 1990; Oberauer, 2003). Our methodology does not allow us to distinguish between item-based effects of output interference (e.g., Nairne, 1988, 1990) and time-based effects of output delay (e.g., Brown et al., 2002), but other recent work has shed light on this issue. Lewandowsky, Duncan and Brown (2004) showed that it is not time *per se* that causes poorer performance in serial recall, but event-based factors (such as output interference or a primacy gradient). Furthermore, in a recent paper, Nairne, Ceo, and Reysen (in press) provide evidence that the retrieval of one list item can have either a positive or a negative effect on the subsequent recall of a second list item. Recall of one item may lead to an increase in the probability of recalling the next one or two items in the list (cf., Kahana & Caplan, 2002) but have negative effects on the recall of other list items. In their experiments, the critical comparisons were made using probed recall, which occurred at a fixed retention interval after the end of the list. The differences observed by Nairne et al., therefore, cannot be attributed to output delay, and further show that effects of item-based output interference are specific to different list positions, and therefore not best modelled by a general decrement in recall of all subsequent items (as modelled by, for example, the general addition of noise, e.g., Brown et al., 2000). However, it is probable that output interference is not the only factor in determining ISR performance since small primacy effects remain even when output interference is controlled for (Cowan et al., 2002; Oberauer, 2003).

We believe our data provide some constraints on theoretical modelling in at least three ways. First, our data support claims that much of the primacy effect reflects processes occurring at output rather than processes occurring at encoding, and so our data constrain the relative importance that should be given to such mechanisms within theories of ISR. Second, our data show that participants are quite capable of starting their output from serial positions other than the first, and that they need not recall items in a strict forwards order to accurately recall the items in their correct serial positions. This questions the extent to which serial recall necessitates a resetting of the context-timing signal, or reinstatement of the learning context, to the beginning of the list. Third, our data suggest that similar immediate memory mechanisms are being used for 6- and 8-item lists, contrary to some claims that specialised STM or Working Memory mechanisms are used for short lists (e.g., Baddeley, 2000; Baddeley & Larsen, 2003; Larsen & Baddeley, 2003). Because the basic patterns of results from Experiment 1 are replicated in Experiment 2, which used a shorter, more conventional list length of 6 items, Experiment 2 not only confirms that these data are suitable for modelling with Working Memory models, but also appears to challenge these models to account for the similarities across list lengths. To be fair to those who argue that different memory mechanisms are used for shorter lists, we should acknowledge that there was one significant difference with the shorter lists - there was a greater tendency to output items in a forwards order in the free output condition of Experiment 2 (6-item list) than in Experiment 1 (8-item list) (see Tables 2 and 4). This tendency was also seen in the pre-cued free output condition of Experiment 2, in which there was a slightly greater tendency for participants to start their recall sequences with items from the beginning of the list. Whether this difference is enough to justify the postulation of separate memory mechanisms over different list lengths is open to debate.

Finally, although it should be noted that the task used here was a free position recall task, which is not strictly identical to the "standard" ISR task, our data are consistent with other studies which have used variations of the ISR task (e.g., Beaman, 2002; Cowan et al., 2002; Crowder, 1969; Posner, 1964) and have similarly found significantly larger recency effects than primacy effects when output position has been taken into account. In addition, the finding that participants in the free output conditions often choose to recall from towards the end of the list is similar to the output protocols typically found in free recall

(Beaman & Morton, 2000; Nilsson, Wright & Murdock, 1975). These findings are in line with the more general finding of recency-dominated serial position curves in other short-term memory tasks such as those found in the sequential digit probe task (Waugh & Norman, 1965), the running memory span task (Hockey, 1973), the probe paired associates task (Murdock, 1963, 1967), and the free recall task (Murdock, 1962; Tan & Ward, 2000; Ward & Tan, 2004). Taken together, these results suggest that the processes underlying ISR may be more sensitive to recency, and hence more similar to other short-term memory tasks, than one might at first think.

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Table 1. Total Number of Correct Responses for Each Output Position and Serial Position in the Forwards Output Conditions (Experiment 1).

		Output Position							
Condition	Serial Position	1	2	3	4	5	6	7	8
Pre-cued	1	382							
	2	11	261						
	3	7	24	170					
	4	4	14	30	106				
	5	12	4	28	35	67			
	6	5	17	10	26	25	43		
	7	1	16	30	22	34	14	32	
	8	2	6	33	47	33	43	10	19
	Total	424	342	301	236	159	100	42	19
Post-cued	1	161							
	2	6	99						
	3	9	10	54					
	4	5	5	10	33				
	5	10	8	10	9	20			
	6	4	10	8	6	8	13		
	7	1	8	15	6	3	2	8	
	8	2	3	22	27	16	5	4	6
	Total	198	144	119	81	47	20	12	6

Table 2. Total Number of Correct Responses for Each Output Position and Serial Position in the Free Output Conditions (Experiment 1).

		Output Position							
Condition	Serial Position	1	2	3	4	5	6	7	8
Pre-cued	1	45	12	51	51	62	17	2	1
	2	2	29	9	43	45	35	8	1
	3	1	3	33	30	35	22	16	5
	4	11	3	16	29	21	18	7	11
	5	89	11	23	32	9	11	4	4
	6	48	87	81	16	8	5	3	3
	7	75	190	86	12	3	2	1	2
	8	205	77	53	76	18	5	1	1
	Total	476	412	352	289	201	115	42	28
Post-cued	1	71	16	21	18	9	2	1	1
	2	1	46	12	21	13	3	1	
	3	4	11	31	7	9	8		1
	4	2	5	4	24	8	3	3	
	5	12	7	12	5	18	5	2	
	6	13	14	21	6	5	15		1
	7	17	58	26	18	3	2	11	
	8	107	31	25	21	4	1	1	7
	Total	227	188	152	120	69	39	19	10

Table 3. Total Number of Correct Responses for Each Output Position and Serial Position in the Forwards Output Conditions (Experiment 2).

		Output Position					
Condition	Serial Position	1	2	3	4	5	6
Pre-cued	1	438					
	2	22	332				
	3	7	39	241			
	4	3	16	46	178		
	5	4	6	47	52	114	
	6		6	20	78	81	87
	Total	474	399	354	308	195	87
Post-cued	1	223					
	2	8	185	1			
	3	4	10	139			
	4	1	7	20	97		
	5	2	3	12	30	66	
	6		4	7	26	42	61
	Total	238	209	179	153	108	61

Table 4. Total Number of Correct Responses for Each Output Position and Serial Position in the Free Output Conditions (Experiment 2).

		Output Position					
Condition	Serial Position	1	2	3	4	5	6
Pre-cued	1	188	10	50	78	37	13
	2	5	154	16	69	58	17
	3	18	13	137	44	42	23
	4	94	24	74	100	8	19
	5	69	176	30	25	68	3
	6	107	73	100	46	45	53
	Total	481	450	407	362	258	128
Post-cued	1	109	17	32	28	9	5
	2	3	91	18	24	26	5
	3	2	10	75	28	13	14
	4	22	6	26	54	10	6
	5	26	66	8	17	35	5
	6	81	29	32	16	27	26
	Total	243	219	191	167	120	61

Figure captions

Figure 1. Data from Experiment 1. The figure shows the mean proportion of correct responses as a function of input serial position for the pre-cued conditions (Figure 1A) and the post-cued conditions (Figure 1B). These data are replotted in Figures 1C and 1D. Figure 1C shows the mean proportion of correct responses as a function of input serial position for the forwards output order conditions. Figure 1D shows the mean proportion of correct responses as a function of input serial position for the free output order conditions.

Figure 2. Data from Experiment 1. The figure shows the proportion of the total number of correct responses for each condition as a function of output position.

Figure 3. Data from Experiment 1. The figure shows the mean proportions of movement and omission errors as a function of input serial position for the forwards output conditions (Figure 3A) and the free output conditions (Figure 3B).

Figure 4. Data from Experiment 2. The figure shows the mean proportion of correct responses as a function of input serial position for the pre-cued conditions (Figure 4A) and the post-cued conditions

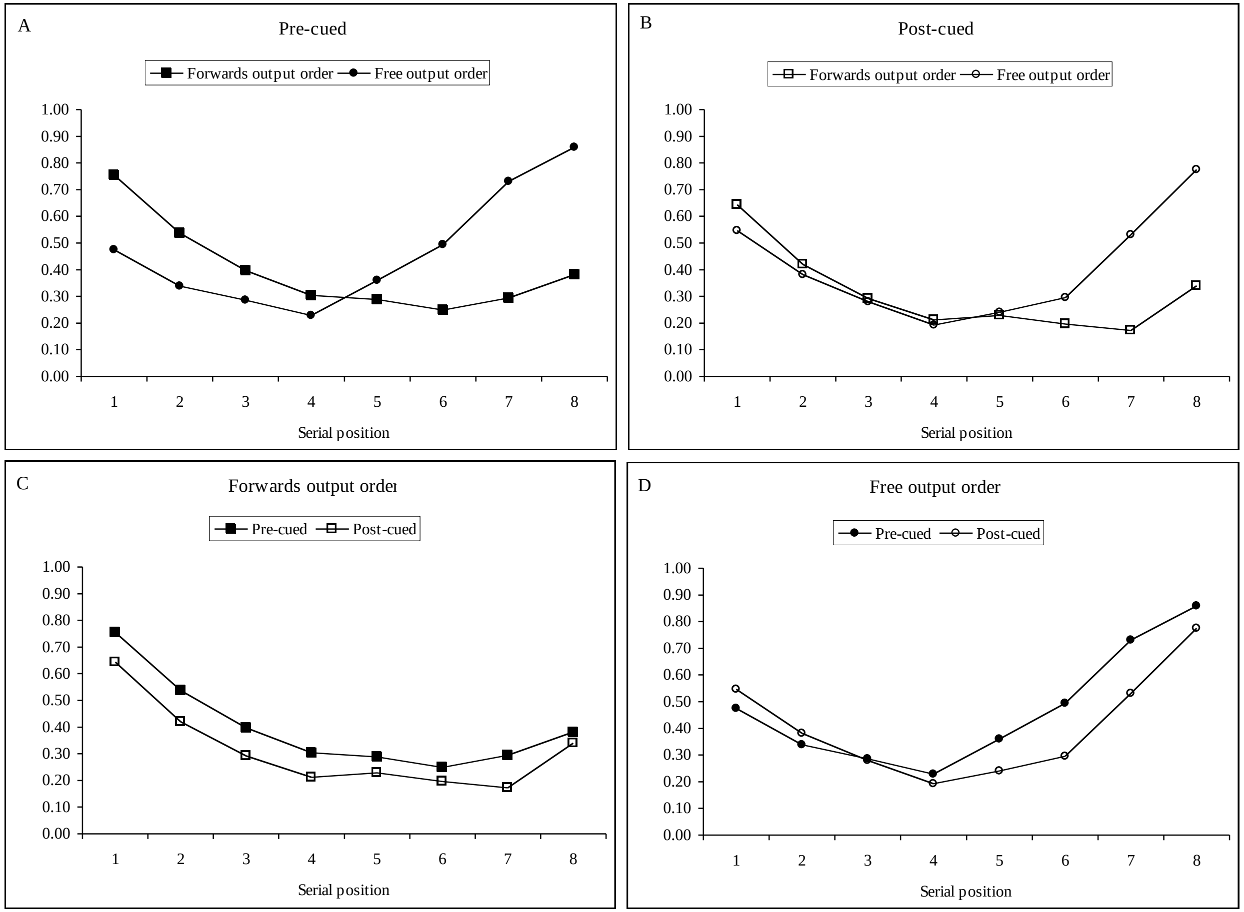
(Figure 4B). These data are replotted in Figures 4C and 4D. Figure 4C shows the mean proportion of correct responses as a function of input serial position for the forwards output order conditions. Figure 4D shows the mean proportion of correct responses as a function of input serial position for the free output order conditions.

Figure 5. Data from Experiment 2. The figure shows the proportion of the total number of correct responses for each condition as a function of output position.

Figure 6. Data from Experiment 2. The figure shows the mean proportions of movement and omission errors as a function of input serial position for the forwards output conditions (Figure 6A) and the free output conditions (Figure 6B).

Production Number C168

Figure 1.



Production Number C168

Figure 2.

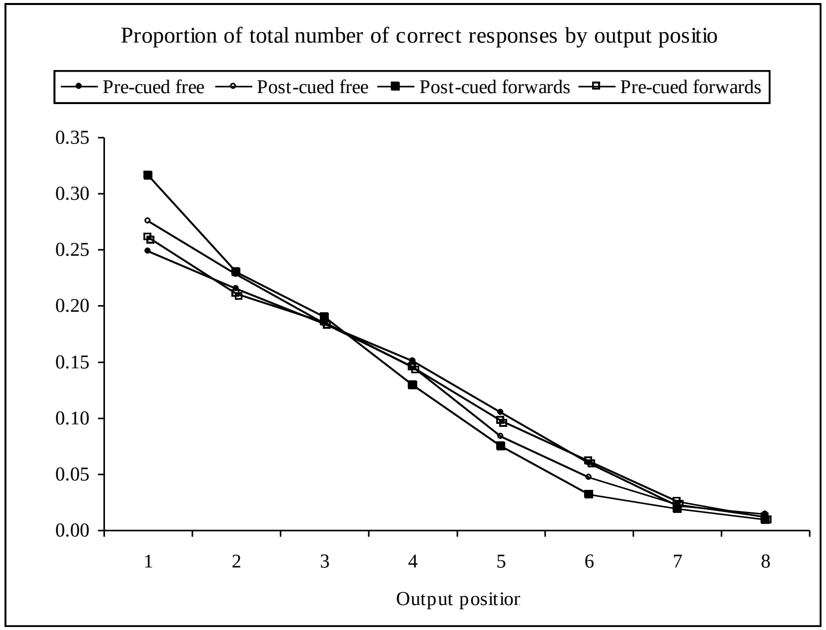
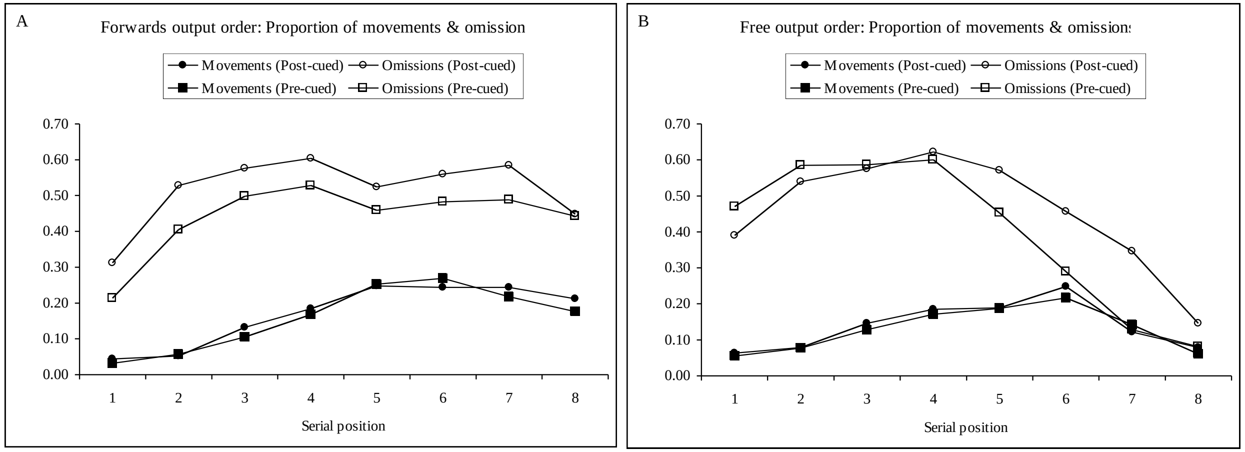
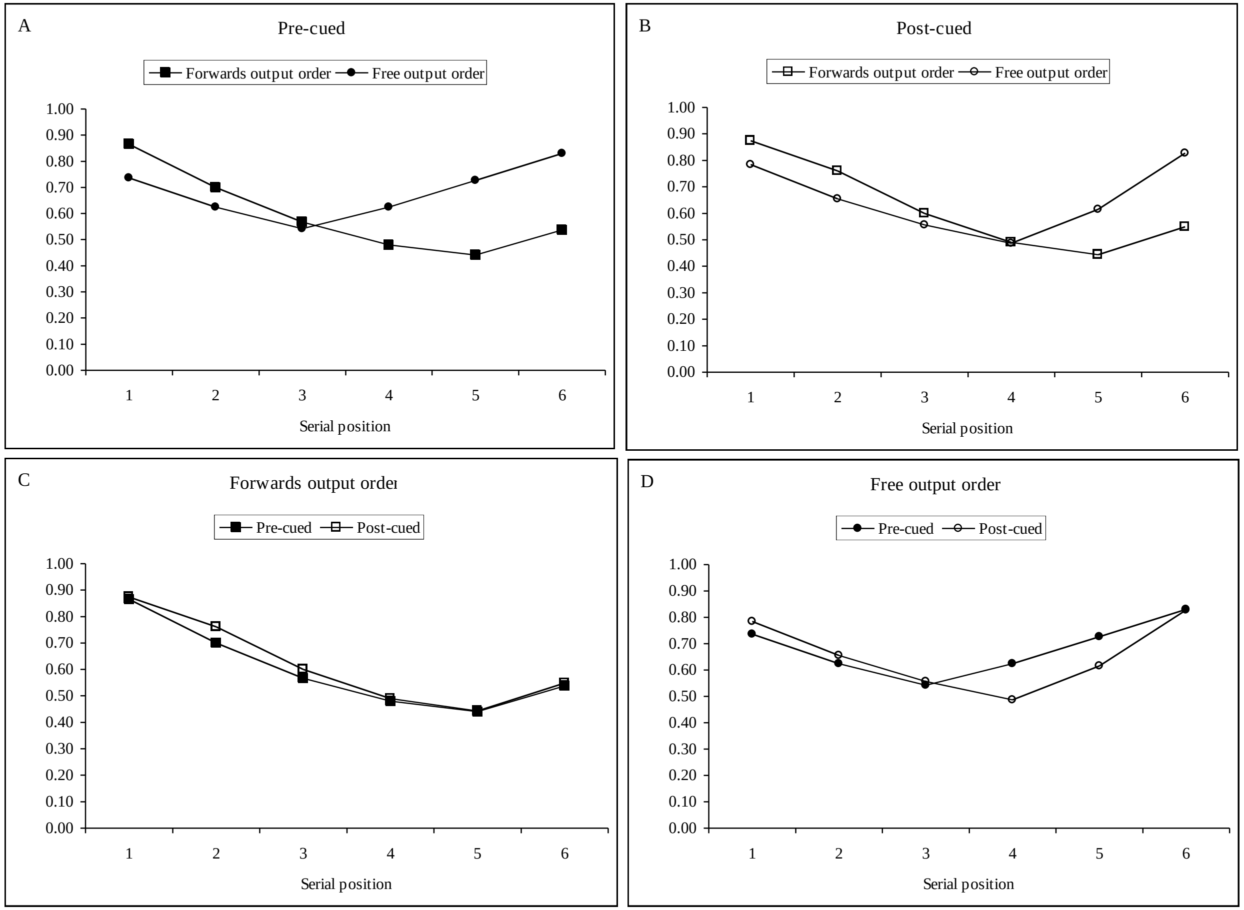


Figure 3.


A
Forwards output order: Proportion of movements & omission
Movements (Post-cued)
Omissions (Post-cued)
Movements (Pre-cued)
Omissions (Pre-cued)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8
Serial position
B
Free output order: Proportion of movements & omissions
Movements (Post-cued)
Omissions (Post-cued)
Movements (Pre-cued)
Omissions (Pre-cued)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8
Serial position

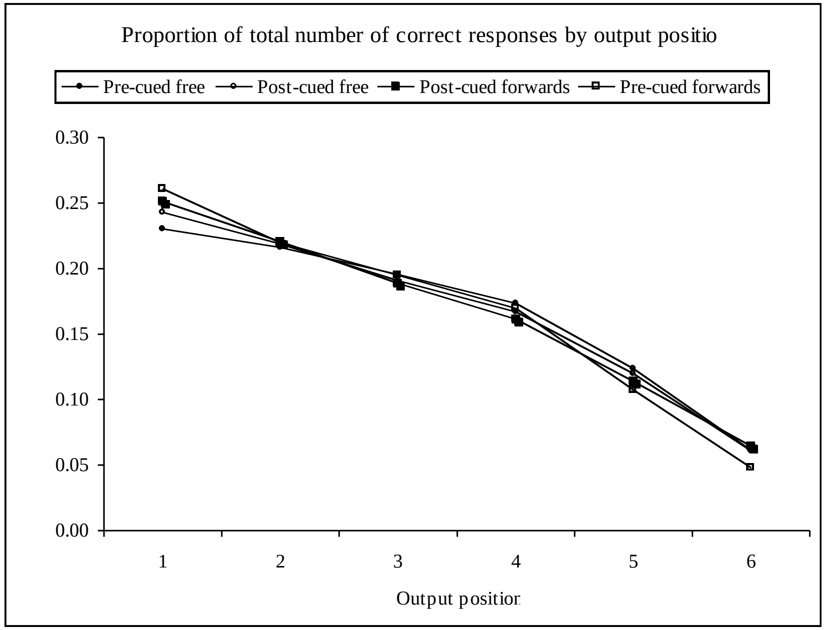
Production Number C168

Figure 4.



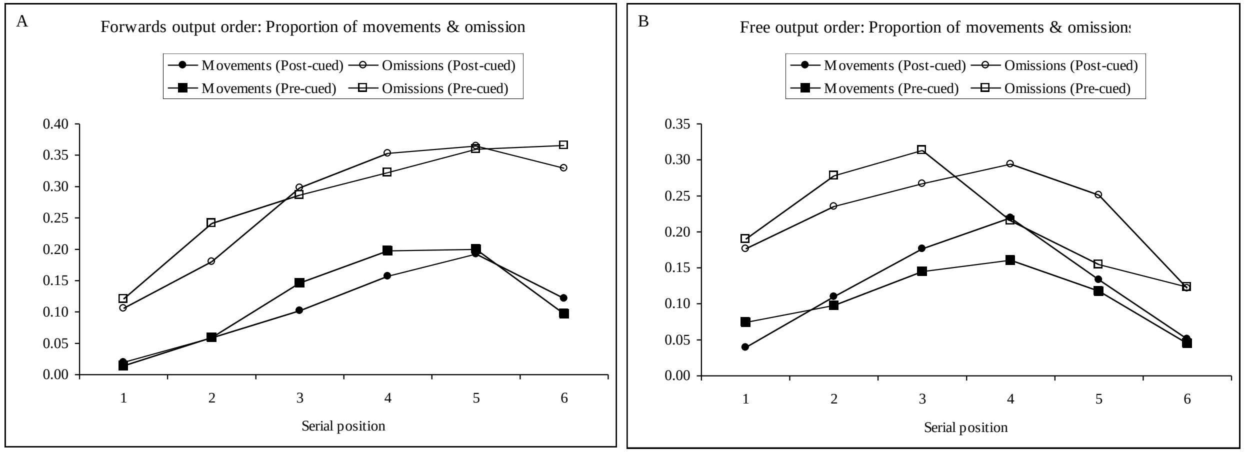
Production Number C168

Figure 5.



Production Number C168

Figure 6.



Appendix

Tables A1 and A2 detail the full distribution of responses across all serial positions for Experiments 1 and 2 respectively. Since cue type had no significant effect on movement errors, values from the pre-cued and post-cued conditions have been combined. Serial position refers to a word's position at presentation; recalled position refers to the row in which a word was written on the response grid. It can be observed that the majority of responses were made in the correct serial positions (values in bold), and when movement errors occurred they tended to be made in neighbouring serial positions.

A1. Full Distribution of Responses Across All Serial Positions for the Forwards and Free Output Conditions of Experiment 1.

		Recalled Position							
Condition	Serial Position	1	2	3	4	5	6	7	8
Forwards Output	1	**543**	13	5	3	3	2	1	0
	2	9	**377**	18	7	2	2	4	0
	3	10	44	**274**	17	3	7	3	2
	4	4	34	70	**207**	16	4	1	2
	5	10	23	53	69	**203**	18	16	1
	6	7	12	17	34	86	**175**	34	7
	7	3	0	15	23	44	70	**192**	16
	8	1	3	5	19	21	38	55	**278**
	Total	587	506	457	379	378	316	306	306
Free Output	1	**380**	27	7	2	4	2	2	0
	2	21	**269**	23	6	2	4	3	0
	3	11	39	**216**	34	7	4	5	2
	4	4	24	53	**165**	32	13	6	2
	5	5	8	24	49	**244**	47	10	0
	6	1	8	11	24	62	**326**	61	6
	7	0	2	6	7	10	66	**506**	12
	8	0	0	1	6	6	7	31	**633**
	Total	422	377	341	293	367	469	624	655

A2. Full Distribution of Responses Across All Serial Positions for the Forwards and Free Output Conditions of Experiment 2.

		Recalled Position					
Condition	Serial Position	1	2	3	4	5	6
Forwards Output	1	**661**	9	1	1	0	1
	2	10	**548**	21	9	5	0
	3	10	47	**440**	27	10	6
	4	1	19	76	**368**	33	11
	5	1	7	27	92	**336**	23
	6	0	1	7	15	57	**412**
	Total	683	631	572	512	441	453
Free Output	1	**576**	33	10	5	0	0
	2	21	**486**	39	13	4	1
	3	8	47	**419**	49	12	3
	4	3	12	73	**443**	45	5
	5	0	4	12	57	**529**	21
	6	0	1	2	4	29	**636**
	Total	608	583	555	571	619	666