The role of rehearsal on the output order of immediate free recall of short and long lists

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Abstract

Participants tend to initiate immediate free recall (IFR) of short lists of words with the very first word on the list. Three experiments examined whether rehearsal is necessary for this recent finding. In Experiment 1, participants were presented with lists of between 2 and 12 words for IFR at a fast, medium, or slow rate, with and without articulatory suppression (AS). The tendency to initiate output with the first item for short lists (1) did not change greatly when presentation rate was increased from a medium to a fast rate under normal conditions, (2) was reduced but not eliminated by AS, and (3) was maintained at slower rates when rehearsal was allowed, but decreased at slower rates when rehearsal was prevented. In Experiment 2, the overt rehearsal methodology was used, and the tendency to initiate output with the first item for short lists was present even in the absence of overt rehearsal. Experiment 3 re-examined IFR under normal encoding conditions and replicated the main findings from the normal encoding conditions of Experiment 1 whilst using the presentation rates and list lengths of Experiment 2. We argue that rehearsal is not strictly necessary for the tendency to initiate recall with the first item under normal conditions, but rehearsal nevertheless contributes to this effect at slower rates.

215 words

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In the immediate free recall (IFR) task, participants are presented with a series of unrelated words, and at the end of the list they must try to recall as many of the list items as they can, in any order that they wish. When lists of around 10-40 words are presented, participants recall a greater proportion of the first few list items (an advantage known as the primacy effect), and a greater proportion of the last few list items (an advantage known as the recency effect), relative to the recall of the middle list items (e.g., Murdock, 1962; Roberts, 1972).

Explanations of the recency effect are central to theories of IFR. Unitary accounts of IFR, which assume that the same memory processes are responsible for recall performance throughout the list, propose that later list items benefit from being more temporally distinct (e.g., Brown, Neath & Chater, 2007; Glenberg & Swanson, 1986), or benefit from greater contextual overlap between the context associated with the recency items and the context associated with the end of the list (e.g., Glenberg *et al.,* 1980; Howard & Kahana, 2002; Polyn, Norman, & Kahana, 2009; Sederberg, Howard & Kahana, 2008; Tan & Ward, 2000). These accounts are well placed to explain the magnitude of recency effects across a range of inter-stimulus intervals and retention intervals (e.g., Baddeley & Hitch, 1977; Bjork & Whitten, 1974; Crowder, 1993; Nairne, Neath, Serra, & Byun, 1997).

The recency effect in IFR was also central to early dual-store accounts of IFR. These accounts assumed that the recency effect reflected the direct output of the later list items from a limited-capacity short-term store (e.g., Atkinson & Shiffrin, 1971; Glanzer, 1972; Raaijmakers & Shiffrin, 1981). However, these classic accounts had difficulty explaining recency effects when a short-term store account of recency was untenable. This limitation has been circumvented by more recent dual-store accounts of free recall, which posit separate short-term recency and long-term recency mechanisms (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarman, & Usher, 2005; Farrell, 2010; Raaijmakers, 1993; Unsworth & Engle, 2007).

By contrast, explanations of the primacy effect are less central to theories of IFR, and many theories assume that the primacy effect reflects selective rehearsal of the early list items. In line with this explanation, participants who are asked to rehearse out loud during the presentation of the list (the overt rehearsal method) tend to rehearse the early list items more often than later list items (e.g., Rundus, 1971; Tan & Ward, 2000; Ward, 2002). In addition, the primacy effect is greatly attenuated and sometimes even eliminated when selective rehearsal of the early list items is discouraged (e.g., Fischler, Rundus, & Atkinson, 1970; Glanzer & Meinzer, 1967; Marshall & Werder, 1972; Tan & Ward, 2000). Some researchers assume that rehearsal in short-term memory increases the associative strength of the rehearsed items in long-term memory (e.g., Atkinson & Shiffrin, 1971; Raaijmakers & Shiffrin, 1981; Rundus, 1971), whereas others assume that rehearsal increases the accessibility of the items by creating multiple instantiations of the items that are more distributed and more recent at the time of recall (e.g., Brodie & Murdock, 1977; Laming, 2010; Tan & Ward, 2000).

Other explanations of the primacy effect in IFR have also been suggested. Some authors argue that the first items in the list may also benefit from being more temporally distinct (e.g., Brown *et al.*, 2007) than the middle list items because they are in a temporally less crowded region of memory than the middle list items. An additional idea is that the primacy items can be selectively accessed at test via the retrieval of a "start of list" signal (e.g., Davelaar *et al*., 2005; Laming, 1999, 2010; Metcalfe & Murdock, 1981). However, regardless of the exact mechanism proposed for primacy, it is normally assumed (mirroring the relative magnitudes of the empirical effects) that the factors that determine primacy are somehow of less importance to the core explanation of IFR than the factors that determine recency.

In recent years it has been increasingly acknowledged that a complete account of IFR must also explain the *order* in which the words are recalled (e.g., Farrell, 2010; Howard & Kahana, 1999; Kahana, 1996; Laming, 2010). Not only are the recency items the most likely to be recalled, but they are also those most likely to be recalled *first* from a long list of words (e.g., Beaman & Morton, 2000; Farrell, 2010; Hogan, 1975; Howard & Kahana, 1999; Laming, 1999), and subsequent recalls are most likely to be from neighboring input serial positions (e.g., Howard & Kahana, 1999;

Kahana, 1996) and / or neighboring rehearsals (e.g., Laming, 2010; Ward, Woodward, Stevens, & Stinson, 2003).

However, a recent development by Ward, Tan, and Grenfell-Essam (2010) has shown that the recency-dominated patterns of recall are typical only for the IFR of longer lists of words. They confirmed that for longer lists of 10 or more words, participants tended to initiate their recall with one of the last four list items (cf. Hogan, 1975; Howard & Kahana, 1999; Laming, 1999), and on these trials, the serial position curves were dominated by extended recency effects and smaller primacy effects. Critically, they also found that for the IFR of shorter lists of words, participants tended to initiate output with the very first list item and, when this occurred, the resultant serial position curves showed elevated levels of recall of the early list items and greatly reduced recency.

Figure 1 reproduces this novel finding from Ward *et al.* (2010, Experiment 1). Here a group of 55 participants was presented with 45 lists of words for IFR (three trials each of the list lengths 1-15, presented in a random order such that participants did not know the list length in advance of the list). The words were presented one at a time at a rate of 1 word per s. As can be seen from Figure 1, at short list lengths of 1-4 words, participants almost always started their recall with the item from serial position 1, but as the list length was increased beyond 6 words, so participants increasingly initiated their recall with one of the last four list items.

--Figure 1 about here--

The Ward *et al*. (2010) data represent a challenge to accounts of IFR (including our own) that assume that IFR is predominantly recency-based (e.g., Brown *et al.,* 2007; Howard & Kahana, 2002; Tan & Ward, 2000; Ward, 2002). Although IFR of long lists appears to be reasonably characterized as recency-dominated, our data showed that participants who were engaged with IFR of short lists showed far greater preference for recalling the first list item than a recency-dominated account might predict.

In this follow-up study, we sought to examine the role of rehearsal in determining the output orders of lists of different lengths. As commented upon earlier, rehearsal has been studied extensively in IFR of longer lists that are presented at slower rates. In these studies, the early list items (most notably the first) are rehearsed more often (e.g., Rundus, 1971; Tan & Ward, 2000), and they are rehearsed to later positions in the list than middle list items (e.g., Brodie & Murdock, 1977; Tan & Ward, 2000). In addition, the rehearsals tend to be output in sequential order (e.g., Laming, 2006, 2008, 2010). It is therefore possible that the novel finding observed by Ward *et al.* (2010) could reflect participants' ability to rehearse covertly the first list item throughout the presented list. If this were the case, then the Ward *et al.* data might yet be explained by existing accounts of IFR that incorporated an appropriate mechanism for rehearsal.

Despite the logical possibility of a rehearsal explanation for the observed output orders in Ward *et al.* (2010), our own inclination was that rehearsal was not necessary for the findings shown in Figure 1. We had assumed that the combination of (1) the requirement to read aloud experiment-unique words from the screen as they were presented, (2) the relatively fast presentation rate of 1 word per s, and (3) the unknown list length might dissuade participants from rehearsal. We had also convinced ourselves through anecdotal evidence that rehearsal was not necessary for this effect. For example, if one asks an unsuspecting someone to recall whatever you say in whatever order they like, one finds that if a sequence such as "table, butter, bookshop" is presented, the response is almost always to recall all three words in the correct serial order ("table, butter, bookshop"), starting with the first item, even though this was not formally required. The unsuspecting someone later confirms that as far as they were aware no rehearsal had taken place. Nevertheless, we decided that it would be prudent to gather empirical evidence examining the role of rehearsal on the dynamics of free recall.

To this end, our study consists of two main experiments. In Experiment 1, we sought to examine the effects of rehearsal by manipulating the presentation rate and articulatory suppression (AS) in addition to the list length. In Experiment 2, we sought to examine the role of rehearsal directly by examining the patterns of overt rehearsals obtained at different list lengths and presentation rates. A third experiment sought to clarify a minor inconsistency in the findings of the first two experiments that may have arisen due to the use of the overt rehearsal method.

Instead of promoting a rehearsal-based explanation for the Ward *et al.* (2010) data, we likened the IFR of short lists to immediate serial recall (ISR). One might think such a comparison would be relatively uncontroversial, because the methodology for IFR of short lists is nearly identical to that of ISR, and there is recent evidence that words on the two tasks are encoded and rehearsed in similar ways and affected by similar independent variables (e.g., Bhatarah, Ward, & Tan, 2008; Bhatarah, Ward, Smith & Hayes, 2009). However, as discussed by Ward *et al.* (2010), there has been surprisingly little theoretical overlap between theories of IFR and theories of ISR. Although there are some models that attempt to explain both tasks (e.g., Anderson, Bothell, Lebiere & Matessa, 1998; Brown *et al.*, 2007; Farrell, in press; Grossberg & Pearson, 2008), the majority of accounts of IFR say little about ISR (e.g., Davelaar, *et al.*, 2005; Howard & Kahana, 2002; Laming, 2006, 2008, 2009, 2010; Polyn *et al.*, 2009; Raaijmakers & Shiffrin, 1981; Sederberg *et al.*, 2008; Tan & Ward, 2000; Unsworth & Engle, 2007), and the majority of the accounts of ISR say little about IFR (e.g., Baddeley, 1986, 2000, 2007; Baddeley & Hitch, 1974; Botvinick & Plaut, 2006; Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1992, 1999, 2006; Farrell & Lewandowsky, 2002; Lewandowsky & Farrell, 2008; Nairne, 1990; Oberauer & Lewandowsky, 2008; Page & Norris, 1998). Moreover, a common theoretical framework for the two tasks remains controversial (for different views on this issue, see e.g., Brown, Chater, & Neath 2008; Murdock, 2008).

We note that in ISR, participants are able to output a short sequence in a forward serial order in the *absence* of rehearsal when the list items are presented at a fast presentation rate, but may use rehearsal to (more than) compensate for the reduced accessibility of list items at slower rates. Evidence for this position comes from studies of ISR that have examined the effects of presentation rate on ISR with and without *articulatory suppression* (AS), the requirement to utter an irrelevant sound in order to prevent the participant from subvocally rehearsing the list items (e.g., Murray, 1968). One of the most pertinent experiments was that conducted by Baddeley and Lewis (1984, Experiment 1), who manipulated presentation rate (one digit every 0.5 s or one digit every 3 s) and also prevented rehearsal for one half of the participants by requiring participants to repeat the sequence "A, B, C, D" during digit presentation. In this experiment, the digits were spoken by the experimenter, and the participants recalled the digits by writing them down on a paper response sheet. Baddeley and Lewis found that if participants were allowed to rehearse, digit span was greater at the slower presentation rate, but if rehearsal was prevented, then digit span was greater with the faster presentation rate.

Baddeley (1986) argued that the decrease in accessibility with increasing retention interval was due to trace decay, and the opposing processes of decay and rehearsal have been used widely to explain a number of phenomena such as memory-span performance and the word-length effect (e.g., Baddeley, Lewis, & Vallar, 1984; Baddeley, Thomson, & Buchanan, 1975). Note that trace decay need not be the only explanation for the loss of accessibility of short sequences of verbal material following an increase in retention interval. For example, theories of temporal distinctiveness also predict that the accessibility of list items will decrease with increasing retention interval if rehearsal is prevented (e.g., Brown *et al.*, 2007; Crowder, 1993).

Further evidence that rehearsal may offset the negative effects of a slower presentation rate in ISR comes from a recent study by Tan and Ward (2008) who explicitly measured the overt rehearsals made during ISR of lists of six words. To measure overt rehearsals, they used three slower presentation rates, which they labelled fast (1 s per word), medium (2.5 s per word) and slow (5 s per word). Tan and Ward found that there was little overt rehearsal at a rate of 1 word per second, but at slower rates, participants rehearsed the list items in a cumulative forwards order and were more or less successful in doing this up to and including the fourth or fifth list item. They found that overall, recall was superior at slower rates, but this finding was observed only for those sequences in which forward-ordered rehearsal occurred. Indeed, if rehearsal did not occur, they found that ISR was worse at slower presentation rates, a finding reminiscent of Baddeley and Lewis (1984), albeit with different rates and different stimuli.

These findings suggest that, in ISR, participants are able to output a short sequence in a forward serial order in the absence of rehearsal during fast presentation, but may use rehearsal to overcome the reduced accessibility of list items at slower rates. If common memory mechanisms are used in ISR and IFR, then we might expect a similar effect of presentation rate and articulatory suppression in IFR. Thus, if participants perform IFR like they perform ISR, then we might expect that there would be reduced overall level of recall and a reduced tendency to initiate output with serial position 1 at slower rates if rehearsal is prevented, but that rehearsal may offset these negative effects of a slower presentation rate when it can realistically be performed (at slower rates, without AS).

EXPERIMENT 1

In Experiment 1, we manipulated presentation rate, articulatory suppression, and list length. Participants were presented with lists of between 2 and 12 words at each of three different presentation rates: a fast rate, 0.5 s per word; a medium rate, 1 s per word; and a slow rate, 3 s per word. These rates were chosen because the fast and slow rates were the presentation rates used by Baddeley and Lewis (1984), whereas the medium rate was that used by Ward *et al.*, (2010). Half the participants engaged in articulatory suppression (repeating the letters A, B, C, D) during the presentation of the list; whereas the other half remained silent. The stimuli were presented both visually (on the computer screen) and were also spoken simultaneously by the in-built speech synthesizer of the computer and presented via headphones. The list lengths of the trials were randomised such participants did not know the list length in advance of its presentation.

Method

Participants. A total of sixty participants from the University of Essex took part in this experiment. All were fluent English speakers.

Materials and Apparatus. The materials consisted of a subset of 528 words that were randomly selected for each participant from the 1,000 words of the Toronto Word Pool (Friendly, Franklin, Hoffman & Rubin, 1982). The words were presented visually in 52-point Times New Roman font in the center of an Apple eMac computer monitor using the Supercard 4.5 application. At the same time as each word was presented visually, it was simultaneously spoken by the speech synthesizer of the Apple Macintosh computer using the synthetic voice "Bruce", and the spoken words were heard via a Logitech USB Headset H330.

Design. The experiment used a mixed design. The between-subjects independent variable was suppression type with two levels (No Articulatory Suppression [No AS] or Articulatory Suppression [AS]). There were two within-subjects independent variables: list length with seven levels (2, 4, 5, 6, 7, 8 and 12), and presentation rate with three levels (fast – 1 word every 0.5 s, medium – 1 word every s, and slow – 1 word every 3 s). The main dependent variables were the proportion of words recalled (in any order) and the probability of initiating recall with the very first list item, i.e., Probability of First Recall = serial position 1.

Procedure. Participants were tested individually and they were informed that they would be shown three practice lists of 7 words (one list at each presentation rate), followed by 84 experimental lists of words. The experimental trials were arranged into three blocks; each block contained 28 trials (4 trials of each of the 7 different list lengths) of a particular presentation rate. For each presentation rate, the words appeared on the screen for 420 ms and the screen was blank during the inter-stimulus interval. The stimulus onsets occurred every 0.5, 1, or 3 s per word (corresponding to the fast, medium, and slow presentation rates, respectively). The order of the blocks was completely counterbalanced across participants, and within all blocks, the order of the list lengths was randomised.

Each trial started with a warning tone and a fixation cross displayed for two seconds, followed after one second by a sequence of between 2 and 12 words presented one at a time in the centre of the screen. As each word appeared it was simultaneously vocalised by the computer. For the No AS condition, participants were instructed to read each word silently as it was presented. For the AS condition, participants had to read each word silently as it was presented whilst repeating the sequence "A, B, C, D" during the presentation of the list. At the end of the list there was an auditory cue and an empty grid was displayed on the screen that contained the same number of rows as there had been words on the current trial. The participants wrote down as many words as they could remember, in any order that they wished in a lined response grid. A maximum of 20 s was allowed for recall, which could be ended earlier at any time by the participant.

Results

Proportion of words recalled. Figure 2 shows the effects of varying suppression type, presentation rate, and list length on the proportion of words recalled from each list. There were clear list length effects for all six conditions: in each case, the proportion of words recalled decreased with increasing list length. There was also a tendency for recall in the No AS conditions to be greater than those in the AS conditions. A closer inspection of the data suggests that slower presentation rates improved recall for the No AS condition but impaired recall for the AS condition. Moreover, recall was superior for fast presentation rates at short list lengths, but at longer list lengths recall was superior for slow presentation rates.

--Figure 2 about here--

A 2 (suppression type: No AS or AS) x 3 (presentation rate: fast, medium, or slow) x 7 (list length: 2, 4-8, & 12) mixed Analysis of Variance (ANOVA) was performed to examine overall recall performance. There was a significant main effect of suppression type, F (1, 58) = 39.0, *MSE*

= .097, $p < .001$, confirming that recall was superior in the No AS conditions compared to the AS conditions. A non-significant main effect of presentation rate was found, F (2, 116) = 2.03, MSE = .013, $p > 0.05$. There was a significant main effect of list length, F (6, 348) = 1103.0, MSE = .008, $p < .001$, confirming that there was a lower proportion of words recalled at longer lists.

Considering now the interactions, all three 2-way interactions were significant. First, the interaction between suppression type and presentation rate was significant, F (2, 116) = 17.6, MSE = .013, $p < .001$. Recall in the No AS condition was always significantly greater than in the AS condition. However, with slower presentation rates, recall significantly reduced in the AS condition but significantly increased in the No AS condition. Second, the suppression type by list length interaction was also significant, F (6, 348) = 13.7, MSE = .008, $p < .001$. There were clear list length effects in both suppression conditions, but recall in the No AS condition was superior to recall in the AS condition at all list lengths except list lengths 2 and 12. Finally, the presentation rate by list length interaction was also significant, F (12, 696) = 8.95, MSE = .005, $p < .001$. Recall decreased as list length increased for all presentation rates. At list length 4 recall was significantly *worse* at the slow rate compared to both fast and medium rates. At list length 7, 8 and 12 recall was significantly *better* at the slow rate compared to the fast rate, and for list length 8 recall was also significantly better in the slow rate compared to the medium rate. As list length increased for each presentation rate, performance was significantly worse across all list lengths, except for list length 7 compared to 8 in the slow condition. Lastly, the three-way interaction between suppression type, list length, and presentation rate was not significant, F (12, 696) = 1.08, MSE = .005, $p > 0.05$.

Analyses of serial position curves of all data. Figure 3 shows the serial position curves for each of the 7 different list lengths in each of the six conditions. The three Panels on the left-hand side of Figure 3 represent the No AS conditions, the three Panels on the right-hand side of Figure 3 represent the AS conditions. The serial position curves for the six conditions at each list length were analysed by a 2 (suppression type: No AS or AS) x 3 (presentation rate: fast, medium or slow) x n serial position mixed ANOVA (where n is the list length). The majority of main effects and 2-way interactions were significant and the exact *p*-values of all the main effects and interactions for each list length can be found in the Appendix A1. To summarise these analyses, there is a tendency for there to be small 1-item primacy effects and larger, extended recency effects in the serial position curves. The lower level of overall recall in the AS conditions compared to the No AS conditions appears to be mainly due to poorer recall in the early and middle serial positions, and this trend becomes more pronounced at slower presentation rates.

--Figure 3 about here--

The Probability of first recall (PFR) data. Table 1 shows the proportion of trials in which a particular list position was recalled first, for each of the 7 different list lengths and six conditions.

--Table 1 about here--

Each of the six different experimental conditions show grossly similar distributions: participants tended to initiate their recalls with serial position 1 (italicised values) for short lists, but as the list length increased so they were more likely to start their free recall with one of the last four list items (values in bold font). It is interesting to note that there were relatively few trials in which recall started with serial positions 2 and 3 (there was not a strong extended primacy effect), but the tendency to start with one of the last four items showed a graded and extended recency effect.

A closer inspection shows that participants were more likely to initiate recall with the first list item in the AS condition when the presentation rate was fast compared to when the presentation rate was slow, but they were more likely to maintain the tendency to initiate recall with the first list item in the No AS condition at slower presentation rates. These main findings can be summarised in Figure 4.

--Figure 4 about here--

An analysis was conducted on the proportion of trials in which the first word recalled from a list was from serial position 1. A 2 (suppression type: No AS or AS) x 3 (presentation rate: fast, medium, or slow) x 7 (list length: 2, 4-8, and 12) mixed design ANOVA was performed on the proportion of trials initiated with the first word for the six condition types. Overall there was a significant main effect of suppression type, F (1, 58) = 34.1, MSE = .406, p < .001, showing that participants were more likely to initiate their recall with the first word in the No AS condition compared to the AS condition. There was a significant main effect of presentation rate, F (2, 116) = 15.3, MSE = .079, p < .001, indicating that as presentation rate slowed so participants became less likely to initiate their output with the first word. Finally, there was a significant main effect of list length, F (6, 348) = 268.3, MSE = .053, p < .001, indicating that a lower proportion of trials were initiated with the first word as list length increased.

Considering now the interactions, all three 2-way interactions were significant. First, the interaction between suppression type and presentation rate was significant, F (2, 116) = 10.3, MSE = .079, p < .001. Participants were significantly more likely to initiate their output with the first word in the No AS condition compared to the AS condition at all presentation rates. However, as the presentation rate slowed, the proportion of trials initiated with the first word decreased in the AS condition but was maintained in the No AS condition. Second, the suppression type by list length interaction was also significant, F (6, 348) = 8.51, MSE = .053, p < .001. Participants were more likely to initiate recall with the first word in the No AS condition compared to the AS condition at all list lengths except 2 and 12. Also as the list length increased so the proportion of trials initiated with the first word decreased in both suppression conditions. Finally, the presentation rate by list length interaction was also significant, F (12, 696) = 12.3, MSE = .036, p < .001. The proportion of trials initiated with the first word decreased as list length increased for all presentation rates, but was less steep for the slow condition at the longest list lengths. At list length 4 and 5 the proportion of trials initiated with the first word was significantly lower at the slow rate compared to both fast and medium rates. At list length 6 the proportion of trials initiated with the first word was significantly higher at the fast rate compared to both medium and slow rates. At list length 12 the proportion of trials initiated with the first word was significantly higher at the slow rate compared to the fast rate. Lastly, the three-way interaction between suppression type, list length and presentation rate was non-significant, F (12, 696) = 1.10, MSE = .036, $p > 0.05$.

A second analysis examining only the proportion of trials starting with one of the last four words for each of the six conditions produced essentially complementary effects, and so it is not reported here.

The effect of the first recall on the resultant serial position curves. We then examined the effect of the first word recalled on the resultant serial position curves. Figure 5 shows the effects of varying suppression type, presentation rate, and list length on the proportion of words recalled for trials in which participants initiated recall with the first word. The serial position curves for the six conditions at each list length were analysed by a 2 (suppression type: No AS and AS) x 3 (presentation rate: fast, medium, and slow) x *n-1* serial position mixed ANOVA (where *n* is the list length). The data from serial position 1 of each list were omitted from these analyses because, by definition for inclusion in these analyses, their values are exactly 1.00. The exact *p*-values of the main effects and interactions for each list length can be found in Appendix A2. Note that there are decreasing numbers of participants who contribute to these analyses at longer list lengths, especially in the AS conditions.

As can be seen in Figure 5, when recall started with serial position 1, there was generally elevated recall of the early list items, and recency was often limited to a single item. For lists of 7 and 8 words, serial position 2 was recalled more often than serial position 3. In addition, there appears to be more extended recency effects at list length 12, but very few participants start these very long lists with the first word, especially under AS conditions, and this makes statistical confirmation difficult. Partitioning the data by trials starting with the first list item reduced the number of significant main effects and interactions within the analyses. Only two main effects and interactions involving presentation rate were significant, and these were only marginally significant (p = .046). At list length 7, the early items were better recalled at slower rates; whereas at list length 8, the No AS group recalled more words than the AS group at slower rates. Nevertheless, there were residual recall advantages for the No AS over the AS conditions at many list lengths, particularly at earlier serial positions of list length 5 and 7.

These analyses show that small primacy effects and elevated recall of early serial positions are mostly attributable to those trials in which recall started with serial position 1.

--Figure 5 about here--

Figure 6 shows the effects of varying suppression type, presentation rate and list length on the proportion of words recalled for trials in which participants initiated recall with one of the last 4 words. These recency-justified serial position curves for the six conditions at each list length were analysed by a 2 suppression type x 3 presentation rate x n serial position mixed ANOVA (where n is the list length). The exact p-values of the main effects and interactions for each list length can be found in the Appendix A3. Note that there are decreasing number of participants who contribute to these analyses at shorter list lengths, especially in the No AS conditions.

Replicating the data from Ward *et al*. (2010), the serial position curves show extended recency effects, and additionally, at the two longest list lengths there was also a 1-item primacy effect. There remained residual recall advantages for the No AS over the AS conditions, and residual recall advantages for the slow rate in the No AS conditions and for the early and middle list serial positions at the slow rate at the longer list lengths.

--Figure 6 about here--

The degree of forward-ordered recall. The final analysis examined the degree of forward- ordered recall in the output sequences. We examined the Conditionalised Response Probabilities (CRP) for making lag +1 responses for each list length for the six different suppression x presentation rate conditions. A lag of +1 refers to the recall of a successive pair of words at test that were from successive serial positions in the study list (e.g., the first word followed by the second word, or the fifth word followed by the sixth word), and so represents a measure of forward-ordered recall. In line with previous work (Howard & Kahana, 1999; Kahana, 1996), the CRPs were calculated by dividing (for each participant, list length and condition) the observed number of transitions at a particular lag by the number of opportunities that there were for them to output that lag. Thus for lag + 1, recall in strict forward order would score as a 1, whereas all other transitions (in which a forward transition was possible) would count as a 0.

Figure 7 shows the effects of varying suppression type, presentation rate, and list length on the CRP of lag +1 transitions, from where it is clear that the degree of serial forward order decreases with increasing list length. It is clear that there is more serial forwards order in the No AS condition compared to the AS conditions. It is also clear that at list length 2 almost all output sequences for all six conditions are in forward order (serial position 1, serial position 2). The degree of forward-ordered recall diverges across the six conditions at list length 4, but converges again at list length 12. To provide a better feel for the divergence in forwards recall at list length 4 in these data sets, of the 120 trials of list length 4 at each presentation condition, the number of complete sequences of the four items in forwards serial order were 80, 88, and 70 for the fast, medium, and slow rates with no AS, and 55, 40, and 14 for the fast, medium, and slow rates with AS.

--Figure 7 about here--

The CRP-values for lag +1 responses were analysed by a 2 (suppression type: No AS or AS) x 3 (presentation rate: fast, medium or slow) x 7 (list length: 2, 4-8, 12) mixed ANOVA. Overall there was a significant main effect of suppression type F (1, 58) = 22.0, MSE = .098, p < .001, confirming that a higher proportion of +1 lags were performed in the No AS condition compared to the AS condition. There was a non-significant main effect of presentation rate, F (2, 116) = 2.42, MSE = .046, p > .05. There was a significant main effect of list length, F (6, 348) = 204.8, MSE = .041, p < .001, indicating that as the list length increased, so a lower proportion of Lag +1 transitions were performed.

Considering now the interactions, only one of the 2-way interactions was significant. First, the interaction between suppression type and presentation rate was not significant, F (2, 116) = 2.85, MSE = .046, p > .05. Second, the suppression type by list length interaction was significant, F(6, 348) = 4.34, MSE = .041, p < .001. The proportion of Lag +1 responses was significantly greater in the No AS condition compared to the AS condition at list lengths 4, 5 and 7. Finally, the presentation rate by list length interaction was not significant, F (12, 696) = 1.23, MSE = .035, p > .05. Lastly, the three-way interaction between suppression type, list length and presentation rate was significant, F (12, 696) = 2.10, MSE = .035, p < .05. This was mainly due to higher degree of serial forwards order in the No AS condition across the middle list lengths (that is, not at list lengths 2 and 12).

Discussion

Experiment 1 examined the role of rehearsal in determining the output order of IFR of short and long lists. Consistent with Ward *et al. (2010),* we found that participants tended to initiate recall with the first list item when the list was short, and initiate free recall with one of the last four list items when the list length was increased. Moreover, as reported by Ward *et al.*, the initial recall had a large effect on the resultant serial position curves: there were elevated early list performance and reduced recency effects when recall started with the first list item, and extended recency and reduced primacy effects when recall started with one of the last list items.

The role of rehearsal was examined by manipulating presentation rate and AS. Our findings show that rehearsal was not strictly necessary for the tendency to initiate recall with serial position 1 under normal encoding conditions: starting recall with the first list item was relatively unaffected by changing the presentation rate from 1 s per word (medium rate) to 0.5 s per word (fast rate) under normal encoding conditions that were free from AS.

However, there was evidence that rehearsal nevertheless may contribute to this tendency, since the tendency to initiate recall with the first item was somewhat reduced although far from eliminated under AS at fast and medium rates. Moreover, the role of rehearsal became increasingly important at slower rates. At the slower presentation rates, participants showed a *reduced* tendency to initiate recall with the first list item in the AS conditions, but they were able to *maintain* their tendency to start their recall with serial position 1 at longer list lengths in the No AS conditions. Thus, rehearsal may have (at least) offset the negative effects of a slower presentation rate when it can realistically be performed (no AS conditions at slower rates). These findings are consistent with the limited data available from Bhatarah *et al.* (2009, Experiment 2) who found that the probability of initiating recall with the first item from an 8-item list was maintained at slower rates when participants could rehearse, and also consistent with the limited data available from Bhatarah *et al.* (2009, Experiment 3) who found that the probability of initiating recall with the first item from an 8-item list was reduced under AS conditions.

Considering next the overall proportion of words recalled, the overall performance on IFR decreased with increasing list length, decreased under AS conditions, and slower presentation rates led to worse recall in the AS conditions but better recall in the No AS conditions. These results are consistent with the effects of slower rates on the proportions of words recalled with IFR (e.g., Bhatarah *et al.*, 2009; Tan & Ward, 2000) and ISR (e.g., Bhatarah *et al.*, 2009; Tan & Ward, 2008).

For the case of overall proportion of words recalled, the effects of rehearsal appear to have (more than) offset the otherwise negative effects of a slower presentation rate.

Overall, our findings show that rehearsal is not strictly necessary for the high tendency to initiate IFR with the first list item at short lengths. However, this tendency is reduced (along with the general accessibility of all the list items) at slower presentation rates when rehearsal is prevented (e.g., Baddeley & Lewis, 1984; Bhatarah *et al.*, 2009; Brown *et al.*, 2007; Crowder, 1993; Peterson & Peterson, 1959; Tan & Ward, 2008), but the overall accessibility of list items is improved (and the tendency to initiate recall with the first word is maintained) at slower presentation rates when rehearsal is possible.

Experiment 2

In Experiment 1, we found evidence that rehearsal was not strictly necessary for the tendency to initiate recall with the first list item under normal conditions, but may nevertheless contribute to this effect, especially at slower rates. In Experiment 2, we sought to gain further support for these conclusions by comparing the patterns of recall directly with observed patterns of rehearsal. We did this by presenting participants with lists of between 3 and 15 words for IFR using the overt rehearsal methodology (e.g., Rundus & Atkinson, 1970; Rundus, 1971; Tan & Ward, 2000) under three different presentation rates.

Three changes were necessary in order to use the overt rehearsal methodology. First, the presentation rates were chosen to be slower than those used in Experiment 1, in order to give participants maximum opportunity to rehearse aloud. The three rates that were used were 1 s per word, 2.5 s per word, and 5 s per word. These rates were used in the overt rehearsal studies of Tan and Ward (2008), and in order to keep approximate consistency with the nomenclature of the rates used in Experiment 1 (fast, 0.5 s per word; medium, 1 s per word; slow, 3 s per word), we shall refer to these three presentation rates of Experiment 2 as medium (1 s per word), slow (2.5 s per word), and very slow (5 s per word). Second, a different set of words was used in Experiment 2.

Experiment 1 used words from the Toronto word pool (Friendly *et al*., 1982), but many of these words are disyllabic, and we thought that we might maximise the chance of observing participants' rehearsals if common monosyllabic words were used. Finally, the words were presented visually (without AS) and the participants were required to read aloud each word as it was presented.

Thus, participants were presented with lists of between 3 and 15 words for IFR at each of three presentation rates, and they were required to rehearse aloud any word from the study lists that came to mind during the inter-stimulus intervals following the presentation of words on the list. Of particular interest was the degree to which recall started with serial position 1 in the absence of overt rehearsal.

Method

Participants. A total of 32 participants from City University London took part in this experiment. All were fluent English speakers.

Apparatus and Materials. The materials consisted of a set of 343 one-syllable nouns randomly selected from the MRC Psycholinguistic Database (Coltheart, 1981), with word frequencies ranging from 29-967 per million (Francis & Kučera, 1982). There were 336 experimental words and 7 practice words. Words were presented visually in the centre of the screen. An Olympus WS-100 digital voice recorder was used to record participants' overt rehearsals.

Design. The experiment used a 3 (presentation rate: medium, slow, and very slow) x 7 (list length: 3, 4, 5, 7, 10, 12, and 15) within-subjects factorial design. The main dependent variable was the proportion of words recalled (in any order). The sequences of overt rehearsals were also recorded.

Procedure. Participants were tested individually and were informed that they would be shown a practice list of 7 words followed by 42 experimental lists of words. The practice list was presented at a very slow rate (5 s per word). The experimental trials were arranged into three blocks; each block contained 14 trials (2 trials each of the 7 different list lengths) of a particular presentation rate. Words were presented at a rate of 1 s per word (medium), 2.5 s per word (slow) or 5 s per word (very slow); the words appeared on the screen for 750ms, and the screen was blank for the remaining inter-stimulus interval. The order of the blocks was randomized across participants, and within all blocks, the order of the list lengths was also randomized.

Each trial started with a fixation cross displayed for 1 s, followed by a sequence of between 3 and 15 words presented one at a time in the centre of the screen. Participants were instructed to read each word aloud as it was presented on the screen. They were also instructed to use the inter-stimulus interval to rehearse aloud any words from the current list that came to mind as they were studying the list. At the end of the list, there was an auditory cue and a visual prompt to recall the words from the list. Participants wrote down as many words as they could remember, in any order they wished, in a lined response grid. The recall period was 30 seconds.

Results

Proportion of words recalled. Figure 8 shows the effects of presentation rate and list length on the proportion of words recalled from each list. The proportions of words recalled for list lengths 3 -5 were similar, but thereafter, the proportion recalled decreased with increasing list length.

--Figure 8 about here--

A 3 (presentation rate: medium, slow and very slow) x 7 (list length: 3, 4, 5, 7, 10, 12, and 15) within-subjects ANOVA was performed to examine overall recall performance. There was a significant main effect of presentation rate, F (2,62) = 21.61, MSE = .015, p < .001, and a significant main effect of list length, F (6,186) = 429.5, MSE = .013, p < .001. The presentation rate x list length interaction was also significant F (12,372) = 5.57, MSE = .007, p < .001. At list lengths 7 and 10, recall was significantly higher at the slower presentation rate than at the medium and fast rates. At list length 12, recall was significantly higher at the slower presentation rate than at the fast rate. At list length 15, the three presentation rates were significantly different from one another. At the fast rate, all list lengths were significantly different from each other, except for list length 3 compared to 4 and 5. At the medium rate, all list lengths were significantly different from each other, except for list length 3 compared to 4 and 5, list length 4 compared to 5, 10 compared to 12, and 12 compared to 15. At the slow rate, all list lengths were significantly different from each other, except for list length 3 compared to 4 and 5, and list length 12 compared to 15.

Serial position curves. Figure 9 shows the serial position curves for each of the 7 different list lengths at each presentation rate. The serial position curves were analysed by a 3 (presentation rate) x *n* (serial position) within-subjects ANOVA (where *n* is the list length). The exact *p*-values of all the main effects and interactions for each list length can be found in Appendix B1. For the shorter list lengths (list lengths 3 to 5), the serial position curves for were relatively flat and there was no effect of presentation rate. At list lengths 7 and 10, there were extended primacy effects and recency effects and there was a general recall advantage throughout the list at the slower rates. Finally, at list lengths 12 and 15 there were significant primacy and recency effects, and the recall advantages for slower rates were limited to the elevated recall of the primacy items.

--Figure 9 about here--

Probability of first recall (PFR). Table 2 shows the proportion of trials in which a particular list position was recalled first, for each of the 7 list lengths at the 3 presentation rates.

--Table 2 about here--

As in Experiment 1, there was a consistent pattern across all conditions – for short lists, participants tended to begin recalling from the first item (italicised values), but as list length increased, there was a decreasing tendency to initiate recall with the first item, and an increasing tendency to initiate recall with one of the last 4 items (values in bold font). In addition, there was a slightly greater tendency for participants to begin their recall with the first item for the longer list lengths at the slower presentation rates. These main findings are summarised in Figure 10, which shows that participants who are instructed to rehearse overtly are more likely to persist in starting recall with the first list item at longer list lengths at slower rates.

--Figure 10 about here--

An analysis was conducted on the proportion of trials in which the first word recalled from a list was from serial position 1. A 3 (presentation rate: medium, slow, and very slow) x 7 (list length: 3-5, 7, 10, 12, and 15) within-subjects ANOVA was conducted to examine the proportion of trials starting with the first word across all conditions. There was a significant main effect of presentation rate, $F(2,62) = 3.56$, $MSE = .103$, $p < .05$, a significant main effect of list length, $F(6,186) = 82.66$, $MSE = .113$, $p < .001$, and a significant interaction between presentation rate x list length, $F(12,372) = 2.24$, $MSE = .052$, $p < .05$. As in Experiment 1, the proportion of trials beginning with the first item decreased as list length increased for all presentation rates, but the decline was less steep for the slow condition at the longer list lengths. With lists of 10 words or more, the proportion of trials starting with the first word was significantly greater at the very slow rate compared to the medium rate. At list length 15, the proportion of trials starting with the first word was additionally significantly greater in the very slow rate compared to the slow rate.

Analyses of rehearsal. We present two analyses that summarize the patterns of rehearsals generated by the participants: (1) a coarse-grained analysis that examined the patterns of rehearsal at the level of an entire trial, and (2) a fine-grained analysis that examined the rehearsal of individual words at different times during the presentation of the list.

Our coarse-grained analysis partitioned all the trials into two gross categories: trials in which there were schedules of *Fixed Rehearsals* and trials in which there were schedules of *Other Rehearsals*. Schedules of Fixed Rehearsals refer to patterns of rehearsal in which participants say during the presentation of the entire list either nothing or they repeat only the most recently presented list item. By contrast, Other Rehearsals refer to all other schedules of rehearsals, where by definition, words presented earlier in the list are rehearsed after the presentation of later list items.

We were first interested in how often participants adopted a fixed rehearsal strategy. A 3 (presentation rate) x 7 (list length) within-subjects ANOVA was performed on the proportion of trials in which there was a Fixed Rehearsal schedule. There was a significant main effect of presentation rate, $F(2,62) = 31.23$, $MSE = .363$, $p < .001$, reflecting a reduction in Fixed Rehearsal with slower presentation rates (58%, 21.7%, and 17.0% of the trials for the medium, slow, and very slow rates, respectively). There was a significant main effect of list length, $F(6,186) = 2.71$, $MSE = .046$, $p < .05$, reflecting a slight reduction in Fixed Rehearsal with increasing list length, and there was a non-significant interaction between the presentation rate and list length, $F(12,372) = 0.93$, $MSE = .043$, $p > .05$.

Our fine-grained analysis of rehearsal examined the rehearsal of individual words in the list. Following Rundus (1971), we use the term *Rehearsal Set* (RS) to refer to the sequence of rehearsals that the participant makes following the reading aloud of each successive list item. The number following the rehearsal set refers to the serial position of the most recently presented item, such that Rehearsal Set 4 (RS 4) refers to the set of rehearsals that the participant makes following the presentation of the fourth list item.

Figure 11 shows the proportion of words rehearsed at least once in the RS that followed each presented word. Since participants did not know the length of the list in advance, we collapsed across list length, such that Figure 11 shows a “serial position curve” of the words that were rehearsed after the presentation of each word, irrespective of the number of words yet to be presented. Consistent with the earlier coarse-grained analysis of rehearsal, it is clear from Figure 11 that words are more likely to be rehearsed at slower presentation rates than faster presentation rates. In addition, the probability of rehearsing any given list item is greater early on in the list (e.g., after the presentation of the third, fourth or fifth words, i.e., during RSs 3, 4, or 5, respectively), than later on in the list (e.g., after the presentation of the tenth, twelfth, or fifteenth words, i.e., during RSs 10, 12, or 15). Finally, it is also clear that whereas the rehearsal serial position curves are relatively flat at early RSs, the rehearsal serial position curves are more bowed at the RSs towards the end of the list. Thus, as the list length increases so participants selectively rehearse the first few list items and the last few list items during the later RSs.

--Figure 11 about here--

Effect of rehearsal on the PFR data. The main aim of Experiment 2 was to examine the role of rehearsal on the PFR data. We used our coarse-grained summary and our fine-grained summary of the rehearsals to provide two analyses of how PFR is related to rehearsal.

In our coarse-grained analysis, we again partitioned trials into the two gross categories: trials in which there were schedules of Fixed Rehearsals and trials containing at least some Other Rehearsals, and we examined the PFR data for each category of trial. We hoped that this subdivision of the data into fixed rehearsal and all other rehearsals might provide evidence supporting the data conducted in Experiment 1 with AS (in which rehearsal was prevented) and with No AS (in which rehearsal was assumed). Figure 12 shows the PFR for each presentation rate with the data partitioned into trials in which there was Fixed Rehearsal and trials in which there was at least some rehearsal of earlier words after the presentation of later list items.

--Figure 12 about here--

As can be seen from Figure 12, the tendency to initiate recall with serial position 1 at short list lengths is present when rehearsal occurs (Other Rehearsal conditions) and is present even in the absence of overt rehearsal (Fixed Rehearsal conditions). If anything, it appears that the tendency to initiate recall with serial position 1 decreased at slower rates under Fixed Rehearsal, but was at least maintained at slower rates when rehearsal occurred.

Statistical analyses are difficult because different participants contributed to the Other Rehearsal and Fixed Rehearsal conditions of Figure 12 for different list lengths and presentation rates. However, for the medium presentation rate (1 word / s) it was possible to select a group of 22 participants who performed Other Rehearsal on trials of all 7 list lengths, and a further 5 critical participants who performed Fixed Rehearsal on trials at all 7 list lengths. We were therefore able to perform a 2 (Rehearsal group) x 7 (list length) mixed ANOVA on the proportion of trials in which participants started recall with the first word. There was no significant main effect of Rehearsal group, F (1, 20) = 0.53, MSE = .320, $p > .05$, a significant main effect of list length, F (6, 150) = 23.37, MSE = .135, $p < .001$, and a non-significant interaction, F (6, 150) = 1.75, MSE = .077, $p >$ .05, $\eta^2_p = .065$. Thus, these results confirm (albeit with small numbers of participants in the Fixed Rehearsal group) the critical finding that participants start their recall with short lists with serial position 1 at medium rates even in the absence of rehearsal.

Furthermore, it was possible to analyse the data from 8 participants who performed Other Rehearsal on trials at all 7 list lengths and at all three presentation rates. Despite the rather small-scale nature of the analysis, there was still a significant main effect of presentation rate, F (2, 14) = 7.20, MSE = .045, $p < .01$, a significant main effect of list length, F (6, 42) = 24.24, MSE = .124, $p < .001$, and a non-significant interaction, F (12, 84) = 0.69, MSE = 0.055, $p > .05$. Thus, these results confirm (albeit with small numbers of participants) that participants who were encouraged to rehearse, and who rehearsed at least one earlier word during a trial are more likely to start their recall with serial position 1 at slower rates, and this tendency is observed across all list lengths.

In our fine-grained analysis, we considered the extent to which the PFR was affected by when words were last rehearsed. Table 3 shows the most recent RS (the Last RS) to which the first word recalled was rehearsed. The left-hand subtables refer to the special case in which the first word recalled was serial position 1, the right-hand subtables refer to the more general case and reports the most recent RS to which the first word recalled was rehearsed, irrespective of the serial position of that word. The upper, middle, and lower subtables refer in each case to the words presented at fast, medium, and slow rates.

-Table 3 about here-

As can be seen from the right-hand subtables of Table 3, which shows the PFR of all list items, there is a general tendency to initiate recall with either the first list item that has not been rehearsed or a recently rehearsed item. At slower presentation rates (e.g., bottom right subtable), participants are more likely to initiate recall with a recently rehearsed item and decreasingly likely to initiate recall with the first list item that has not been rehearsed. Considering now the left-hand subtables of Table 3, which shows the specific cases in which recall was initiated with the first list item, participants are again increasingly likely to rehearse the first list item towards the end of the list at slower rates. Note, however, that at the medium presentation rate, initiating recall with the first word is not fully dependent upon rehearsing the first items towards the end of the list. In fact, as can be seen from the top left subtable of Table 3, when the medium presentation rate of 1 word per s is used, participants initiate recall with the first item more often in the absence of rehearsal than following rehearsal.

Table 3 therefore provides further support for the main claim of the paper that participants initiate recall with the first item, even in the absence of rehearsal, but that rehearsal may help maintain (or indeed sometimes enhance) this tendency at slower presentation rates.

Discussion

Experiment 2 examined the effect of presentation rate and list length on IFR under overt rehearsal conditions. Consistent with Experiment 1 and many previous experiments, the overall recall performance in IFR increased with slower presentation rates at longer lists ((e.g., Bhatarah *et al.*, 2009; Glanzer and Cunitz, 1966; Murdock, 1962; Tan & Ward, 2000), a finding that is also observed in ISR (e.g., Bhatarah *et al.*, 2009; Tan & Ward, 2008).

The main motivation for this overt rehearsal experiment was to seek confirmation that participants initiated IFR of short lists of words with the very first list item, even in the absence of rehearsal. The critical finding from Experiment 2, therefore, comes from those participants who performed Fixed Rehearsal, that is did not rehearse any words other than to repeat the words immediately after their presentation. These participants still showed the tendency to initiate recall with the first word even in the absence of rehearsal and this finding is entirely consistent with the PFR data under AS in Experiment 1 at the fast and medium rates. Moreover, there was an indication that a lack of rehearsal by participants with Fixed Rehearsal schedules resulted in a decreased tendency to initiate recall with serial position 1 at the slower rates, a finding consistent with recall under AS in Experiment 1 at the slow rates.

There was evidence that rehearsal may nevertheless play a role at slower rates in the tendency to initiate recall with the first list item. In Experiment 1 we had found that the tendency to initiate recall with serial position 1 was *maintained* at slower rates when there was an opportunity to rehearse. However, participant in Experiment 2 who were instructed to overtly rehearse any earlier words that came to mind during the presentation of the list showed an *increase* in the tendency to initiate recall with serial position 1 at slower rates, a finding consistent with the early list items being rehearsed more often to later RSs at slower rates.

These findings are therefore broadly consistent with the main conclusions from Experiment 1: the data confirm that rehearsal is not strictly necessary for the tendency to initiate the IFR of short lists with serial position 1, and further suggests that rehearsal may nevertheless contribute to this tendency, especially at slower rates with longer lists.

Experiment 3

Finally, we briefly report a third experiment, Experiment 3, which was identical in all respects to Experiment 2, except that participants were not required to perform overt rehearsal. It could be argued that the overt rehearsal methodology used in Experiment 2 might have resulted in findings that were somewhat atypical of more standard encoding conditions. Although some previous research has shown that there is little difference in the serial position curves between overt rehearsal and silent rehearsal conditions (e.g., Horton, 1976; Murdock & Metcalfe, 1978; Roenker, 1974; Wixted & McDowell, 1989), there are other instances in which the overt rehearsal methodology has resulted in subtle differences in the serial position curves. For example, Fischler, Rundus and Atkinson (1970) examined IFR of long lists using the overt rehearsal methodology and found reduced recency effects compared with a silent study condition, and Tan and Ward (2008) examined ISR of short lists, and found that the overt rehearsal methodology resulted in steeper primacy effects than a condition in which participants were told to remain silent after reading aloud each word.

Although there were many similarities between the overall proportion correct data from the No AS participants in Experiment 1 and the overt rehearsal participants in Experiment 2, there were also some subtle differences between the experiments in the PFR data. In both Experiment 1 and Experiment 2, the overall proportion of words recalled increased with slower presentation rates at longer lists when rehearsal could occur. Thus, the effect of assumed (Experiment 1) and observed

(Experiment 2) rehearsal appeared to more than offset any reduction in overall correct recall associated with slower rates when rehearsal was prevented. By contrast, when the PFR curves in the two experiments were examined, slower presentation rates only *maintained* the tendency to initiate recall with the first word at slower rates in Experiment 1, but slower presentation rates actually *increased* the tendency to initiate recall with the first word at slower rates in Experiment 2.

This subtle difference in PFR could be explained if participants under overt rehearsal instructions in Experiment 2 were encouraged to rehearse more than they normally would under more standard study instructions. A third experiment was therefore performed which was identical in all respects to Experiment 2, except that participants were not required to perform overt rehearsal. Rather, the participants in Experiment 3 were told to remain silent after reading aloud each word as it was presented on the computer screen.

Method

Participants. A total of 32 participants from City University London and the University of Essex took part in this experiment. None had taken part in Experiment 1 or Experiment 2.

Apparatus and Materials, Design, and Procedure. This was identical to Experiment 2, except that participants were told to remain silent after reading aloud each word as it was presented on the computer screen.

Results

Proportion of words recalled. Figure 13 shows the effects of presentation rate and list length on the proportion of words recalled from each list in Experiment 3. A 3 (presentation rate: medium, slow and very slow) x 7 (list length: 3, 4, 5, 7, 10, 12, and 15) within-subjects ANOVA was performed to examine overall recall performance in the control condition. As with the experimental condition of Experiment 2, there was a significant main effect of presentation rate, F (2,62) = 29.37, MSE = .015, $p < .001$, a significant main effect of list length, F (6,186) = 316.7, MSE = .016, $p < .001$, and there was a significant interaction, F (12, 372) = 4.85, MSE = .000, p <

.001. The interaction arose because at the longer list lengths (list lengths 10, 12, and 15) recall significantly increased at slower presentation, whereas at the shorter list lengths, there was no significant difference between the different presentation rates.

--Figure 13 about here--

Probability of first recall (PFR). Figure 14 shows the PFR data from Experiment 3. An analysis was conducted on the proportion of trials in which the first word recalled from a list was from serial position 1. A 3 (presentation rate: medium, slow, and very slow) x 7 (list length: 3-5, 7, 10, 12, and 15) within-subjects ANOVA was conducted to examine the proportion of trials starting with the first word across all conditions in the control data. There was a non-significant main effect of presentation rate, F (2,62) = 0.86, MSE = .079, p = .43, a significant main effect of list length, F(6,186) = 107.9, MSE = .105, $p < .001$, and critically a non-significant interaction between presentation rate x list length, F(12,372) = 1.23, MSE = .059, p = .26.

--Figure 14 about here--

For all three presentation rates, participants tended to initiate recall with serial position 1 at short lists, but this tendency decreased to a similar extent with increasing list length. Therefore, under normal encoding conditions, the tendency to initiate IFR with the first word in shorter lists was maintained at slower presentation rates.

Discussion

Experiment 3 examined the effect of presentation rate and list length on IFR under the presentation rates and list lengths of Experiment 2, but under more standard encoding conditions.

Although the experiment adds little to the main thrust of the paper, that rehearsal is not strictly necessary for the tendency to initiate IFR with the first word in the list, it does help explain the subtle differences in the effect of presentation rates on the PFR data for longer lists.

Participants who performed IFR under normal encoding conditions in Experiment 3 performed like the No AS (normal encoding conditions) participants from Experiment 1. In both cases, the overall proportion of words recalled in IFR increased with slower presentation rates at longer lists, but the tendency to initiate recall with serial position 1 was *maintained* at slower rates when there was an opportunity to rehearse. This finding contrasts with the PFR data collected under overt rehearsal conditions in Experiment 2, where the tendency to initiate recall with serial position 1 actually *increased* at slower rates.

Our best interpretation of these data is that the participants who were instructed to perform overt rehearsal (Experiment 2) performed more rehearsal (on average) than those studying the lists under more normal conditions (Experiments 1 and 3). If rehearsal, where it occurs, helps (at least) offset the otherwise negative effects of slower presentation rates on the PFR, then we can explain the subtle differences in the PFR data across the three experiments in terms of differential rates of rehearsal in the three experiments. That is, the participants in Experiments 1 and 3 who performed IFR under standard instructions performed standard amount of rehearsal, on average, and so maintained the tendency to initiate IFR with the first word at slower rates, whereas the participants in Experiment 2 who performed IFR under overt rehearsal instructions performed more rehearsal and thus actually increased the tendency to initiate IFR with the first word at slower rates.

Although this contrast between Experiment 2 and Experiment 3 could be considered a cautionary tale when using the overt rehearsal methodology, it is also important to note that it is only by using the overt rehearsal method in Experiment 2 that we could measure which words were actually rehearsed, and so thereby confirm the main point of the experiment, that the tendency to initiate IFR with the first word need not require rehearsal at fast and medium rates.

General Discussion

The findings from our experiments strongly suggest that rehearsal is not necessary for the observed tendency for participants to initiate their IFR of a short list of words with the very first list item. The tendency was still present at fast presentation rates of 0.5 s per word (Experiment 1), the tendency was observed (albeit slightly reduced) under conditions of articulatory suppression (Experiment 1), and the tendency was still seen in trials in which there were no overt rehearsals of earlier list items (Experiment 2).

Our experiments suggest that rehearsal may nevertheless contribute to this tendency, especially at slow and very slow presentation rates. In Experiment 1, we found a reduction in the proportion of trials in which participants initiated recall with the first item under AS conditions relative to No AS conditions, and this difference was exaggerated at the slower rates. By contrast, when participants were assumed or observed to rehearse, the proportion of trials starting with serial position 1 was preserved (Experiments 1 and 3) or even increased (Experiment 2) at slower rates.

The challenge to recency-based accounts of IFR

These findings confirm that the Ward *et al*. (2010) data represent a challenge to accounts of IFR that assume that IFR is predominantly recency-based (e.g., Brown *et al.,* 2007; Davelaar, *et al.* 2005; Howard & Kahana, 2002; Tan & Ward, 2000; Ward, 2002). For short lists, there is simply far too great a tendency for participants to initiate IFR with the first list item. Thus, although recency-based accounts that assume that there is rehearsal appear to explain IFR of long lists at slow rates, these accounts appear to have difficulty in accounting for the very high tendency to initiate IFR with the very first item with short lists in the absence of rehearsal.

The current experiments therefore confirm the position assumed by Ward *et al.* (2010) that the first list item is preferentially accessed in IFR of short lists for reasons other than selective rehearsal. This finding obtained using IFR mirrors that obtained using ISR where participants are able to output a short sequence in a forward serial order in the absence of rehearsal during fast presentation rates (Baddeley & Lewis, 1984; Tan & Ward, 2008).

Alternative accounts of primacy from IFR

As raised in the introduction, rehearsal is not the only mechanism proposed to aid the primacy effect in IFR, and there are existing free recall data sets in which modest primacy effects are observed and for which a rehearsal explanation is unlikely. For example, modest primacy effects are sometimes observed in the continual distractor free recall task, in which rehearsal-preventing activity is interleaved between each of the stimuli including the last (Bhatarah, Ward & Tan, 2006; Bjork & Whitten, 1974; Howard & Kahana, 1999). Modest primacy effects are also observed in our own IFR data, in which participants see long lists of words presented at slow rates under overt rehearsal. Under these conditions, we quite often observe residual 1-item primacy effects (often representing very small numbers of trials) for words that were presented at serial position 1 but were not overtly rehearsed to later list positions (e.g., Tan & Ward, 2000; Ward, 2002; Ward & Tan, 2004). One alternative to a rehearsal-based explanation of primacy for these modest primacy effects is that the first items in the list may also benefit from being more temporally distinct (e.g., Glenberg & Swanson, 1986; Brown *et al.*, 2007) than the middle list items because they are in a temporally less crowded region of memory than the middle list items. Although these explanations can readily predict a modest primacy effect relative a large recency effect, these accounts have difficulty in predicting that the accessibility of the first list item will actually be far greater than the accessibility of the last list item.

An additional idea is that the primacy items can be selectively accessed at test via the retrieval of a "start context" which is itself a product of increased attention (e.g., Davelaar, *et al*., 2005). A related idea is that participants might try to retrieve the "Get Ready" warning signal that is typically used prior to the presentation of the first list item (Laming, 1999, 2010), in order to gain privileged initial access to serial position 1. Finally, the participants' internal contextual state could be the functional first item on the list (Metcalfe & Murdock, 1981) to which subsequent items are associated. One advantage of these ideas is that the privileged accessibility of the early list items appears to be limited to serial position 1 and there is little evidence of an extended primacy gradient in the PFR. One disadvantage of this explanation is that there has been little research as to what a "start of list" signal might be like, nor whether recall of early items is particularly affected if a warning signal is withheld.

Integrating theories of IFR and ISR

The data from our experiments suggest that instead of simply adjusting theories of IFR to account for the IFR of short lists, a more universal approach would be to attempt to integrate the IFR and ISR literatures (Bhatarah *et al.*, 2008, 2009; Ward, 2001; Ward *et al*., 2010). Consistent with the theoretical integration of the two tasks, our experiments showed that IFR was affected by presentation rate and articulatory suppression in similar ways to ISR (Baddeley & Lewis, 1984; Tan & Ward, 2008). In both tasks, recall tends to be initiated with the first list item for short lists in the absence of rehearsal, and the exact effect of presentation rate depends upon whether or not rehearsal can (more than) compensate for the increased retention interval of the early items at the slower rates.

Several accounts already try to explain both IFR and ISR (Anderson *et al.*, 1998; Brown, *et al.*, 2007; Farrell, in press; Grossberg & Pearson, 2008), and in the following paragraphs, we shall discuss each account in turn.

The first account to consider is the ACT-R account of Anderson *et al*. (1998). Although the authors should be commended for trying to provide an account of both IFR and ISR (as well as other list memory tasks), one can identify two major weaknesses in the approach. First, the model assumes that that items are encoded in very different way in the two tasks: in ISR, list items were associated to a hierarchically-organised list structure which could flexibly output the items in forward or backward order, whereas in IFR items were encoded using a simple rehearsal buffer that could maintain four list items. Second, primacy in IFR is heavily underpinned by rehearsal. Clearly, our current experiments provide evidence contrary to a rehearsal-based account of primacy, and recent evidence by Bhatarah *et al.* (2008, 2009) shows that IFR and ISR of 8-item lists are supported by very similar patterns of rehearsal, such that the two tasks can be performed even when the words are encoded in identical manner and the task is post-cued, and recent evidence by Grenfell-Essam and Ward (submitted) shows that this flexibility of recall to post-cue instruction can be extended to lists of between 1 and 15 words. Moreover, it is not clear that models of IFR that use a rehearsal buffer can adequately capture the forward-ordered nature of recall in different variants of the free recall tasks and it is unclear whether the account of IFR would predict the high tendency to initiate recall with the first list item with shorter lists.

The second account to consider is the SIMPLE account by Brown *et al.* (2007). In SIMPLE, each stimulus item is represented in multidimensional space, which includes the position of the items along a temporal dimension. Recency is an emergent property of representing items along a temporal dimension, and SIMPLE also predicts a smaller degree of primacy due to "edge effects" (the first list items will be more discriminable from the majority of the list items, owing to the greater temporal distances, on average, between the first and other list items). SIMPLE often assumes that rehearsal contributes to the primacy effect, and once the recencies of the rehearsed items are properly considered, SIMPLE can readily model IFR data showing large primacy effects (e.g., Brodie & Murdock, 1977; Brown, Della Sala, Foster, & Vousden, 2007; Rundus, 1971; Tan & Ward, 2000). SIMPLE often assumes that there is an additional positional dimension, which is used to sharpen up the serial position curves, to help with the directionality in recall, and to capture the grouping and chunking effects in serial recall. It may be that the positional dimension may also be increasingly dominant through (overt) rehearsal, leading to enhanced ordered recall of the rehearsed items at slower rates. The findings of Bhatarah *et al.* (2008, 2009) suggest that both temporal and positional dimensions are simultaneously encoded, and participants select the dimension of choice used by SIMPLE at retrieval. For IFR, the temporal dimension may be most dominant (but there could be some contribution from the positional dimension), whereas for ISR the positional dimension may be increasingly important. A related conclusion from manipulations of test expectancy in variants of reconstruction of order tasks has been proposed by Lewandowsky Nimmo, and Brown (2008). Currently, the SIMPLE model does not provide a full account of output order in IFR (but for some possible instantiations, see Brown *et al.*, 2008), and one must assume that a successful implementation would provide a principled reason why participants tend to perform forward-ordered recall in IFR, and tend to initiate IFR with the first list item and not a recency item on short lists of words.

One advantage of the LIST-PARSE model of Grossberg and Pearson (2008) is that it assumes that exactly the same working memory representations underpin ISR and IFR. Moreover, LIST-PARSE successfully captures the development of the serial position curve from primacy-dominant (with shorter lists) to recency-dominant (with longer lists). It assumes that working memory operates as a leaky integrator, and order is represented by the relative activations of the list items. Early in the list, a primacy gradient is established because earlier items have been integrated over a longer period. However, when the total activation of working memory reaches a maximum limit, the activitation of the list items decrease due to competitive self-normalising dynamics, such that at list lengths greater than those typical of ISR, these same mechanisms drive the evolution of a recency effect. One potential difficulty of the LIST-PARSE model is that it assumes that there are different patterns of rehearsal on the two tasks (contrary to the data from Bhatarah *et al.*, 2009). It is also unclear whether it adequately captures the degree of forward-ordered recall present in both ISR and IFR.

Finally, a very recent account of IFR and ISR has been proposed by Farrell (in press). Farrell proposes that continuous lists of words of different list lengths are encoded as one or more episodic clusters. In this account, each word is associated with both a group context and a within-group marker. It is assumed that list and group contexts evolve in response to the arrival of new events, and that the cluster size is variable across and within-individuals in different circumstances. The strength of encoding within a group follows a primacy gradient, which is assumed to be due to the cognitive system being sensitive to the novelty of the incoming information. In order to recall the words at test, participants must first recall the superordinate cluster before the contents of the cluster can be accessed. The retrieval of a cluster is error-prone and much of the failure to recall is derived from failure to access the cluster. The exception is that it is assumed that retrieval of the currently ‘open’ group is error-free leading to recency effects in IFR. Indeed, the account predicts that participants will tend to initiate IFR of longer lists with the first item of the most recent cluster. When the list length is unknown, the graded recency effect observed in the PFR data may be explained by assuming that participants on different trials are tested at a time where there are different sizes of terminal cluster. The account can also explain the tendency present in some (but by no means all) IFR datasets for participants to initiate recall of long lists of known lengths with an item two or three words in from the end of the list (e.g., Farrell, 2010). This tendency is explained if participants output in order from the most recent cluster containing 3 or 4 words.

Upon successful retrieval of a cluster, the items within a cluster are probed sequentially with the in-position markers, leading to forward-ordered recall and typical error gradients. Finally, the retrieval of a second or subsequent cluster is made more difficult by output interference at the level of accessing clusters. It is difficult to fully assess the impact of this new account, but the overall scope of the model and its integration of the main findings from both the ISR and IFR data sets are to be admired. This model does not assume that rehearsal is required to provide primacy in short lists, since with short lists there may be but a single cluster, which is easily accessed and recall will probed in a forward order starting with the first list item. As list length progresses it is increasingly likely that multiple groups will be formed, which will reduce the likelihood that the first chunk will be the first probed.

One might imagine that AS might act to reduce the group size, but rehearsal in the No AS conditions could strengthen the coherence within- (and possible increase the size) of possible groups. One potential criticism with the account is that there are many mechanisms for generating primacy effects (clustering with an emphasis on the first cluster, ordered retrieval via within-list position markers, primacy gradient, output interference) and future work may be needed to determine the relative importance of each mechanism.

Adapting current accounts of IFR and ISR to unified accounts of both tasks

An integrated account of ISR and IFR could also evolve from the adaptation of current theories of IFR to ISR. Both the Temporal Context Model (TCM, Howard & Kahana, 2002) and the account by Laming (2010) assume that retrieval in IFR proceeds in a forward ordered manner (for supporting data, see Bhatarah *et al*., 2008; Golomb, Peelle, Addis, Kahana, & Wingfield, 2008; Klein, Addis, & Kahana, 2005). Furthermore, as described in the preceding section, the accounts by Metcalfe and Murdock (1981), Laming (2010), and by Davelaar *et al.* (2005) already assume that the PFR can be initiated by a "Get Ready" or "Start" of list or Internal context signal. Our experiments certainly contained a fixation cross and a warning signal that could be used to prepare participants for the start of a list. It may be that these details from accounts of IFR can be adapted to ISR.

Alternatively, an integrated account of ISR and IFR could also evolve from the adaptation of current theories of ISR, such as the phonological loop model (Baddeley, 1986), to account for IFR of longer lists. The phonological loop could help account for (a) the initial tendency to start recall with the first list item for short lists in IFR, (b) the high tendency to output responses in forward serial recall in IFR of short lists (e.g., the relatively high tendency to output the complete four-item list in correct serial order), and (c) the susceptibility of IFR of short lists to manipulations of presentation rate and AS.

The phonological loop has been modelled using a primacy gradient to represent serial order (e.g., the Primacy Model, Page & Norris, 1998), and this type of ordinal representation of serial order is similar to the mechanism proposed by Grossberg and Pearson (2008). An alternative approach is to encode serial order by using positional cues. For example, in the Start-End Model (Henson, 1998), the list items were assumed to be associated with start and end of list markers.

These positional codes are sufficient to support the serial recall of short lists, but might only give small primacy and recency advantages to the accessibilities of items from longer lists. Henson (1998, p.116) argued that the Start-End Model could therefore in principle account for the data from IFR of short lists because the recall order is similar to ISR (Corballis, 1967; see also, Neath & Crowder, 1996; Ward *et al.*, 2010). However, at longer lists, the predictions of the Start-End model might converge with those proposed by Glenberg and Swanson (1986). One acknowledged weakness of an end of list marker of the type characterised by Henson (1998) is that one needs to know the list length before presentation (see Murdock, 2001) and so the Start-End model might have difficulties in methodologies such as our own, in which the list length is not known in advance.

Relationship between IFR and other immediate memory tasks

We have so far spent time discussing the relationship between IFR and ISR, but we note that there are many similarities between our data and the data from other immediate memory tasks. For example, Bunting, Cowan, and Saults (2006) examined the effect of presentation rate on the running memory span task. Participants viewed lists of unpredictable length of between 12 and 20 digits and were instructed to try to remember the last seven digits. At the end of the list, the participants received a digit cue, between 1 and 7, and had to recall that number of digits in order from the end of the list. The authors found clear extended recency effects throughout their data, and also found that performance was higher at slower rates, leading to more shallow serial position curves. The authors argued that they found evidence for both an active rehearsal mechanism and a passive (recency-based) memory mechanism. The authors' data and conclusions certainly share similarities with our own findings and can be easily reconciled with position adopted by Bhatarah *et al.* (2009): with long lists of stimuli, participants tend to naturally start with one of the last few items and recall in forward order (generating extended recency effects and ordered terminal runs) but can also rehearse earlier list items (an active mechanism) at slower rates. However, a development that arises from the current set of experiments is that our account presupposes that there must be something different about the first list item that makes it particularly memorable, over and above the level of rehearsal that it receives. Interestingly, there are also recall advantages to the early list items in a running memory span task, if the first item to be recalled was the first item in the list, and these effects can be greatest when the start item and list length is known in advance (for related data, see Crowder, 1969; Hockey & Hamilton, 1977; Palladino & Jarrold, 2008).

It should also be noted that primacy effects can be obtained using hard-to-verbalise stimuli in tests of human immediate memory, such as snowflakes (Neath, 1993), random checkerboards (Avons, 1998; Avons & Mason, 1999; Ward, Avons, & Melling, 2005), or spatial dots (Jones Farrand, Stuart, & Morris, 1995). They can also be obtained in IFR when a rehearsal explanation is unlikely due to fast presentation rates (Neath & Crowder, 1996), and more controversially can be obtained in tests of non-human immediate memory (e.g., Gaffan, 1992, 1994; Wright, 1994). It is highly unlikely that verbal rehearsal is responsible for all these effects.

One additional mechanism proposed from experiments with non-human participants is the idea that primacy effects may be related to the responses that are made to initiate a trial (so-called list-initiation-responses artefacts, Gaffan, 1994; Wright, 1994). Although human participants rarely press down on a bar to initiate a trial, they quite often make a mouse click or press a computer key to continue with the next trial, which could serve the same memorial purpose. To our knowledge, however, the memorial consequences of these list-initiation-responses to PFR has not been systematically examined in human list-learning studies.

Reflection on our previous accounts of IFR

In Ward *et al.* (2010), we assumed that the preferred explanation of IFR at short lists was likely to arise through the theoretical integration of the IFR and ISR literatures. However, we argued that our earlier recency-based accounts of the primacy effect in IFR (e.g., Tan & Ward, 2000; Ward, 2002) could yet explain our findings if participants selectively rehearsed the first list item towards the end of the list. Our findings that participants initiate IFR of short lists with the first list items in the *absence* of rehearsal clearly demonstrate that a rehearsal-based explanation of primacy is no longer tenable, and that some additional non-rehearsal based mechanism must be responsible for the preferential accessibility of the first list item with short lists.

However, there is clear evidence for the role of rehearsal at slower rates in IFR and it is important to try to reconcile our current position to our earlier claims in more recent papers such as Bhatarah *et al.* (2008, 2009). In Bhatarah *et al.* (2008, 2009) we were keen to understand why there were marked differences in the shapes of the serial position curves in IFR and ISR, even though participants encoded and rehearsed lists of items for the two tasks in near-identical ways. We maintained that accessibility in episodic memory was governed by the number, recency, and distribution of the rehearsals of the items (Tan & Ward, 2000; Ward, 2002), and we argued that the shape of the serial position curve was affected by both the accessibility of individual list items and the output order of the words recalled at test.

We recognized that participants had some control over which words they output first (Bhatarah *et al.*, 2008, 2009; Tan & Ward, 2007) and could respond in different orders to IFR and ISR instructions, even when the task instructions were post-cued (see also Grenfell-Essam & Ward, submitted). However, we assumed that participants were free to output at test only those words that were currently accessible, and we assumed that as additional words were added to the list (or were rehearsed or recalled), so words that were not rehearsed would become less accessible. In line with these assumptions, we found elevated primacy effects for words that were likely to be rehearsed (e.g., slow presentation rates, short monosyllabic words, conditions free from AS), but far more modest primacy effects for non-rehearsed items, which we assumed reflected the accessibilities of the originally encoded events.

Following a successful recall, Bhatarah *et al*. (2009) found that participants showed an increased tendency to continue recall in a forward direction (Bhatarah, *et al*., 2008; Howard &

Kahana, 1999; Laming, 2010; Nairne, Ceo, & Reysen, 2007), such that the output orders and resultant serial position curves differed depending upon the initial recall (Ward, *et al*., 2010).

Bhatarah *et al*. (2009) investigated lists of fixed list length, which varied across experiments from between 6 and 12 items, and with these list lengths, participants tended to start recall with the first list item on only a minority of trials. It was perhaps for this reason that no special case was made for the first word in the list; the increased tendency to initiate recall with the first item for the short lists was put down to the increased rehearsal afforded to the first list items.

Our current experiments demonstrate that the Bhatarah *et al.* (2009) position must be amended to accommodate the enhanced accessibility of the first list item in the recall of short lists in the absence of rehearsal, and we are actively pursuing many possibilities. These include: increased attention, temporal distinctiveness, recall of the start of list cue, and/or the use of additional ISR mechanisms.

Perhaps the minimal change necessary to salvage the Bhatarah *et al.* (2009) position is to assume that participants pay more attention to the first item or associate the first list item with some sort of start of list marker. If one assumes that participants start each list with good intentions to try to recall as many of the list items as possible, it is not unreasonable that they would pay close attention to the first list item, intending to recall the first item (and all subsequent items) as soon as they were able to do so. However, as the list length increases, so the accessibility of the first list item decreases with the increasing number of intervening items (such that the PFR of serial position 1 decreases with increasing list length) and also decreases with the functional retention interval. The retention interval of the first item will increase with slower presentation rates when rehearsal is prevented through AS (and hence the accessibility of the first list item will decrease at slow rates under AS). However, when rehearsal can take place, the attended item may be preferentially rehearsed and the rehearsal may (more than) offset any decrease in the accessibility of the first item at a slower rate (Bhatarah *et al.*, 2009; Tan & Ward, 2008).

Alternatively, it may be that following Ward *et al*. (2010), our data are best interpreted by a new fully integrated account of ISR and IFR such as that recently proposed by Farrell (in press) or a modification of those proposed by Brown *et al.* (2007), or Grossberg and Pearson (2008). We feel that that the merger of the IFR and ISR literatures is in its infancy, and requires theoretically-motivated empirical work to explore the boundary conditions of what is similar and what is dissimilar between the two tasks, or indeed, to determine if they should be merged at all. We hope that our current discovery that there are similar effects of AS and presentation rate on recall and output orders in IFR and ISR (Baddeley & Lewis, 1984; Tan & Ward, 2008) helps provides a further step towards the theoretical integration of the two tasks.

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Appendix A1

Analyses of the serial position curves from Figure 3 using all the data. At each list length, the free recall data were subjected to a 2 (Suppression condition: AS, No AS) x 3 (Presentation rate: fast, medium, slow) x *n* (serial position: SP, 1, … *n*) mixed ANOVA, where *n* is the list length.

List length	**Main effects**			**Two-way interactions**			**Three-way interaction**
	Suppression	**SP**	**Pres rate**	**Suppression x SP**	**Suppression x Pres Rate**	**SP x Pres Rate**	**Suppression x SP x Pres Rate**
2	F (1, 58) = 3.17, MSE = .011, p = .080	F (1, 58) = 0.875, MSE = .003, p = .353	**F (2, 116) = 3.34, MSE = .003, p = .039**	F (1, 58) = 0.219, MSE = .003, p = .642	F (2, 116) = 2.28, MSE = .003, p = .107	F (2, 116) = 1.85, MSE = .003, p = .161	**F (2, 116) = 4.72, MSE = .003, p = .011**
4	**F (1, 58) = 46.6, MSE = .067, p < .001**	**F (3, 174) = 16.5, MSE = .027, p < .001**	**F (2, 116) = 9.25, MSE = .036, p < .001**	**F (3, 174) = 6.05, MSE = .027, p = .001**	**F (2, 116) = 3.82, MSE = .036, p = .025**	**F (6, 348) = 2.79, MSE = .026, p = .012**	F (6, 348) = 0.357, MSE = .026, p = .905
5	**F (1, 58) = 33.1, MSE = .154, p < .001**	**F (4, 232) = 20.9, MSE = .057, p < .001**	F (2, 116) = 1.54, MSE = .045, p = .219	**F (4, 232) = 11.3, MSE = .057, p < .001**	**F (2, 116) = 6.03, MSE = .045, p = .003**	F (8, 464) = 1.06, MSE = .044, p = .393	F (8, 464) = 1.19, MSE = .044, p = .306
6	**F (1, 58) = 32.1, MSE = .181, p < .001**	**F (5, 290) = 35.4, MSE = .080, p < .001**	F (2, 116) = 1.47, MSE = .057, p = .235	**F (5, 290) = 3.44, MSE = .080, p = .005**	**F (2, 116) = 6.60, MSE = .057, p = .002**	F (10, 580) = 0.791, MSE = .049 p = .637	F (10, 580) = 1.19, MSE = .049, p = .297
7	**F (1, 58) = 30.1, MSE = .184, p < .001**	**F (6, 348) = 55.5, MSE = .070, p < .001**	**F (2, 116) = 6.93, MSE = .047, p = .001**	**F (6, 348) = 7.60, MSE = .070, p < .001**	**F (2, 116) = 9.00, MSE = .047, p < .001**	**F (12, 696) = 2.17, MSE = .058, p = .012**	F (12, 696) = 0.924, MSE = .058, p = .522
8	**F (1, 58) = 22.9, MSE = .207, p < .001**	**F (7, 406) = 69.6, MSE = .076, p < .001**	**F (2, 116) = 20.1, MSE = .045, p < .001**	**F (7, 406) = 2.14, MSE = .076, p = .038**	**F (2, 116) = 4.98, MSE = .045, p = .008**	**F (14, 812) = 2.75, MSE = .057, p = .001**	F (14, 812) = 1.13, MSE = .057, p = .323
12	**F (1, 58) = 21.0, MSE = .159, p < .001**	**F (11, 638) = 131.6, MSE = .059, p < .001**	**F (2, 116) = 10.4, MSE = .049, p < .001**	**F (11, 638) = 1.86, MSE = .059, p = .041**	**F (2, 116) = 4.87, MSE = .049, p = .009**	**F (22, 1276) = 8.95, MSE = .046, p < .001**	F (22, 1276) = 0.871, MSE = .046, p = .634

Note: significant main effects and interactions are presented in bold

Appendix A2.

Analyses of the serial position curves from Figure 5 using only data from trials starting with SP1. At each list length, the free recall data were subjected to a 2 (Suppression condition: AS, No AS) x 3 (Presentation rate, Pres rate: fast, medium, slow) x *n-1* (serial position, SP, 2, … *n*), where *n* is the list length. SP 1 was excluded since it was, by definition always, recalled. Note that there were relatively few participants included in the analyses at longer list lengths, particularly in the AS conditions.

List length	**Main effects**			**Two-way interactions**			**Three-way interaction**
	Suppression	**SP**	**Pres rate**	**Suppression x SP**	**Suppression x Pres Rate**	**SP x Pres Rate**	**Suppression x SP x Pres Rate**
2	F (1, 58) = .445, MSE = .003, p = .507		F (2, 116) = 0.429, MSE = .003, p = .652		F (2, 116) = 1.71, MSE = .003, p = .185		
4	**F (1, 52) = 16.3, MSE = .067, p < .001**	**F (2, 104) = 13.47, MSE = .034, p < .001**	F (2, 104) = 2.41, MSE = .052, p = .095	F (2, 104) = 2.59, MSE = .034, p = .081	F (2, 104) = 0.98, MSE = .052, p = .380	F (4, 208) = 0.747, MSE = .040, p = .561	F (4, 208) = 0.830, MSE = .040, p = .508
5	**F (1, 42) = 13.7, MSE = .150, p < .001**	**F (3, 126) = 6.72, MSE = .106, p < .001**	F (2, 84) = 0.37, MSE = .075, p = .689	**F (3, 126) = 3.56, MSE = .106, p = .016**	F (2, 84) = 0.59, MSE = .075, p = .555	F (6, 252) = 0.345 MSE = .071, p = .912	F (6, 252) = 0.34, MSE = .071, p = .915
6	**F (1, 39) = 7.68, MSE = .236, p = .008**	**F (4, 156) = 8.46, MSE = .154, p < .001**	F (2, 78) = 1.34, MSE = .107, p = .268	F (4, 156) = 0.93, MSE = .154, p = .449	F (2, 78) = 2.23, MSE = .107, p = .115	F (8, 312) = 0.85, MSE = .122 p = .558	F (8. 312) = 1.16 MSE = .122, p = .325
7	F (1, 21) = 0.31, MSE = .272, p = .582	**F (5, 105) = 7.98, MSE = .118, p < .001**	F (2, 42) = 2.60, MSE = .123, p = .086	**F (5, 105) = 2.86, MSE = .118, p = .019**	F (2, 42) = 0.36, MSE = .123, p = .697	**F (10, 210) = 1.91, MSE = .126, p = .046**	F (10, 210) = 1.15, MSE = .126, p = .325
8	**F (1, 22) = 6.26, MSE = .289, p = .020**	**F (6, 132) = 7.07, MSE = .168, p < .001**	F (2, 44) = 0.73, MSE = .114, p = .486	F (6, 132) = 0.63, MSE = .168, p = .709	**F (2, 44) = 3.32, MSE = .114, p = .046**	F (12, 264) = 0.94, MSE = .130, p = .504	F (12, 264) = 0.73, MSE = .130, p = .718
12	F (1, 5) = 0.17, MSE = .297, p = .697	**F (10, 50) = 2.96, MSE = .201, p = .005**	F (2, 10) = 1.41, MSE = .117, p = .289	F (10, 50) = 0.15, MSE = .201, p = .999	F (2, 10) = 0.74, MSE = .083, p = .502	F (20, 100) = 1.64, MSE = .128, p = .058	F (20, 100) = 0.95, MSE = .128, p = .533

Note: significant main effects and interactions are presented in bold

Appendix A3.

Analyses of the serial position curves from Figure 6 using only data from trials starting with one of the last four serial positions. At each list length, the free recall data were subjected to a 2 (Suppression condition: AS, No AS) x 3 (Presentation rate, Pres rate: fast, medium, slow) x *n* (serial position, SP, 1, … *n*), where *n* is the list length. Note that there were relatively few participants included in the analyses at shorter list lengths, particularly in the No AS conditions.

List length	**Main effects**			**Two-way interactions**			**Three-way interaction**
	Suppression	**SP**	**Pres rate**	**Suppression x SP**	**Suppression x Pres Rate**	**SP x Pres Rate**	**Suppression x SP x Pres Rate**
2							
4	***F* (1, 8) = 44.7, *MSE* = .046, *p* < .001**	***F* (3, 24) = 3.05, *MSE* = .137, *p* = .048**	*F* (2, 16) = 0.01, *MSE* = .120, *p* = .986	*F* (3, 24) = 1.16, *MSE* = .137, *p* = .346	*F* (2, 16) = .47, *MSE* = .120, *p* = .636	*F* (6, 48) = 0.36, *MSE* = .113, *p* = .903	*F* (6, 48) = 0.54, *MSE* = .113, *p* = .775
5	*F* (1, 17) = 2.69, *MSE* = .117, *p* = .119	***F* (4, 68) = 10.2, *MSE* = .105, *p* < .001**	*F* (2, 34) = 1.26, *MSE* = .108, *p* = .296	*F* (4, 68) = 2.24, *MSE* = .105, *p* = .074	*F* (2, 34) = 1.31, *MSE* = .108, *p* = .284	*F* (8, 136) = 1.09, *MSE* = .087, *p* = .375	***F* (8, 136) = 2.05, *MSE* = .087, *p* = .045**
6	***F* (1, 31) = 17.8, *MSE* = .121, *p* < .001**	***F* (5, 155) = 45.41, *MSE* = .116, *p* < .001**	*F* (2, 62) = 1.15, *MSE* = .071, *p* = .322	*F* (5, 155) = 0.77, *MSE* = .116, *p* = .571	*F* (2, 62) = 2.98, *MSE* = .071, *p* = .058	*F* (10, 310) = 1.17, *MSE* = .093 *p* = .313	*F* (10, 310) = 0.92, *MSE* = .093, *p* = .515
7	***F* (1, 39) = 16.44, *MSE* = .190, *p* < .001**	***F* (6, 234) = 53.2, *MSE* = .111, *p* < .001**	***F* (2, 78) = 4.53, *MSE* = .071, *p* = .014**	*F* (6, 234) = 0.81, *MSE* = .111, *p* = .566	***F* (2, 78) = 5.61, *MSE* = .071, *p* = .005**	***F* (12, 468) = 2.00, *MSE* = .098, *p* = .023**	*F* (12, 468) = 0.79 *MSE* = .098, *p* = .663
8	***F* (1, 40) = 8.17, *MSE* = .224, *p* = .007**	***F* (7, 280) = 77.6, *MSE* = .093, *p* < .001**	***F* (2, 80) = 4.77, *MSE* = .055, *p* = .011**	*F* (7, 280) = 1.20, *MSE* = .093, *p* = .301	***F* (2, 80) = 3.71, *MSE* = .055, *p* = .038**	***F* (14, 560) = 1.72, *MSE* = .088, *p* = .048**	***F* (14, 560) = 2.05, *MSE* = .088, *p* = .013**
12	***F* (1, 55) = 10.15, *MSE* = .171, *p* = .002**	***F* (11, 605) = 142.6, *MSE* = .071, *p* < .001**	***F* (2, 110) = 7.90, *MSE* = .076, *p* = .001**	***F* (11, 605) = 2.81, *MSE* = .071, *p* = .001**	***F* (2, 110) = 3.48, *MSE* = .076, *p* = .034**	***F* (22, 1210) = 4.94, *MSE* = .069, *p* < .001**	*F* (22, 1210) = 0.901, *MSE* = .069, *p* = .594

Note: significant main effects and interactions are presented in bold

Appendix B1

Analyses of the serial position curves from Figure 9 using all the data. At each list length, the free recall data were subjected to a 3 (Presentation rate: fast, medium, slow) x *n* (serial position, SP, 1, … *n*) within-subjects ANOVA, where *n* is the list length.

List length	**Main effects**		**Two-way interactions**
	Presentation rate	**SP**	**Presentation rate x SP**
3	*F* (2,62) = 1.20, *MSE* = .014, *p* =.310	*F* (2,62) = 0.693, *MSE* = .009, *p* =.504	*F* (4,124) = 0.097, *MSE* = .009, *p* =.983
4	*F* (2,62) = 0.926, *MSE* = .009, *p* = .401	*F* (3,93) = 0.255, *MSE* = .010, *p* = .858	*F* (6,186) =1.39, MSE = .010, *p* = .222
5	*F* (2,62) = 0.035, *MSE* = .045, *p* = .966	*F* (4,124) = 2.18, *MSE* = .041, *p* = .075	*F* (8,248) = 1.438, *MSE* = .037, *p* = .181
7	***F* (2,62) = 9.83, *MSE* = .091, *p* < .001**	***F* (6,186) = 7.73, *MSE* = .117, *p* < .001**	*F* (12,372) = 1.60, *MSE* = .091, *p* = .089
10	***F* (2,62) = 13.0, *MSE* = .117, *p* < .001**	***F* (9,279) =18.5, *MSE* = .131, *p* < .001**	*F* (18,558) = 1.42, *MSE* = .103, *p* = .115
12	***F* (2,62) = 6.92, *MSE* = .108, *p* < .005**	***F* (11,341) = 23.6, *MSE* = .131, *p* < .001**	***F* (22,682) = 3.66, *MSE* = .111, *p* < .001**
15	***F* (2,62) = 32.1, *MSE* = .098, *p* < .001**	***F* (14,434) = 19.8, *MSE* = .119, *p* < .001**	***F* (28,868) = 3.23, *MSE* = .105, *p* < .001**

Note: significant main effects and interactions are presented in bold

<u>Table Captions</u>

<u>Table 1.</u> Data from Experiment 1. The distribution of the first words recalled on each trial, as a function of the list length and the words' serial position. There are three different subtables, one for each of the presentation rates. The top panel of each subtable shows the No AS condition and the bottom panel of each subtable shows the AS condition. The first subtable shows the Fast presentation rate data, the middle subtable shows the medium presentation rate data, and the last subtable shows the slow presentation rate data. The italicised values represent the frequency of trials in which the first word recalled was from serial position 1, and the bold values represent the frequency of trials in which the first word recalled was from one of the last four serial positions. The values in regular font represent the frequency of trials in which the first word recalled was from one of the other serial positions. Void = no words were recalled on a particular trial.

<u>Table 2.</u> Data from Experiment 2. The distribution of the first words recalled on each trial, as a function of the list length and the words' serial position. There are three different subtables, one for each of the presentation rates. The first subtable shows the medium presentation rate, the second subtable shows the slow presentation rate data, and the third subtable shows the very slow presentation rate. The italicised values represent the frequency of trials in which the first word recalled was from serial position 1, and the bold values represent the frequency of trials in which the first word recalled was from one of the last four serial positions. The values in regular font represent the frequency of trials in which the first word recalled was from one of the other serial positions. Void = no words were recalled on a particular trial.

<u>Table 3.</u> Data from Experiment 3. The distribution of the first words recalled on each trial, as a function of when they were last rehearsed. A Rehearsal Set (RS) refers to the sequence of words that is rehearsed in the inter-stimulus interval immediately following a presented item, such that RS 7 refers to the sequence of words rehearsed immediately after the

presentation of the seventh word in the list. Last RS refers to the most recent RS to which a particular word was rehearsed. There are six different subtables in total, the upper, middle and lower subtables refer to the data from the medium, slow, and very slow presentation rates, respectively; the left-hand subtables refer to the most recent rehearsals of the PFR data when the first word rehearsed was from serial position 1, whereas the right-hand subtables refer to the most recent rehearsals of the PFR data when the first word rehearsed was from any serial position (including serial position 1).

Table 1.

Data from Experiment 1

Fast Presentation Rate

Serial Position	List Length 2	4	5	6	7	8	12
				No AS Fast			
1	*119*	*114*	*100*	*83*	*61*	*52*	*11*
2	**1**	**5**	**4**	6	7	1	6
3		**0**	**5**	**5**	3	2	3
4		**1**	**0**	**7**	**10**	3	2
5			**6**	**6**	**12**	**8**	3
6				**9**	**10**	**13**	6
7					**12**	**23**	4
8						**17**	7
9							**15**
10							**11**
11							**20**
12							**27**
Void	0	0	0	0	0	0	0
Error on first word	0	0	5	4	5	1	5
Total	120	120	120	120	120	120	120
				AS Fast			
1	*117*	*100*	*78*	*58*	*35*	*28*	*10*
2	**3**	**5**	**7**	2	6	3	1
3		**5**	**10**	**8**	2	3	0
4		**5**	**9**	**12**	**5**	4	0
5			**12**	**13**	**13**	**7**	0
6				**22**	**16**	**10**	2
7					**39**	**26**	7
8						**35**	11
9							**7**
10							**24**
11							**13**
12							**42**
Void	0	0	0	0	0	0	0
Error on first word	0	5	4	5	4	4	3
Total	120	120	120	120	120	120	120

Data from Experiment 1

Medium Presentation Rate

Serial Position	List Length 2	4	5	6	7	8	12
				No AS Medium			
1	*117*	*110*	*91*	*72*	*63*	*43*	*22*
2	**1**	**3**	**3**	3	3	3	0
3		**3**	**8**	**4**	5	5	5
4		**1**	**9**	**12**	**8**	8	1
5			**6**	**11**	**14**	**4**	5
6				**16**	**7**	**14**	5
7					**18**	**20**	6
8						**16**	5
9							**11**
10							**11**
11							**20**
12							**27**
Void	0	0	0	0	0	0	0
Error on first word	2	3	3	2	2	7	2
Total	120	120	120	120	120	120	120
				AS Medium			
1	*118*	*88*	*61*	*39*	*25*	*24*	*7*
2	**2**	**8**	**7**	3	0	3	2
3		**7**	**17**	**7**	5	6	0
4		**11**	**16**	**18**	**6**	5	2
5			**18**	**22**	**22**	**3**	2
6				**26**	**22**	**17**	1
7					**36**	**27**	1
8						**31**	1
9							**5**
10							**11**
11							**33**
12							**52**
Void	0	0	0	0	0	0	0
Error on first word	0	6	1	5	4	4	3
Total	120	120	120	120	120	120	120

Data from Experiment 1

Slow Presentation Rate

Serial Position	List Length 2	4	5	6	7	8	12
				No AS Slow			
1	*115*	*92*	*79*	*70*	*63*	*63*	*40*
2	**5**	**15**	**13**	7	7	7	9
3		**3**	**8**	**7**	7	6	5
4		**9**	**7**	**11**	**3**	6	2
5			**11**	**11**	**9**	**2**	0
6				**6**	**12**	**5**	5
7					**17**	**10**	2
8						**19**	3
9							**8**
10							**9**
11							**10**
12							**24**
Void	0	0	0	0	0	0	0
Error on first word	0	1	2	8	2	2	3
Total	120	120	120	120	120	120	120
				AS Slow			
1	*107*	*48*	*27*	*28*	*25*	*17*	*12*
2	**8**	**52**	**8**	8	8	5	6
3		**19**	**11**	**7**	6	3	3
4		**24**	**28**	**9**	**7**	3	1
5			**40**	**17**	**10**	**4**	3
6				**43**	**20**	**8**	3
7					**39**	**28**	3
8						**47**	4
9							**2**
10							**7**
11							**28**
12							**45**
Void	0	0	0	0	0	0	0
Error on first word	5	5	6	8	5	5	3
Total	120	120	120	120	120	120	120

Table 2.

Data from Experiment 2

Serial Position	List Length 3	4	5	7	10	12	15
				Medium			
1	*59*	*59*	*49*	*41*	*23*	*10*	*7*
2	**3**	**3**	**4**	2	3	1	1
3	**1**	**0**	**2**	0	0	0	2
4		**2**	**2**	**1**	2	1	1
5			**5**	**7**	2	2	2
6				**6**	1	3	0
7				**6**	**8**	1	0
8					**8**	2	5
9					**7**	**5**	1
10					**9**	**5**	1
11						**13**	3
12						**20**	**6**
13							**9**
14							**15**
15							**10**
Error/Void on first word	1	0	2	1	1	1	1
Total	64	64	64	64	64	64	64

Serial Position	List Length 3	4	5	7	10	12	15
				Slow			
1	*61*	*59*	*57*	*39*	*23*	*18*	*12*
2	**2**	**3**	**3**	2	1	1	1
3	**0**	**0**	**1**	1	1	1	0
4		**2**	**1**	**1**	0	1	1
5			**2**	**5**	3	2	1
6				**6**	3	3	2
7				**8**	**2**	3	2
8					**3**	0	3
9					**12**	**5**	1
10					**13**	**4**	3
11						**9**	3
12						**17**	**2**
13							**6**
14							**8**
15							**17**
Error/Void on first word	1	0	0	2	3	0	2
Total	64	64	64	64	64	64	64

Serial Position	List Length 3	4	5	7	10	12	15
				Very Slow			
1	*58*	*56*	*56*	*41*	*36*	*20*	*19*
2	**2**	**3**	**1**	5	1	2	3
3	**2**	**2**	**2**	2	1	3	1
4		**3**	**1**	**1**	0	0	4
5			**3**	**0**	1	0	0
6				**5**	0	2	2
7				**6**	**3**	2	1
8					**4**	3	2
9					**8**	**3**	2
10					**10**	**2**	3
11						**10**	3
12						**15**	**2**
13							**3**
14							**5**
15							**13**
Error/Void on first word	2	0	1	4	0	62	63
Total	64	64	64	64	64	64	64

Table 3.

Data from Experiment 3

	PFR = Serial position 1							PFR = Any serial position						
	List length							List length						
	3	4	5	7	10	12	15	3	4	5	7	10	12	15
Last RS	Medium presentation rate													
1	35	35	27	27	12	7	5	35	35	27	27	12	7	5
2	7	1	3	0	0	0	0	10	3	5	1	1	1	0
3	17	7	3	2	4	0	0	18	8	5	2	4	0	1
4		16	8	5	0	0	0		18	10	6	1	1	1
5			8	2	2	1	2			15	10	3	2	3
6				4	1	0	0				10	2	3	1
7				1	1	1	0				7	8	1	0
8					2	0	0					11	1	3
9					1	1	0					8	5	2
10					0	0	0					13	6	2
11						0	0						14	3
12						0	0						22	5
13							0							10
14							0							17
15							0							10
Last RS	Slow presentation rate													
1	21	13	13	6	1	5	4	21	13	13	6	1	5	4
2	6	1	0	0	0	0	0	7	3	1	2	0	0	0
3	34	12	0	0	2	1	2	35	12	1	0	2	1	2
4		33	13	2	2	2	1		36	13	2	2	3	2
5			31	6	2	1	0			36	8	4	1	0
6				9	3	0	0				15	3	0	2
7				16	4	1	1				29	6	5	2
8					1	1	0					4	1	1
9					4	1	1					17	2	2
10					4	2	1					22	5	1
11						4	0						11	2
12						0	0						29	1
13							0							6
14							2							16
15							0							21
Last RS	Very Slow presentation rate													
1	14	11	4	5	4	1	3	14	11	4	5	4	1	3
2	7	0	1	0	0	0	0	7	1	1	0	0	0	0
3	37	6	1	1	0	0	0	41	7	1	1	0	0	0
4		39	5	0	1	2	2		45	5	2	1	2	3
5			45	7	3	2	0			52	8	3	2	0
6				7	3	1	1				10	3	1	2
7				21	5	2	2				34	6	3	4
8					2	1	2					2	3	2
9					8	4	0					14	4	1
10					10	3	1					32	6	3
11						1	0						8	2
12						3	1						32	2
13							1							2
14							3							8
15							3							31

Figure 1. Summary of the Probability of First Recall data for immediate free recall as a function of list length. At short list lengths, participants tend to initiate recall with the first word in the list (circles), but as the list length increases, so participants increasingly start their recall with one of the last four list items (triangles). Source: Data from Experiment 1 of Ward, Tan, & Grenfell-Essam (2010). Examining the relationship between free recall and immediate serial recall: The effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory & Cognition, 36(5),* 1207-1241.

Figure 2. Data from Experiment 1. Mean proportion of words recalled in the six conditions as a function of list length.

Figure 3. Data from Experiment 1. Serial position curves for list lengths 2 to 12 in each of the six conditions. The left-hand panels show the serial position curves for list lengths 2 to 12 for lists presented without articulatory suppression [No AS]; whereas the right-hand panels show the serial position curves for list lengths 2 to 12 for lists presented under articulatory suppression [AS]. The upper, middle, and lower panels represent recall from lists presented at fast, medium, and slow presentation rates, respectively.

Figure 4. Data from Experiment 1. Summary of the Probability of First Recall data in immediate free recall as a function of list length for each of the six conditions. The left-hand panels show the Probability of First Recall data for list lengths 2 to 12 for lists presented without articulatory suppression [No AS]; whereas the right-hand panels show the Probability of First Recall data for list lengths 2 to 12 for lists presented under articulatory suppression [AS]. The upper, middle, and lower panels represent first recalls from lists presented at fast, medium, and slow presentation rates, respectively. At short list lengths, participants tend to initiate recall with the first word in the list (circles), but as the list length increases, so participants increasingly start their recall with one of the last four list items (squares).

Figure 5. Data from Experiment 1. Resultant Serial position curves for list lengths 2 to 12 in each of the six conditions, given that the first word recalled was from serial position 1. The left-

hand panels show the serial position curves for list lengths 2 to 12 for lists presented without articulatory suppression [No AS]; whereas the right-hand panels show the serial position curves for list lengths 2 to 12 for lists presented under articulatory suppression [AS]. The upper, middle, and lower panels represent recall from lists presented at fast, medium, and slow presentation rates, respectively.

Figure 6. Data from Experiment 1. Resultant Serial position curves for list lengths 2 to 12 in each of the six conditions, given that the first word recalled was from one of the last serial positions. These serial position curves have been recency-justified, such that the right-hand data point for each list length have been aligned and represent the recall of the last item in each list. The left-hand panels show the serial position curves for list lengths 2 to 12 for lists presented without articulatory suppression [No AS]; whereas the right-hand panels show the serial position curves for list lengths 2 to 12 for lists presented under articulatory suppression [AS]. The upper, middle, and lower panels represent recall from lists presented at fast, medium, and slow presentation rates, respectively.

Figure 7. Data from Experiment 1. The proportion of lag+1 responses in the six conditions as a function of list length.

Figure 8. Data from Experiment 2. Mean proportion of words recalled in the three conditions as a function of list length.

Figure 9. Data from Experiment 2. Serial position curves for list lengths 2 to 12 in each of the three conditions. The upper, middle, and lower panels represent recall from lists presented at medium, slow and very slow presentation rates, respectively.

Figure 10. Data from Experiment 2. Summary of the Probability of First Recall data in immediate free recall as a function of list length for each of the three conditions. The upper, middle, and lower panels represent recall from lists presented at medium, slow and very slow presentation rates, respectively. At short list lengths, participants tend to initiate recall with

the first word in the list (circles), but as the list length increases, so participants increasingly start their recall with one of the last four list items (squares).

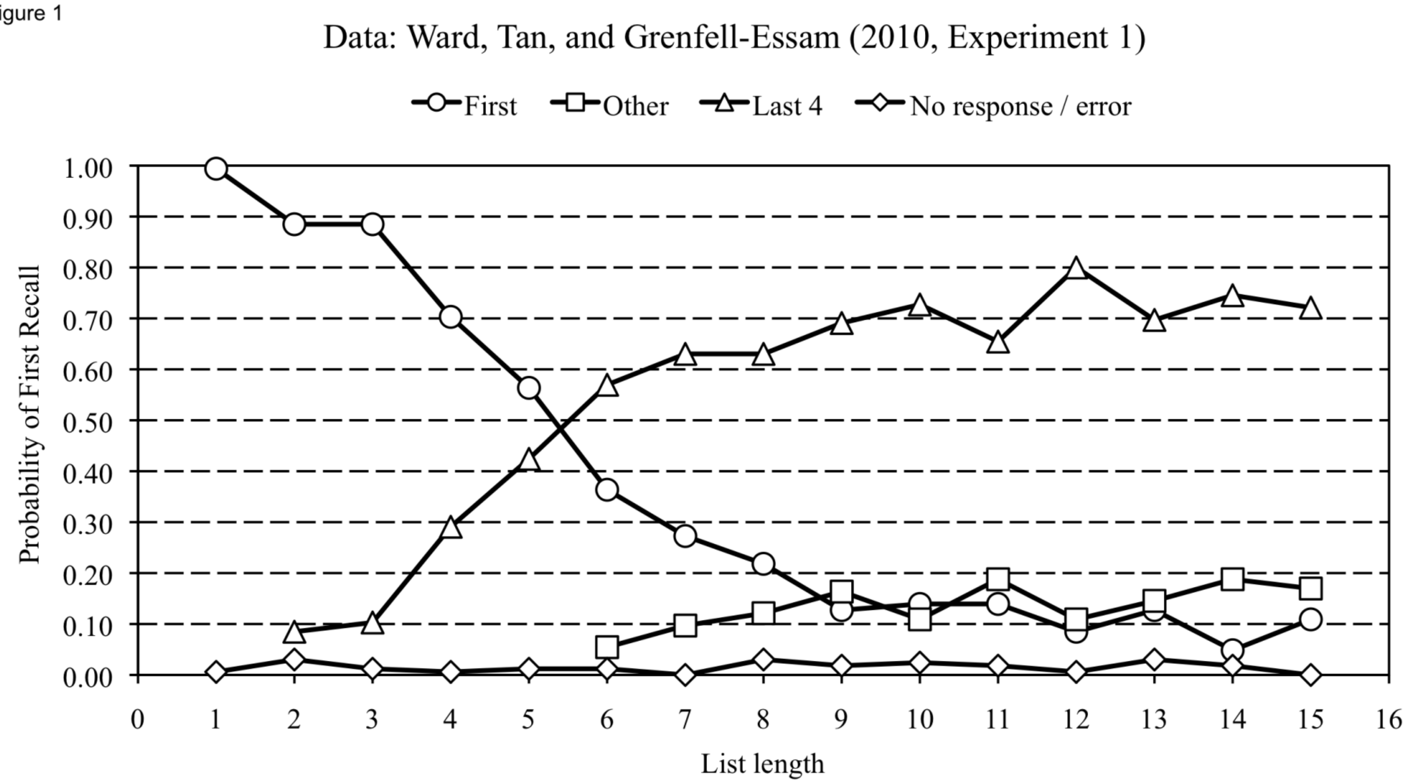
Figure 11. Data from Experiment 2. Proportion of words from each serial position that were rehearsed at least once during each of the Rehearsal Sets (RSs) during the encoding of the study lists for each of the three conditions. The upper, middle, and lower panels represent recall from lists presented at medium, slow and very slow presentation rates, respectively.

Figure 12. Data from Experiment 2. Summary of the Probability of First Recall data in immediate free recall as a function of list length for each of six conditions. The left-hand panels (Other Rehearsal) represent trials during which there was at least some rehearsal of earlier words; the right-hand panels (Fixed Rehearsal) represent trials during which there was no rehearsal of any word other than the most recently presented list item. The upper, middle, and lower panels represent recall from lists presented at medium, slow and very slow presentation rates, respectively. At short list lengths, participants tend to initiate recall with the first word in the list (circles), but as the list length increases, so participants increasingly start their recall with one of the last four list items (squares).

Figure 13. Data from Experiment 3. Mean proportion of words recalled in the three conditions as a function of list length.

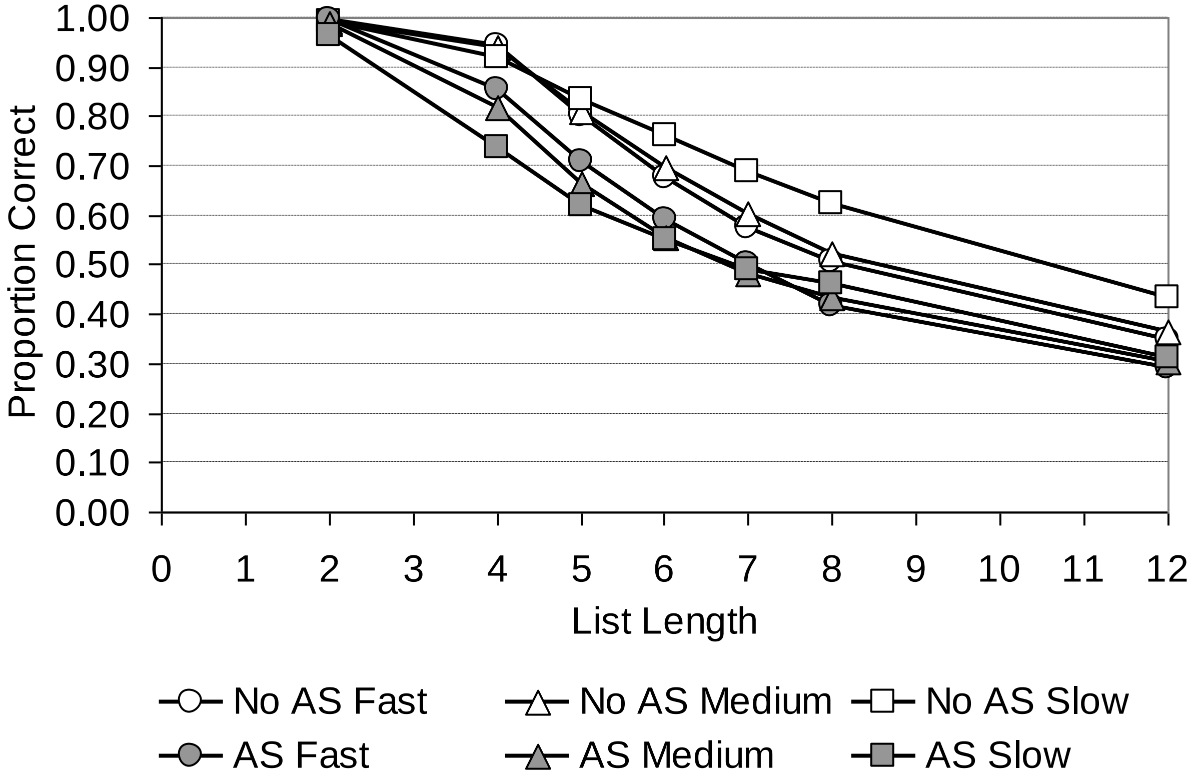
Figure 14. Data from Experiment 3. Summary of the Probability of First Recall data in immediate free recall as a function of list length for each of the three conditions. The upper, middle, and lower panels represent recall from lists presented at medium, slow and very slow presentation rates, respectively. At short list lengths, participants tend to initiate recall with the first word in the list (circles), but as the list length increases, so participants increasingly start their recall with one of the last four list items (squares).

Figure 1



Data: Ward, Tan, and Grenfell-Essam (2010, Experiment 1)
First
Other
Last 4
No response / error
Probability of First Recall
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
List length

Figure 2



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Proportion Correct
0
1
2
3
4
5
6
7
8
9
10
11
12
List Length
No AS Fast
No AS Medium
No AS Slow
AS Fast
AS Medium
AS Slow

Figure 3

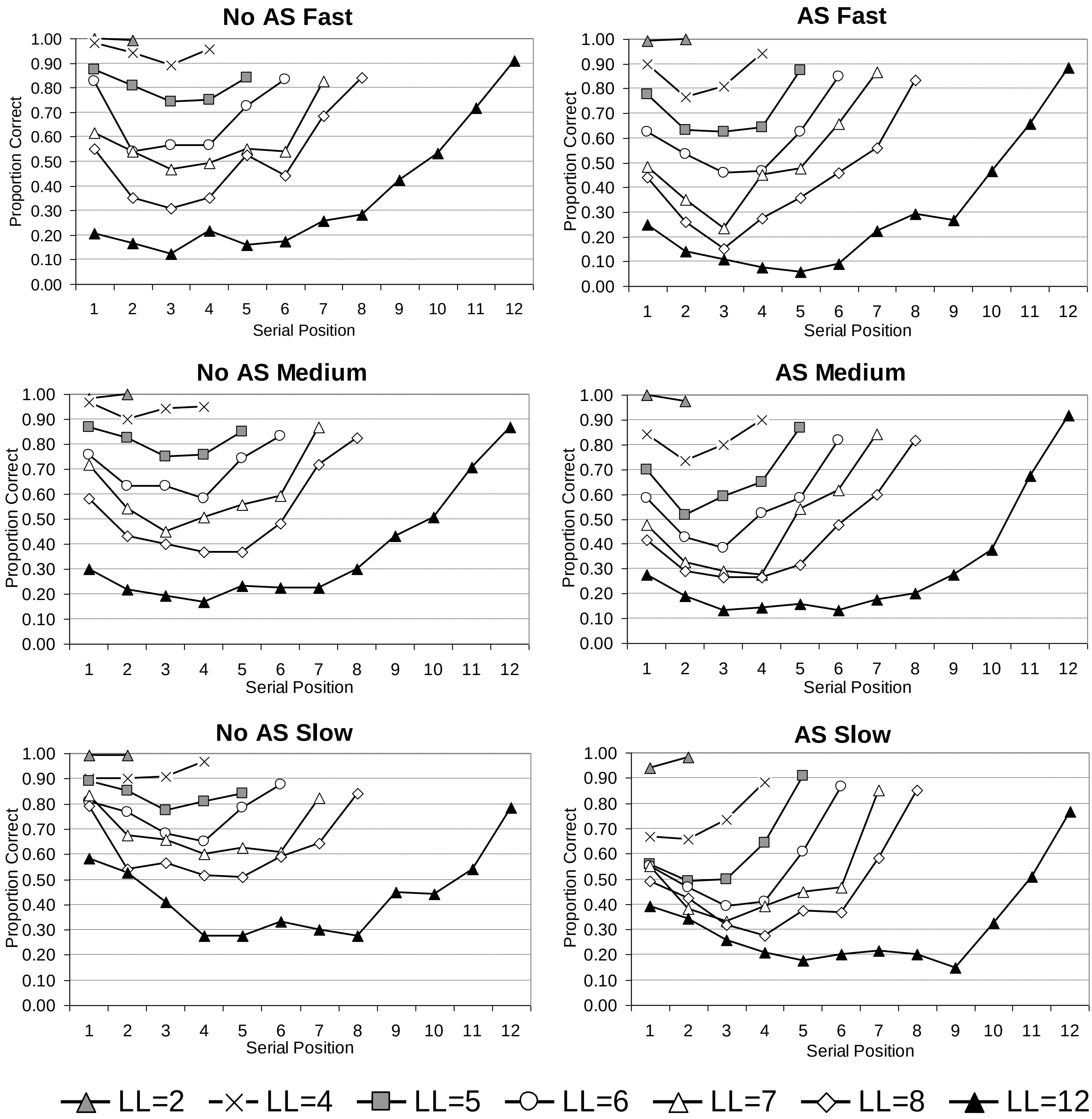
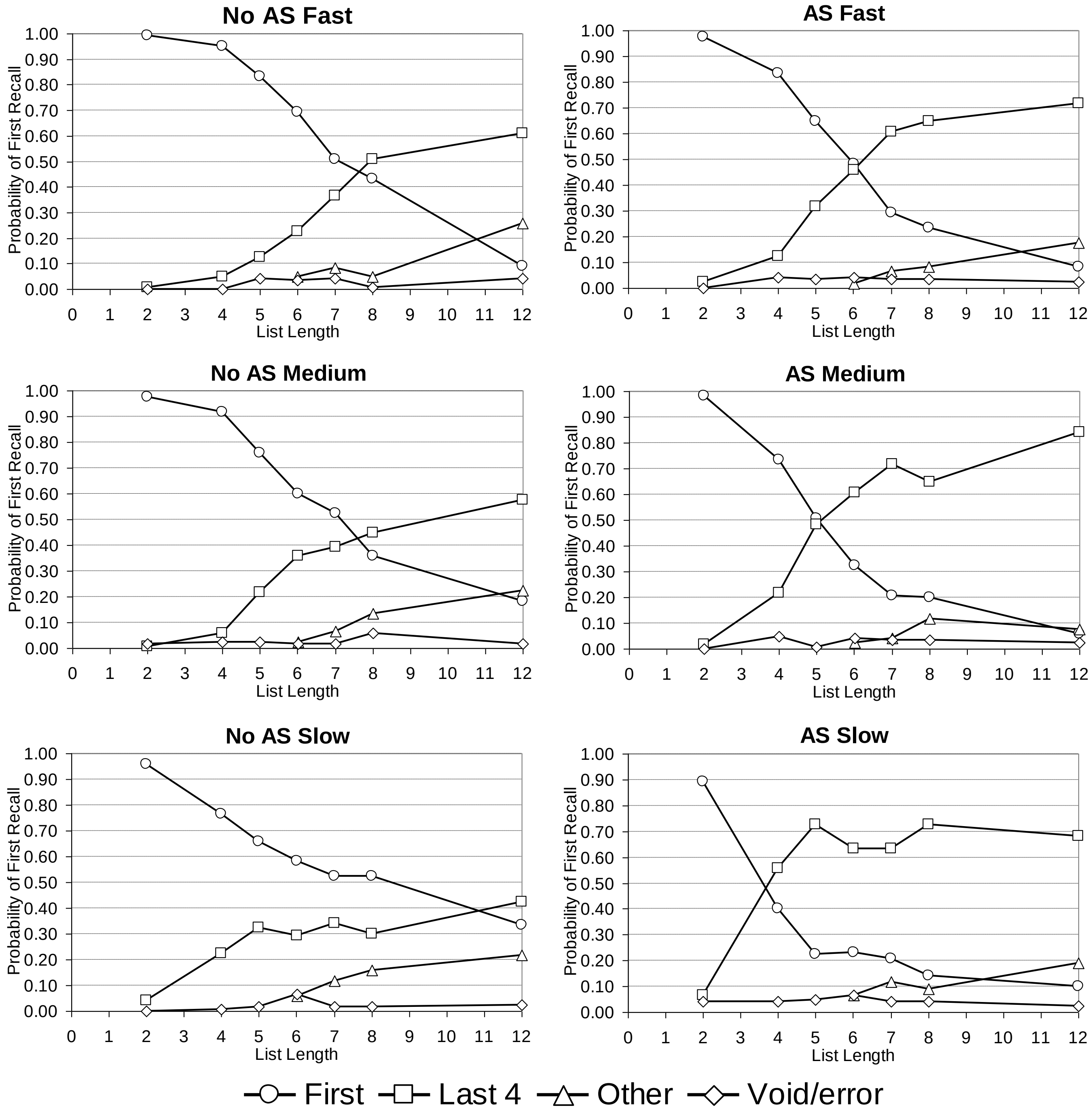

No AS Fast
AS Fast
No AS Medium
AS Medium
No AS Slow
AS Slow
Proportion Correct
Serial Position
LL=2
LL=4
LL=5
LL=6
LL=7
LL=8
LL=12

Figure 4



No AS Fast
AS Fast
No AS Medium
AS Medium
No AS Slow
AS Slow
Probability of First Recall
List Length
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12
First
Last 4
Other
Void/error

Figure 5

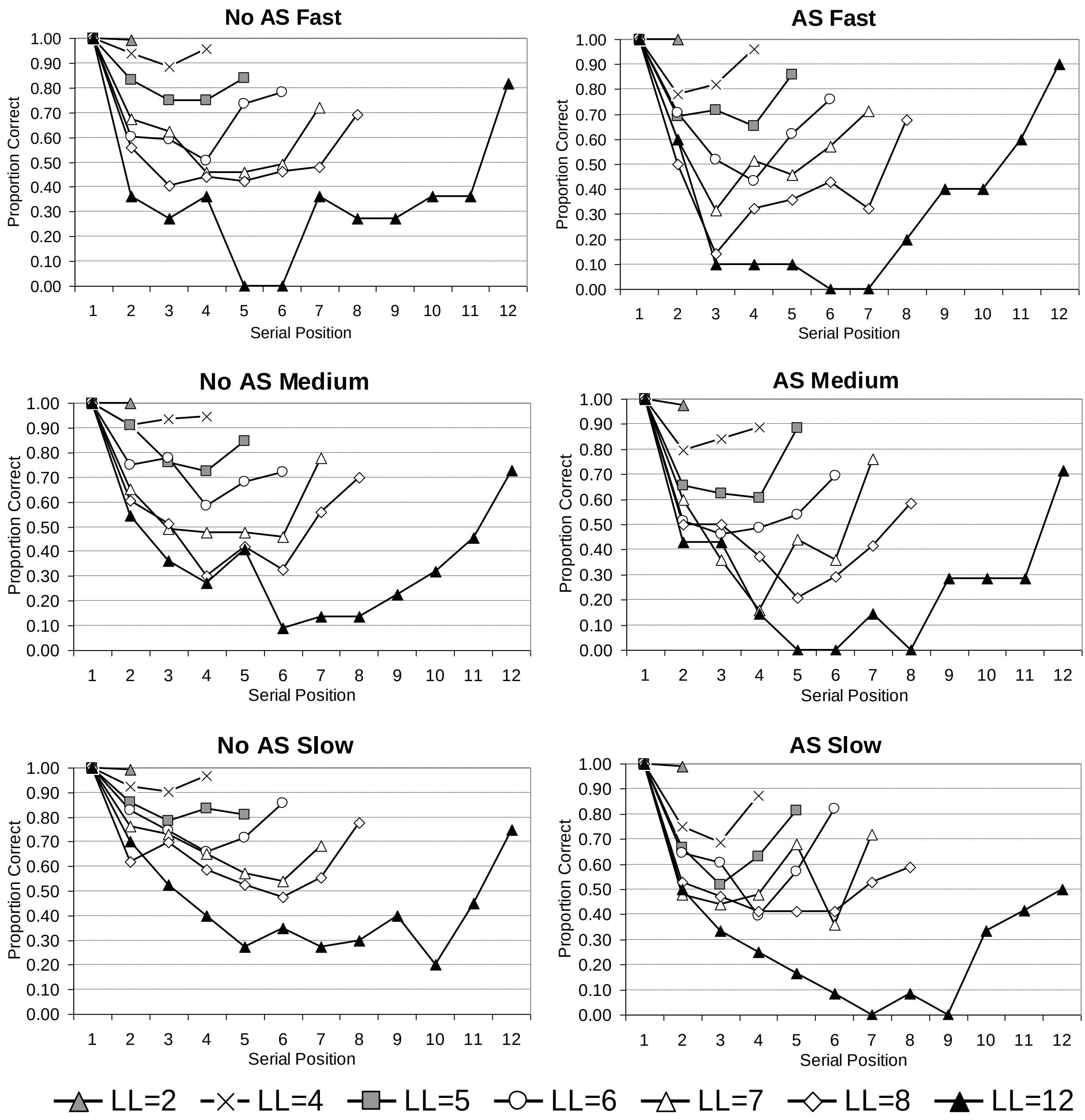

No AS Fast
AS Fast
No AS Medium
AS Medium
No AS Slow
AS Slow
Proportion Correct
Serial Position
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12
LL=2 LL=4 LL=5 LL=6 LL=7 LL=8 LL=12

Figure 6

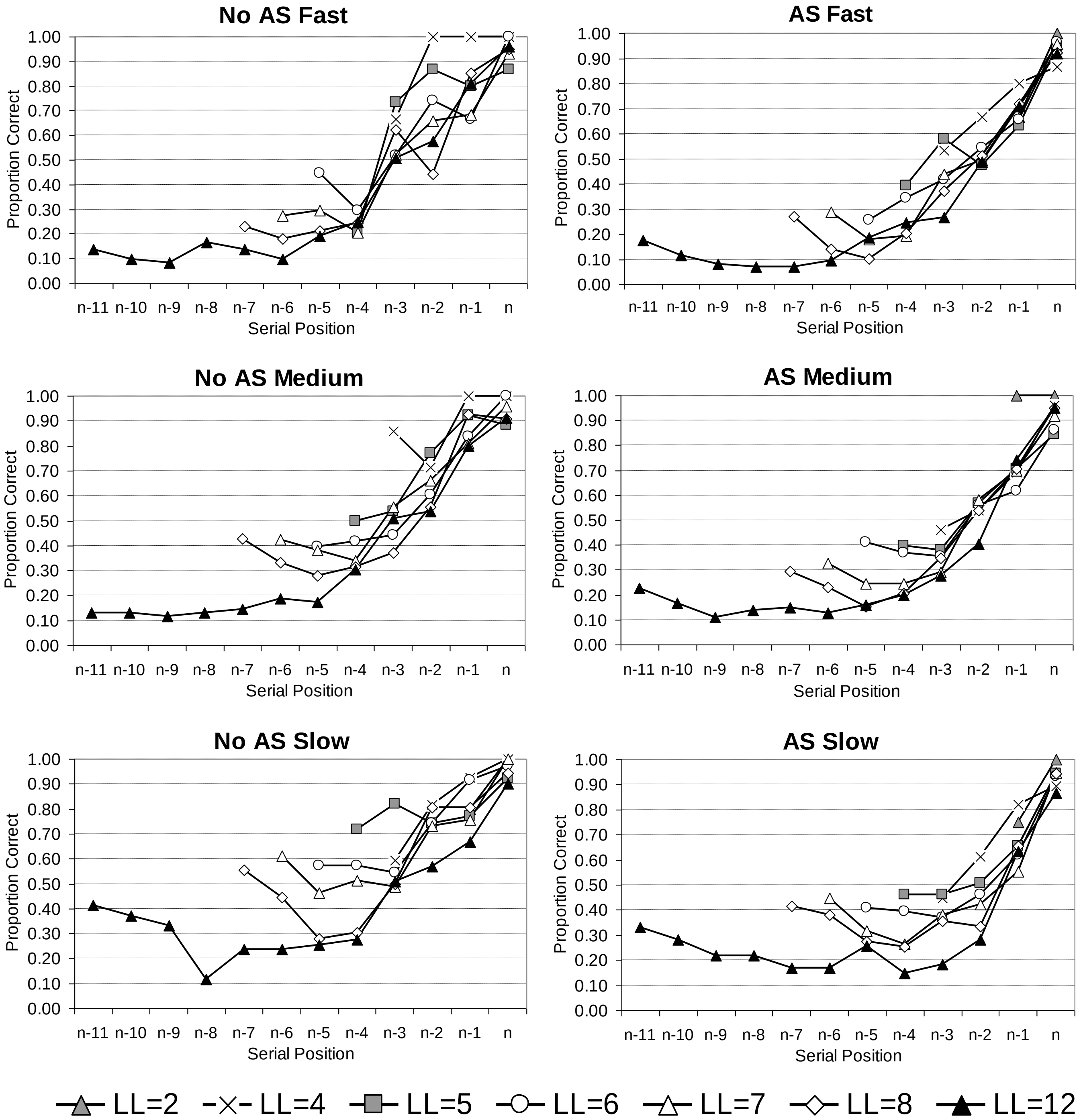
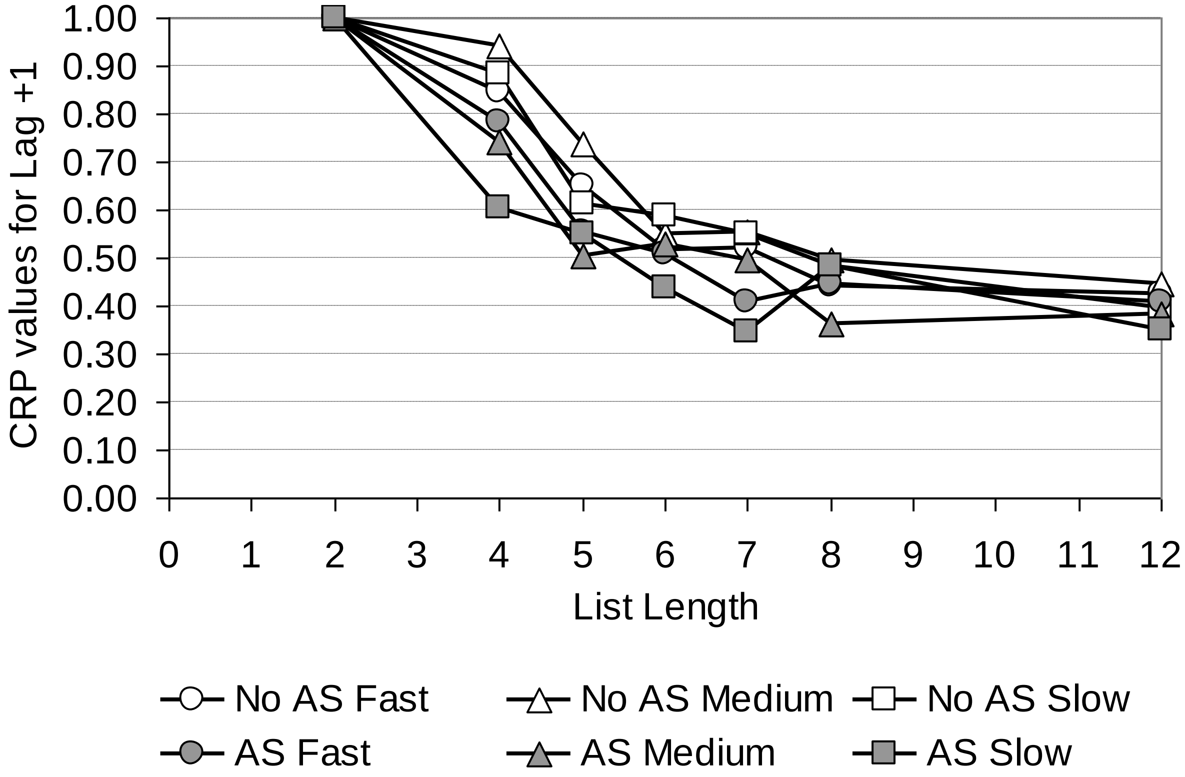
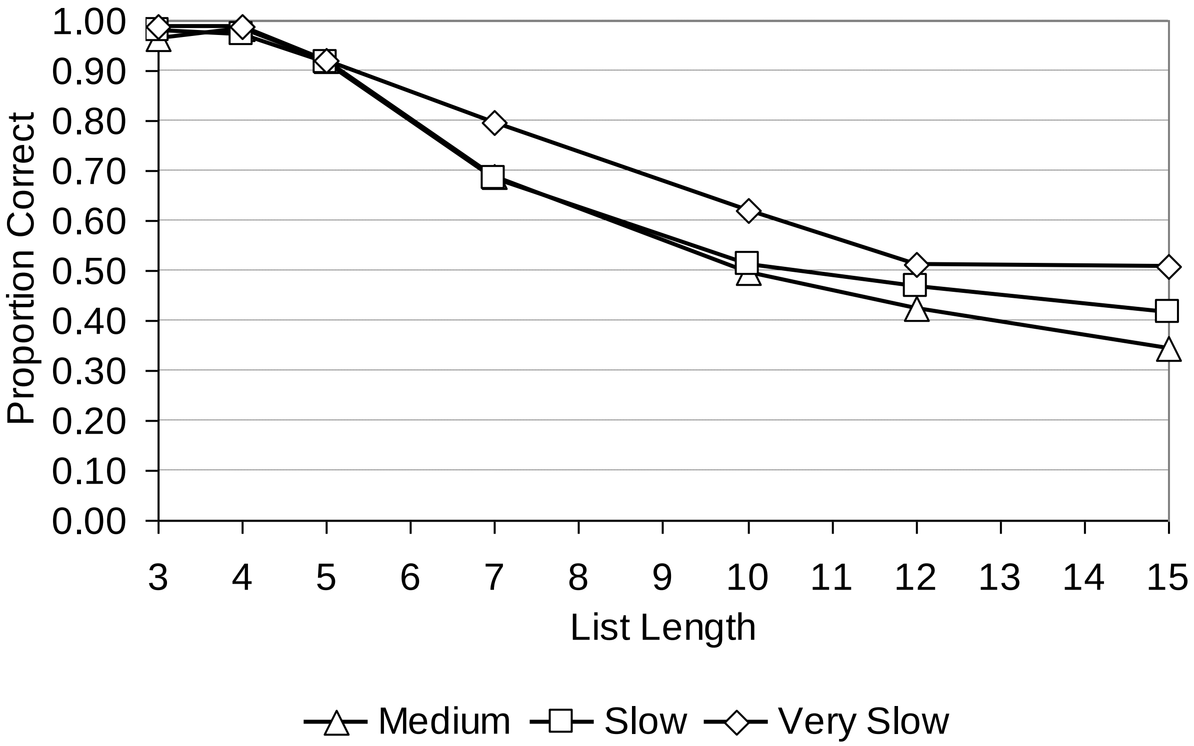

No AS Fast
AS Fast
No AS Medium
AS Medium
No AS Slow
AS Slow
Proportion Correct
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
n-11 n-10 n-9 n-8 n-7 n-6 n-5 n-4 n-3 n-2 n-1 n
Serial Position
LL=2
LL=4
LL=5
LL=6
LL=7
LL=8
LL=12

Figure 7



CRP values for Lag +1
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
List Length
No AS Fast
No AS Medium
No AS Slow
AS Fast
AS Medium
AS Slow

Figure 8



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Proportion Correct
3
4
5
6
7
8
9
10
11
12
13
14
15
List Length
Medium
Slow
Very Slow

Figure 9

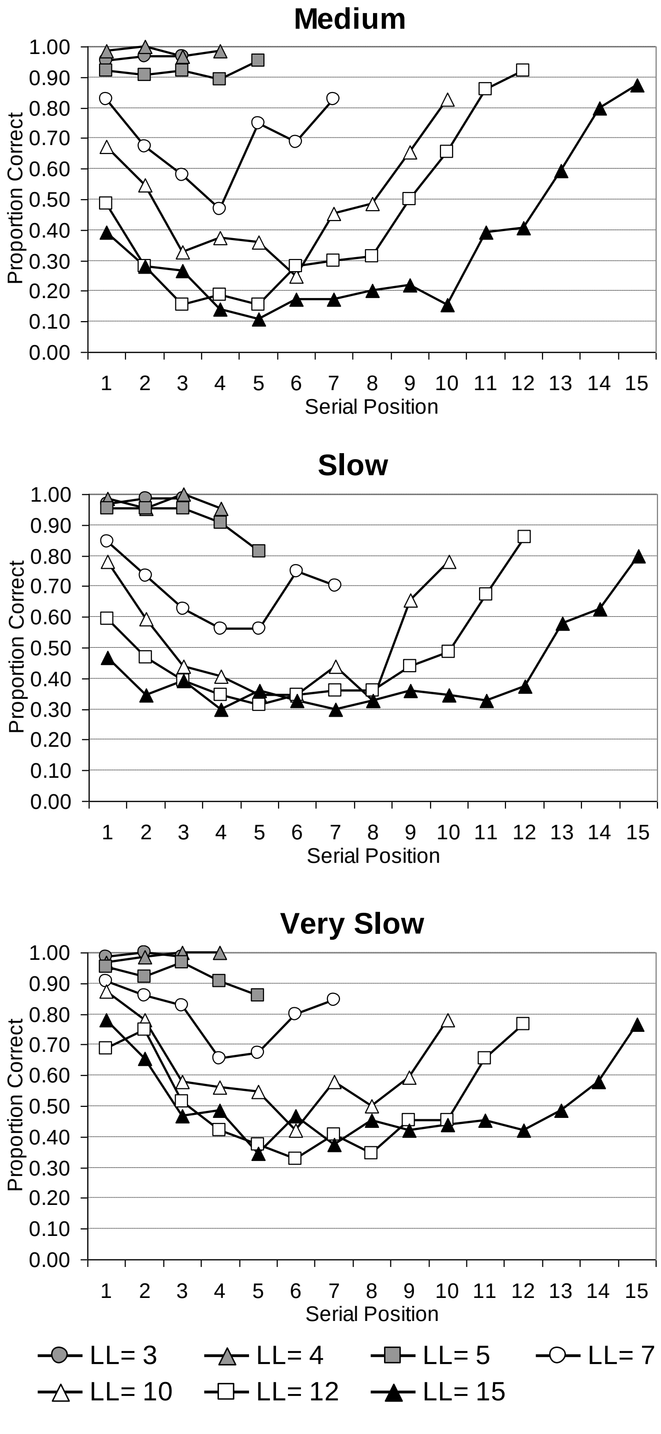

Medium
Proportion Correct
Serial Position
Slow
Proportion Correct
Serial Position
Very Slow
Proportion Correct
Serial Position
LL= 3
LL= 4
LL= 5
LL= 7
LL= 10
LL= 12
LL= 15

Figure 10

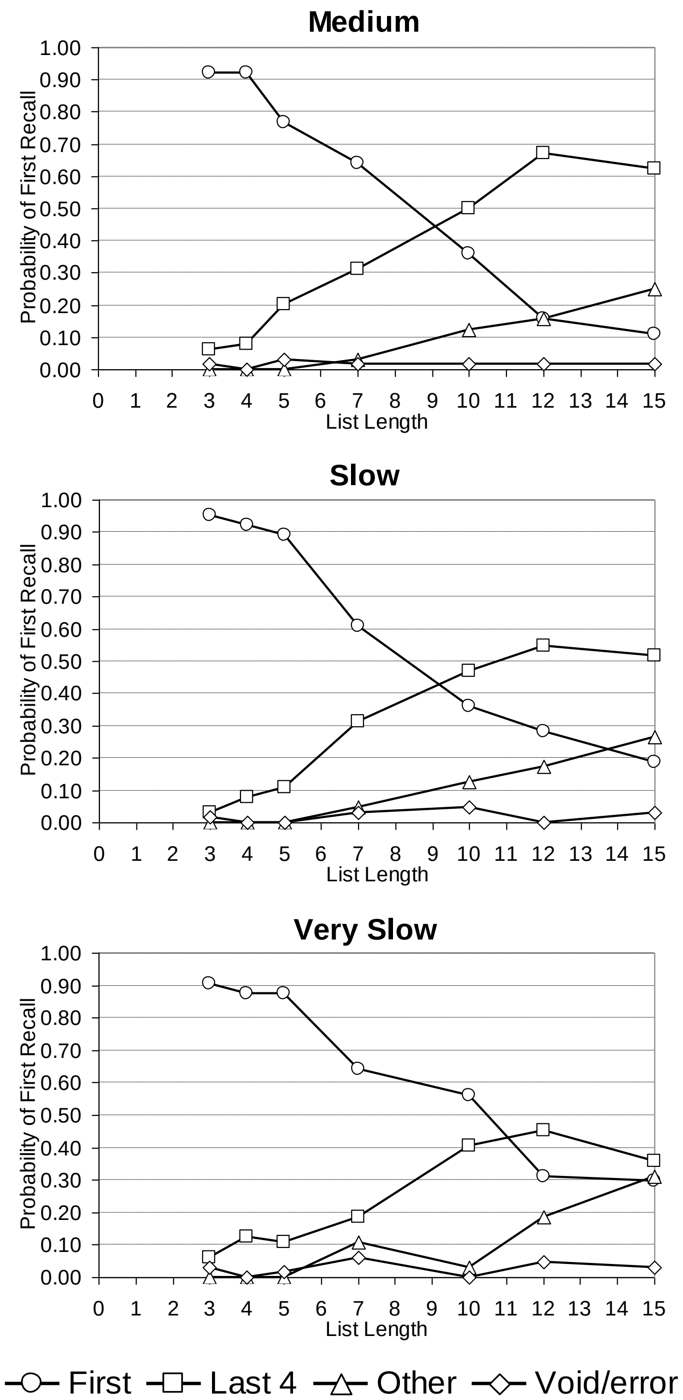
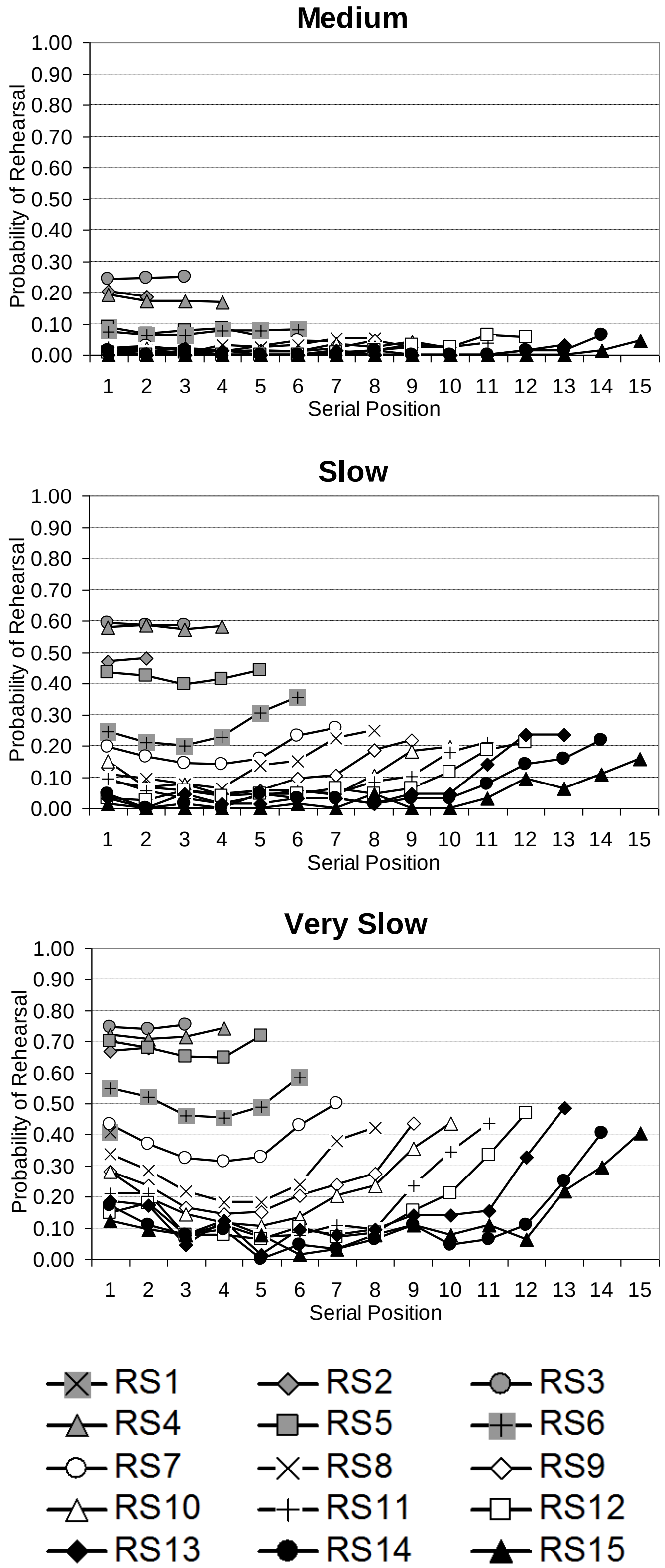

Medium
Probability of First Recall
List Length
Slow
Probability of First Recall
List Length
Very Slow
Probability of First Recall
List Length
First
Last 4
Other
Void/error

Figure 11



Medium
Slow
Very Slow
Probability of Rehearsal
Serial Position
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
RS1
RS2
RS3
RS4
RS5
RS6
RS7
RS8
RS9
RS10
RS11
RS12
RS13
RS14
RS15

Figure 12

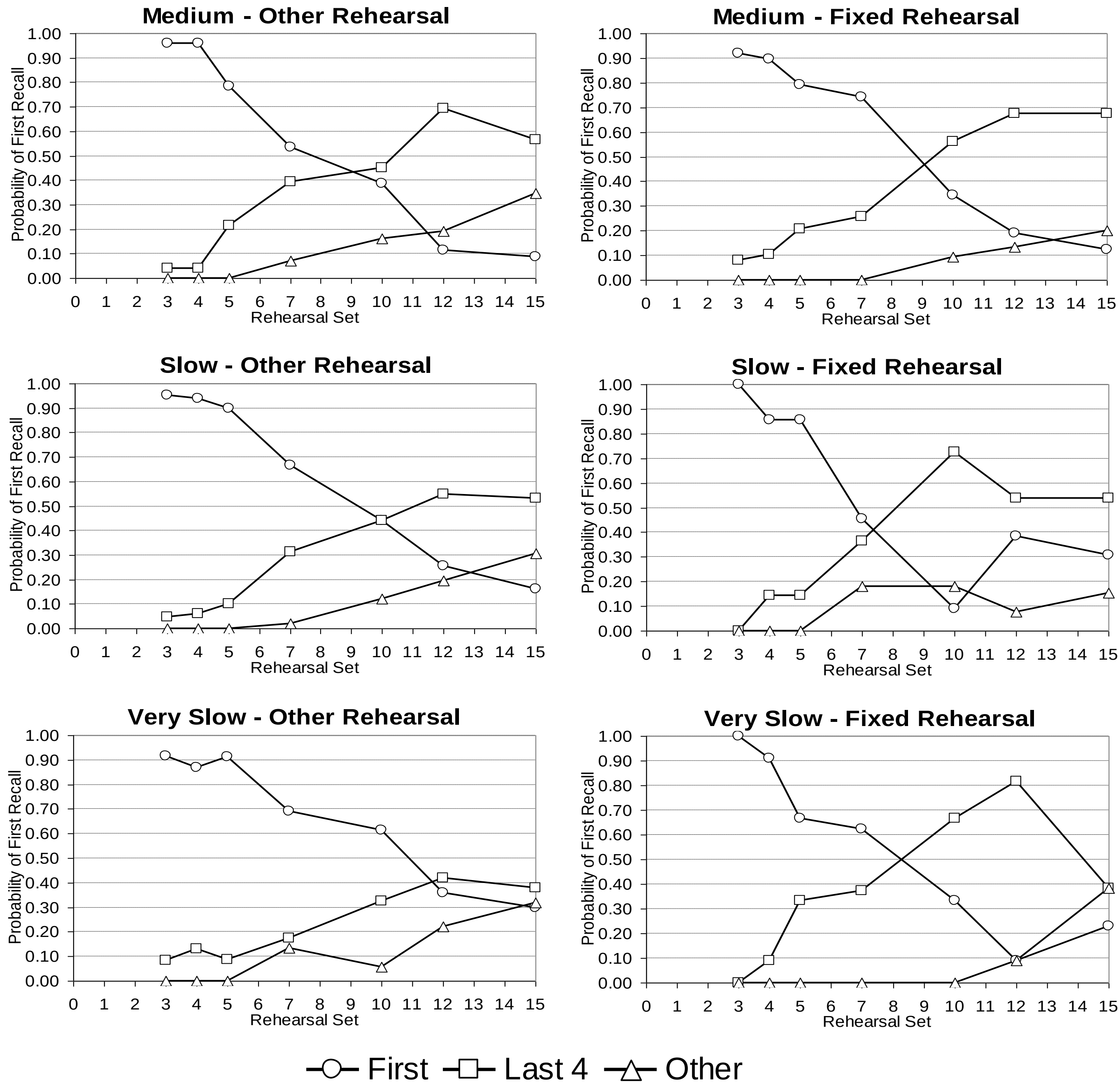
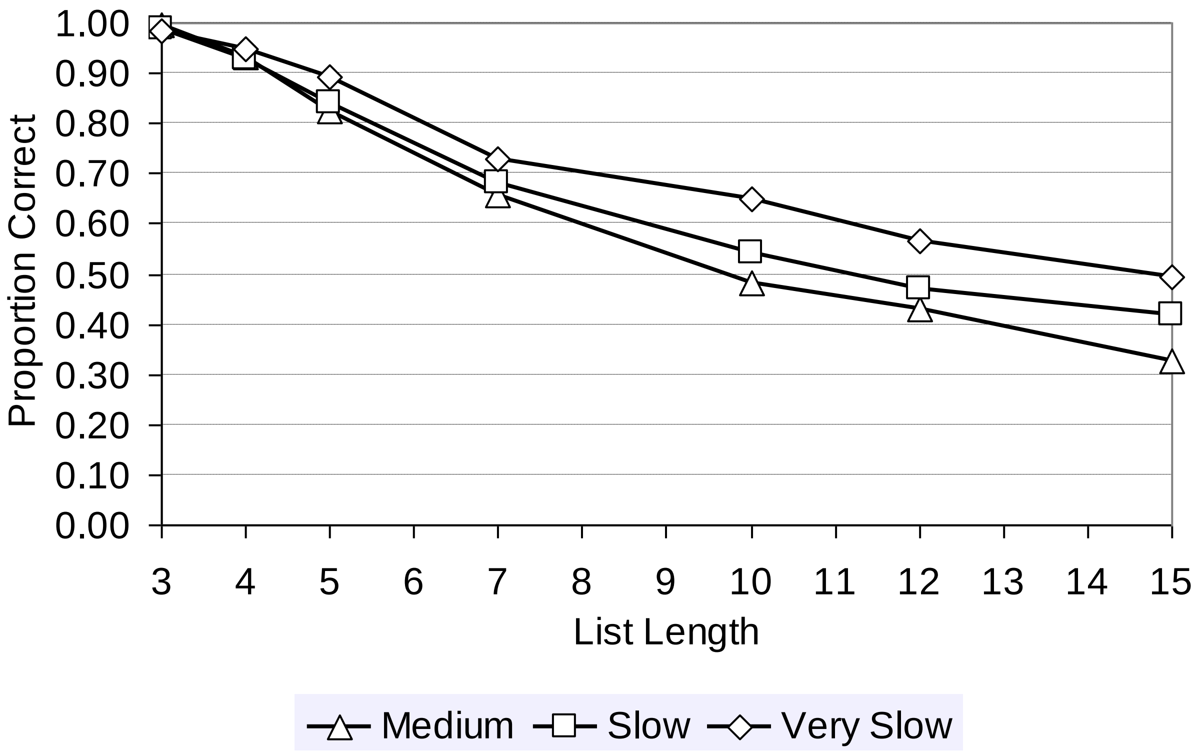
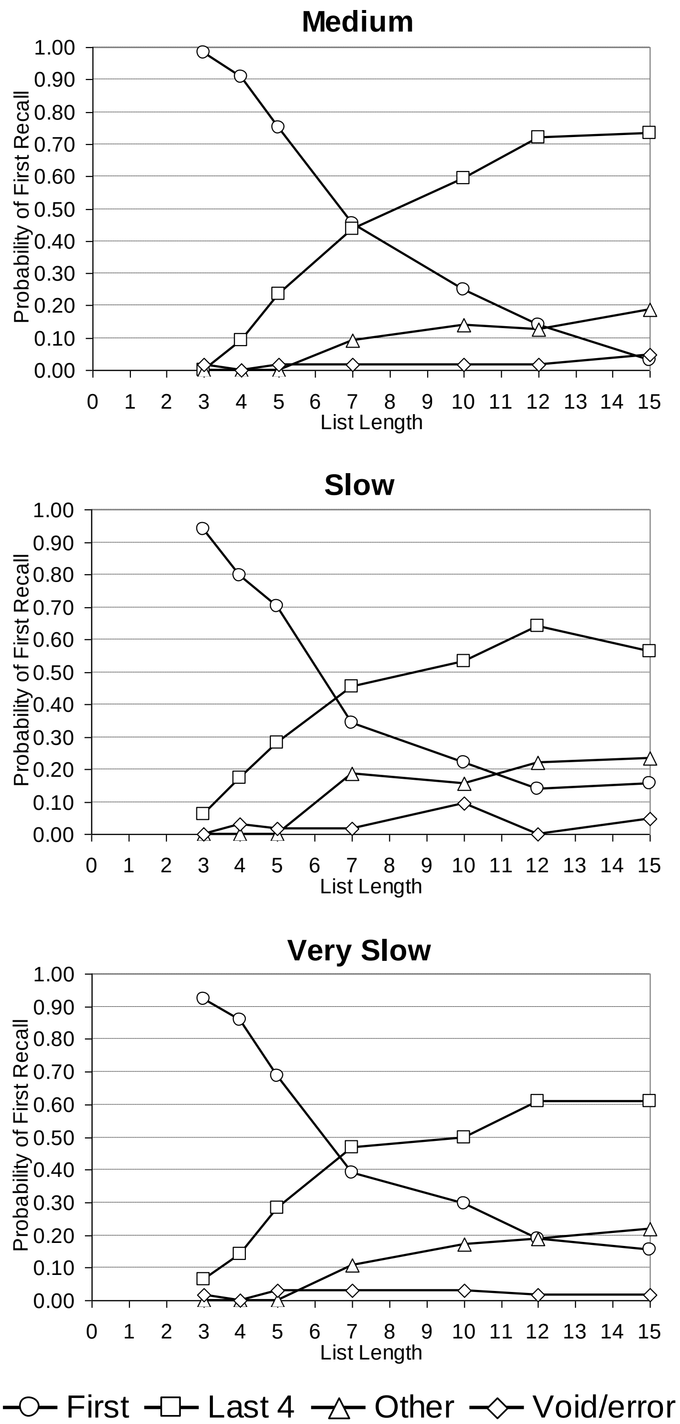

Medium - Other Rehearsal
Medium - Fixed Rehearsal
Slow - Other Rehearsal
Slow - Fixed Rehearsal
Very Slow - Other Rehearsal
Very Slow - Fixed Rehearsal
Probability of First Recall
Rehearsal Set
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
First
Last 4
Other

Figure 13



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Proportion Correct
3
4
5
6
7
8
9
10
11
12
13
14
15
List Length
Medium
Slow
Very Slow

Figure 14


Medium
Slow
Very Slow
Probability of First Recall
List Length
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
First
Last 4
Other
Void/error