Rehearsal in immediate serial recall

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Abstract

We report for the first time overt rehearsal data in immediate serial recall (ISR) undertaken at three presentation rates (1 s/word, 2.5 s/word and 5 s/word). Two groups of participants saw lists of 6 words for ISR and were required either to engage in overt rehearsal or to remain silent after reading aloud the currently presented word during list presentation. Typical ISR serial position effects were obtained for both groups, and recall increased with slower rates. When participants rehearsed, they tended to rehearse in a cumulative forwards order up to serial position 4, after which the amount of rehearsal decreased substantially. There were similarities between rehearsal and recall data: both broke down towards the end of longer sequences, and there were strong positive correlations between the maximum sequence of participants' rehearsals and their ISR performance. We interpret these data as suggesting that similar mechanisms underpin rehearsal and recall in ISR.

(150 words, 979 characters)

In the immediate serial recall (ISR) task, participants are presented with sequences of to-be-remembered items, and immediately after the last item has been presented, must try to recall as many of the items as possible in the same order as that in which they were presented. Performance on ISR is typically characterized by extended primacy effects and small recency effects.

It is widely acknowledged that participants may rehearse during ISR, especially if the presentation rate is slow. For example, the working memory model assumes that rehearsal, via an articulatory control process, refreshes memory traces which would otherwise undergo rapid decay in the phonological store (Baddeley, 1986). The opposing processes of decay and rehearsal have been widely used to explain a number of phenomena such as memory span performance, the phonological similarity effect and word length effect (e.g., Baddeley, Lewis & Vallar, 1984; Baddeley, Thomson & Buchanan, 1975).

One of the ways in which experimenters to date have examined the role of rehearsal has been to restrict the amount of rehearsal during ISR by requiring participants to engage in articulatory suppression (i.e., continuously repeating a word such as "the" aloud) during list presentation. The key finding that the phonological similarity effect and word length effect are eliminated under articulatory suppression with visually presented items has been critical in specifying the detailed architecture of the working memory model (e.g., Baddeley & Lewis, 1984; Baddeley et al., 1984).

Many formal computational models similarly assume that rehearsal occurs during ISR (e.g., Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998). Burgess and Hitch's (1999) Phonological Loop model implements rehearsal in the same way as it does serial recall, such that the two processes are equivalent. The

Primacy model of Page and Norris (1998) similarly models rehearsal as a cumulative process, and considers rehearsals of list items simply to be more recent re-presentations of these items. They assume that participants rehearse in a cumulative forwards order until such a point in the list when rehearsal cannot be completed before the next item is presented. There is empirical evidence that a cumulative forwards order rehearsal strategy can enhance the primacy effect. Palmer and Ornstein (1971) required participants to rehearse items covertly, either cumulatively or in most recent pairs. They found that performance on a subsequent serial probed recall task was strongly affected by participants' rehearsal strategy, with much larger primacy effects being obtained in the cumulative rehearsal conditions.

Despite the widespread assumption that rehearsal plays an important role in ISR, it is perhaps surprising that no evidence exists as to which words (if any) participants actually rehearse during the task. The present experiment therefore sought to investigate directly participants' patterns of rehearsal in ISR. This was done using the overt rehearsal methodology, in which participants were asked to rehearse aloud during list presentation (Rundus, 1971; Tan & Ward, 2000). Clearly, knowledge of the actual patterns of rehearsals used by participants in ISR would enable us to examine directly the assumptions inherent in models of ISR. For example, one could determine whether Page and Norris (1998) are correct in assuming that participants rehearse in a cumulative forwards order until they can no longer rehearse the sequence prior to the next item being presented. In addition, a detailed understanding of participants' rehearsals in ISR would allow us to examine whether there might be similarities between the mechanisms underpinning rehearsal in ISR and those underpinning recall (Burgess & Hitch, 1999).

The overt rehearsal method necessitated that we presented the words at a slower rate than is typically used in ISR tasks. We used three different presentation rates (fast, medium and slow) in order to vary the amount of rehearsal that occurred across conditions. The effect of presentation rate in ISR has been shown to be ambiguous. In some cases, a slower presentation rate leads to poorer recall (e.g., Conrad & Hille, 1958), whereas in other studies, slower presentation rates lead to superior recall (e.g., Mackworth, 1962). These contradictory findings may perhaps be due to the two counteracting effects of rehearsal and retention interval: slower presentation rates are associated with increases in retention interval, but typically also lead to increased rehearsal (which should improve recall). In addition, a silent control group was used in order to determine whether the requirement to rehearse aloud had any effect on recall performance.

A final advantage of using the overt rehearsal method was that we could examine directly the effect of rehearsal on recall for each presentation rate and serial position. If rehearsal improves recall by decreasing the functional retention interval, then we should see positive benefits of rehearsal on ISR performance to the extent that forward cumulative rehearsal has been completed successfully throughout the list.

Method

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

Materials. The materials were selected from the Toronto Word Pool (Friendly, Franklin, Hoffman & Rubin, 1982) and consisted of 290 disyllabic nouns, four to six letters in length, with frequencies of occurrence of 75-1199 per million based on the

Kucera and Francis (1967) norms. From this word pool, 48 experimental lists were randomly selected for each participant, each consisting of 6 words. Three additional practice lists of 6 words were similarly generated. No participant received the same word twice during the experiment. The materials were presented using the application Supercard on an Apple Macintosh computer.

Design. A mixed design was used. Type of rehearsal (overt vs. silent) was a between-subjects factor. There were two within-subjects factors: presentation rate (fast, 1 s/word; medium, 2.5 s/word; and slow, 5 s/word) and serial position (1-6).

Procedure. The participants were randomly assigned to two groups of 20, and were tested individually. Following the instructions, each participant saw a total of 3 practice lists followed by 48 experimental lists of 6 words for immediate verbal serial recall. Participants in the overt rehearsal conditions were asked to rehearse aloud any words from the list that they were currently thinking of, whereas participants in the silent condition were told to remain silent after reading aloud each word. Each list began with a warning tone, followed after 3 seconds by the presentation of a six-word list. The words were presented visually one at a time in the center of the computer screen, and participants were required to say each word aloud as it appeared on the screen. A series of three beeps at the end of each list signalled the beginning of a 15-second recall period. Participants were instructed to recall in forwards serial order, and to say "blank" if they could not remember an item in the list. At the end of the recall period, a tone sounded and participants were prompted to continue with the next list by clicking the mouse. The presentation rates for the fast, medium, and slow conditions were: 1 s/word (0.25 s on, 0.75 s off), 2.5 s/word (1.75 s on, 0.75 s off) and 5 s/word (4.25 s on, 0.75 s off) respectively. The presentation rates were blocked, with 16 lists per presentation rate. The ordering of the blocks was randomly assigned,

and this same ordering of presentation rates was used in the three practice trials at the start of the experiment.

Results

Recall

Serial Position. The proportion of items recalled at each serial position for each condition is shown in Figure 1. We used the standard method of ISR scoring in which each response was considered to be correct if it was output in the same absolute serial position as it was input (with each "blank" response counting as an output serial position). A 2 (Rehearsal type: overt or silent) x 3 (Presentation rate: fast, medium or slow) x 6 (Serial position: 1-6) mixed ANOVA was performed. This revealed a significant main effect of presentation rate, $F(2, 76) = 32.22$, $MSE = 1.76$, $p < .0001$, and serial position, $F(5, 190) = 109.05$, $MSE = 3.22$, $p < .0001$, but not of rehearsal type, $F(1, 138) = 2.88$, $p > .05$.

The rehearsal type x serial position interaction was significant, $F(5, 190) = 3.23$, $MSE = .095$, $p < .01$, as was the presentation rate x serial position interaction, $F(10, 380) = 3.36$, $MSE = .047$, $p < .001$. However, the 2-way rehearsal type x presentation rate interaction was not significant ($F < 1$), nor was the 3-way rehearsal type x presentation rate x serial position interaction, $F(10, 380) = 1.21$, $p > .05$.

Despite these two-way interactions, roughly similar serial position curves are found across presentation rate and rehearsal conditions. Figure 1 shows comparable levels of performance in the silent and overt rehearsal conditions, significant and extended primacy effects at all three presentation rates and a one-item recency effect under fast and medium presentation rates. The main differences are that there was a slightly larger difference between serial positions 3 and 4 in the overt rehearsal conditions and that there was no significant recency at the slow presentation rate. The

general lack of recency may at first be surprising given that each item was spoken by the participant upon presentation. However, any modality effect that one might expect to see may have been abolished by the participants' spoken rehearsal and recall, which may have acted as a stimulus suffix.

--Figure-1-about-here--

Distribution of Rehearsal Strategies

We analyzed the patterns of rehearsal obtained from each of the three presentation rates of the overt rehearsal conditions. We borrowed the term rehearsal set (RS) from the overt rehearsal literature in free recall (e.g., Rundus, 1971; Tan & Ward, 2000) to refer to the set of words that is rehearsed after the presentation of each stimulus item. For example, the set of words in RS 4 at the slow presentation rate refers to those words rehearsed in the 5 s immediately after the onset of the fourth word in the list.

We defined four different rehearsal strategies that could be used during a RS. A "fixed" rehearsal strategy refers to the strategy of rehearsing only the most recently presented item. A "full cumulative" rehearsal strategy refers to the strategy of rehearsing in the correct order all of the items presented to date. A "partial cumulative" rehearsal strategy refers to that of rehearsing in the correct order only some of the items presented to date. Finally, any other pattern of rehearsal is categorized under "other".

To illustrate how these definitions were applied in practice, suppose a participant was presented with the sequence "A B C D E F", where the letters A to F refer to the sequence of six words. If we take as our example an analysis of RS 4 (the

sequence of rehearsals immediately following presentation of word D) then a participant was deemed to have used a fixed rehearsal strategy if they rehearsed “D” or “D D” or indeed repeated solely “D” any number of times. A full cumulative rehearsal strategy was deemed to have been used if somewhere in RS 4 participants rehearsed the string “A B C D” in that exact order. That is, rehearsals “D D A B C D” or “A B C D A B C D” or “A B C D A B” would also be deemed full cumulative rehearsals, whereas rehearsing “A B D C” or “A B C C D” would not. Similarly, a partial cumulative rehearsal strategy was deemed to have been used if somewhere in RS 4 participants rehearsed “A”, “A B” or “A B C” in these exact orders, such that rehearsing “D A B C”, “A B D D” would be considered partial cumulative rehearsals but “D B C” would not. Finally, “other” referred to any other pattern of response.

--Figure-2-about-here--

Figure 2 shows the distribution of rehearsal strategies used at each RS for each of the different presentation rates. There are four main points to make. First, at fast rates, there was little time to rehearse, and essentially all the rehearsals are of the most recently presented item (fixed rehearsal). Second, at medium and slow rates there was substantial cumulative rehearsal early in the list. Over RSs 2-4, participants adopted a full cumulative rehearsal strategy approximately 45% of the time at the medium rate and approximately 70% at the slow rate, but there were still significant amounts of fixed rehearsal (over 40% for medium rate and around 20% for the slow rate). Third, towards the end of the list at RSs 5 and 6, the amount of cumulative rehearsal decreased and the amount of fixed rehearsal increased. Finally, there was little evidence that participants adopted any other type of rehearsal strategy, save towards

the end of the list at the slow rate. These other responses are hard to generalize, but many contained forward-ordered sequences such as “45” or “456”.

Rehearsal and Recall

The relationship between rehearsal and recall was examined in three separate analyses. First, for each trial, a score was calculated that refers to the maximum length of sequence that was rehearsed. A score of 4 on this measure refers to a trial in which the participant rehearsed the first four words (but neither the first five nor all six words) in the list in the correct sequence at some point during the trial, whereas a score of 1 on this measure refers to a trial in which the participant adopted a fixed rehearsal strategy throughout the trial. Figure 3 shows the relationship between this measure and ISR performance. There was not enough rehearsal to merit analysis at the fast presentation rate, and so the upper panel refers to data from the medium presentation rate and the lower panel refers to data from the slow presentation rate. As can be seen from the data at both presentation rates, as the maximum sequence rehearsed increases, so ISR performance increases.

--Figure-3-about-here--

Second, Figure 4 shows the ISR data across all three presentation rates in which participants adopted a fixed rehearsal strategy throughout the trial. Contrary to the overall advantage of slower presentation rates on ISR performance, participants performed better at the faster presentation rates throughout the first half of the list. This advantage was eliminated in the second half of the list.

--Figure-4-about-here--

Finally, an analysis of individual differences was conducted. The mean proportion of words correctly recalled in ISR and the mean maximum number of words rehearsed correctly in sequence were calculated for each participant for the medium and slow presentation rates. There were strong positive correlations between the maximum rehearsed sequence length and the overall proportion correct for both the medium (r = .67, R^2 = .45, p = .001) and slow (r = .77, R^2 = .59, p < .001) rates.

--Figure-5-about-here--

Table 1 shows these correlations for each serial position. As can be seen, these correlations were relatively high for serial positions 1-4, and were reduced at serial positions 5 and 6.

--Table-1-about-here--

Discussion

There are four main findings from the current experiment. First, considering the rehearsal data, when participants are asked to rehearse aloud during ISR, they tend to adopt either a fixed rehearsal strategy or a cumulative forwards order strategy. At fast presentation rates (and to a lesser extent at slower rates), participants tend to rehearse only the currently presented item (the fixed rehearsal strategy). However, at slower rates, when this does not take place, they tend to rehearse in cumulative forwards order. That is, they rehearse the maximum possible sequence of items in forwards serial order during each RS, up to RS 4. At RSs 5 and 6, however, participants appear to refrain from rehearsal, rehearse only incomplete sequences (i.e.,

sequence lengths of 4 and below), or else rehearse shorter sequences of later items. These patterns of rehearsals are consistent with the assumptions of Page and Norris (1998): participants rehearse early items in a cumulative forwards order throughout the early part of the list, but towards the middle of the list, they are unable or unwilling to rehearse complete sequences of items.

Second, ISR performance was superior overall at the slow presentation rate compared to the fast presentation rate. However, the precise relationship between presentation rate and recall appears complex. A slow rate might be expected to reduce recall due to the increased retention interval but also increase recall due to the increased opportunity to rehearse. Our data suggest that, on average, the increase in accuracy afforded by participants' rehearsals in our study more than offset the reduction in accuracy attributable to longer retention intervals. When one considers ISR performance across presentation rates in the absence of cumulative forwards rehearsal (Figure 4), we find that recall accuracy is indeed reduced with slower presentation rates. However, many participants tended to engage in rehearsal at slower rates, and within each slower rate, ISR performance increased with increased forwards order rehearsal (Figure 3). Furthermore, there are strong positive correlations between the rehearsal of sequences of words and their subsequent recalls, suggesting that increased rehearsal counteracts the effects of increased retention interval at slower rates.

Third, the general shape of the serial position curve in ISR was similar for all presentation rates, including the fast rate, in which there was little or no rehearsal. This suggests that the extended primacy observed in ISR need not always be a direct consequence of increased rehearsal (see also e.g., Coltheart & Langdon, 1998). This finding contrasts with that typically observed with free recall of longer lists (Rundus,

1971; Tan & Ward, 2000), in which there is a close relationship between rehearsal and extended primacy effects. Rather, we believe that other factors, such as the order of recall, which was identical across all presentation rate conditions, has a large effect on the shape of the serial position curve in ISR (e.g., Tan & Ward, 2007).

Finally, our demonstration that performance breaks down in rehearsal and recall in similar ways provides support for the idea that similar mechanisms underpin rehearsal and recall in ISR (Burgess & Hitch, 1999). Rehearsal of sub-span length lists (4 items or fewer) when it is attempted is near perfect in our data, matching the near-perfect recall performance that is normally found on such short lists (Miller, 1956). However, when the list length increases to 5 or 6 items, rehearsal is no longer perfect. Earlier items can still be rehearsed in their correct order, but rehearsal tends to break down towards the end of the list. (This may simply be an artifact of the limited time available to rehearse all items during the inter-stimulus interval). We observe that this pattern is suggestively mirrored in the recall data.

One difficulty with interpreting the positive correlations observed between overt rehearsals and subsequent recalls is that a number of alternative factors could lead to relations being seen between rehearsal and recall even if the former is not causing the latter. A number of potential confounds include subject-selection effects, item-selection effects, or trial-by-trial fluctuations in motivation or attention. Apparent correlations between rehearsal and recall could reflect the fact that more able participants rehearse more and then recall more than less able participants. Alternatively, participants may be more motivated on some lists than others or find some words to be more easy to rehearse and remember than others. The controlled rehearsal procedure (Murdock & Metcalfe, 1978), and the yoked rehearsal procedure (Tan & Ward, 2000) have gone some way towards alleviating similar concerns in free

recall. In these procedures, recall is similar when participants can freely select which words to rehearse, and when they are presented with schedules of repetitions over which they have no control.

Overall, we have provided for the first time detailed descriptions concerning the words rehearsed during ISR. This information can be used to help constrain and test different computational models of ISR. More specifically, the data here tend to support the assumptions regarding participants' rehearsal strategies in the Primacy Model (Page & Norris, 1998), and provide evidence that certain similarities exist between rehearsal and recall (Burgess & Hitch, 1999). The examination of the similarities and differences between rehearsal and recall in ISR mirrors recent examinations of the similarities and differences between rehearsal and recall in free recall (Laming, 2006; Tan & Ward, 2000). It is often assumed that ISR can be differentiated from free recall because of the requirement for forwards serial order recall in the former but not in the latter. However, over the last ten years or so there has been emerging evidence for the tendency for forwards order output even in free recall (Beaman & Morton, 2000; Bhatarah, Ward & Tan, in press; Howard & Kahana, 1999; Klein, Addis & Kahana, 2005; Ward, Woodward, Stevens & Stinson, 2003), and we believe there are grounds for suggesting that the processes underpinning the recall and rehearsals in free recall and ISR may be more similar than has hitherto been assumed.

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Table Captions

Table 1. Table of correlations between the proportions of words recalled in the correct serial order and the maximum sequence length to which the words were rehearsed, for the words presented in each of the six serial positions and for both the medium and slow presentation rates.

Figure Captions

Figure 1. The serial position curves for immediate serial recall of words presented at fast, medium and slow presentation rates in the silent condition (top panel) and overt rehearsal condition (bottom panel).

Figure 2. Data from the overt rehearsal conditions. The distribution of rehearsal strategies used during each Rehearsal Set (RS), plotted separately for the fast (top), medium (middle) and slow (bottom) presentation rates. A rehearsal set refers to the set of words that was rehearsed immediately after the presentation of each word, such that RS 4 refers to the set of words rehearsed immediately after the presentation of the fourth word in the list. The different rehearsal strategies are described fully in the main text.

Figure 3. Data from the overt rehearsal conditions. The mean proportion of words recalled in the correct order plotted as a function of serial position and the maximum rehearsed sequence length during the trial. A score of 5 on this measure indicates that at any point during a trial, the longest sequence of words rehearsed in correct serial order, starting from the first, was five. Data in the upper panel are for the medium presentation rate and data in the lower panel are for the slow presentation rate.

Figure 4. Data from the overt rehearsal conditions in which only the fixed rehearsal strategy was used throughout the trial. The mean proportion of words recalled in the correct order plotted as a function of the presentation rate and serial position.

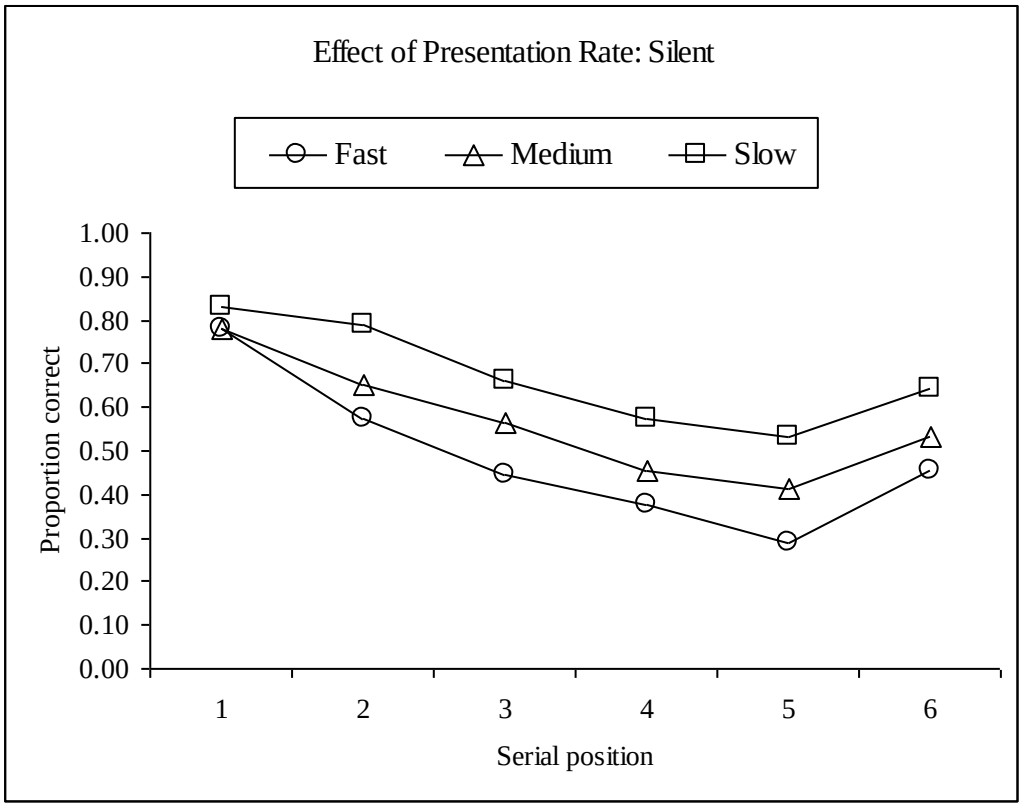
Figure 5. Data from the overt rehearsal conditions. Scatterplots showing the relationship between the mean proportion correct ISR performance and the mean length of the maximum sequence of words rehearsed in the correct serial order, for the medium presentation rate (top panel) and slow presentation rate (bottom panel).

Table 1.

	Presentation Rate			
	Medium		Slow	
Serial Position	r	r^2	r	r^2
1	**.62	.39	***.81	.65
2	**.62	.38	*.53	.28
3	*.54	.30	**.63	.39
4	**.68	.47	**.68	.46
5	.33	.11	*.48	.23
6	.31	.09	.25	.06

*$p < .05$ **$p < .01$ ***$p < .001$

Figure 1


Effect of Presentation Rate: Silent
Fast
Medium
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
1
2
3
4
5
6
Serial position

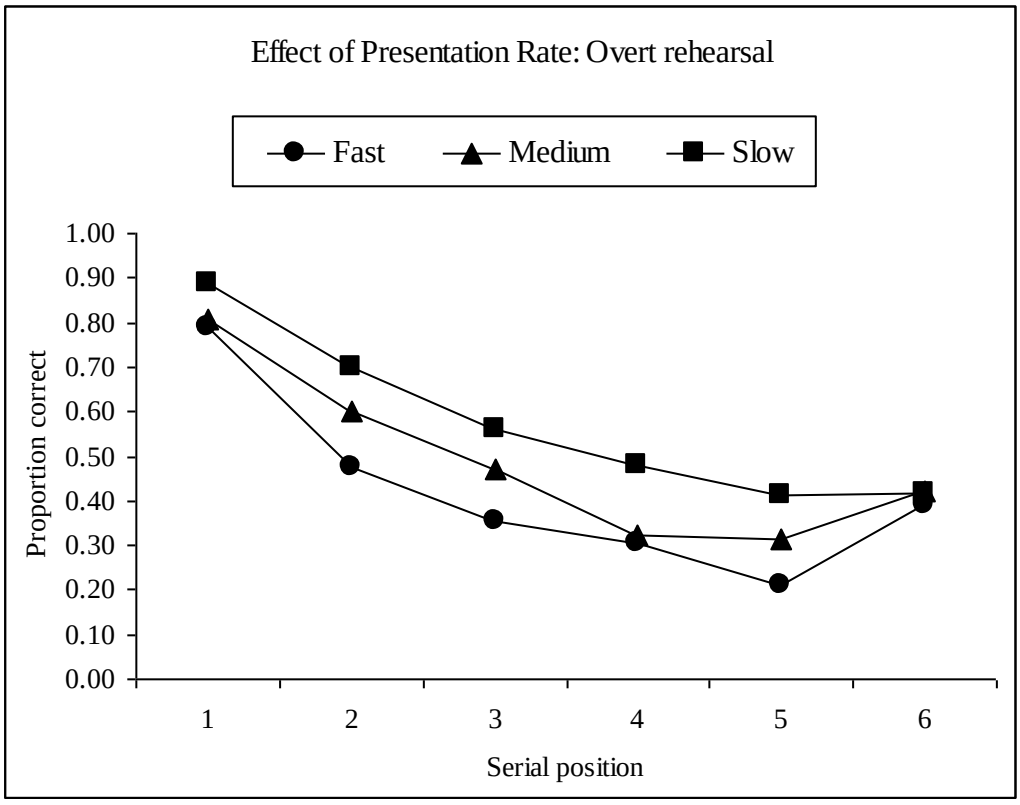
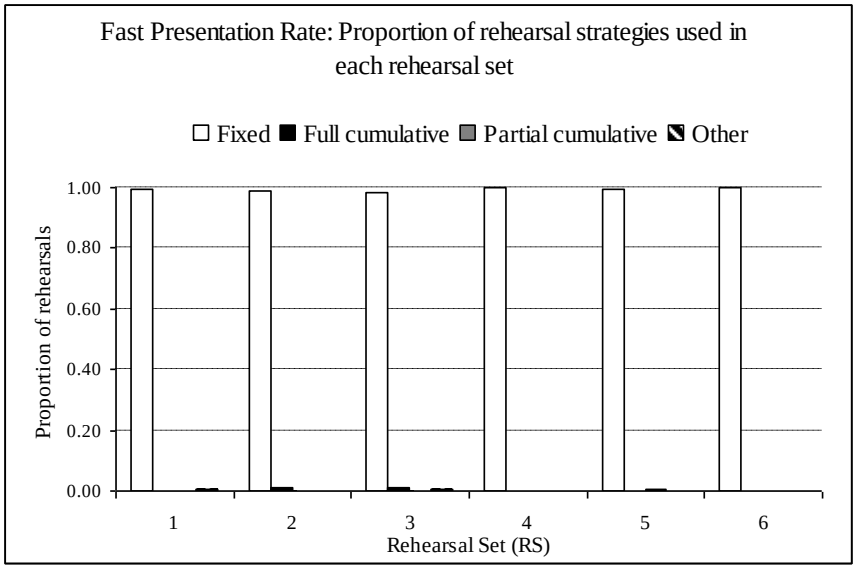
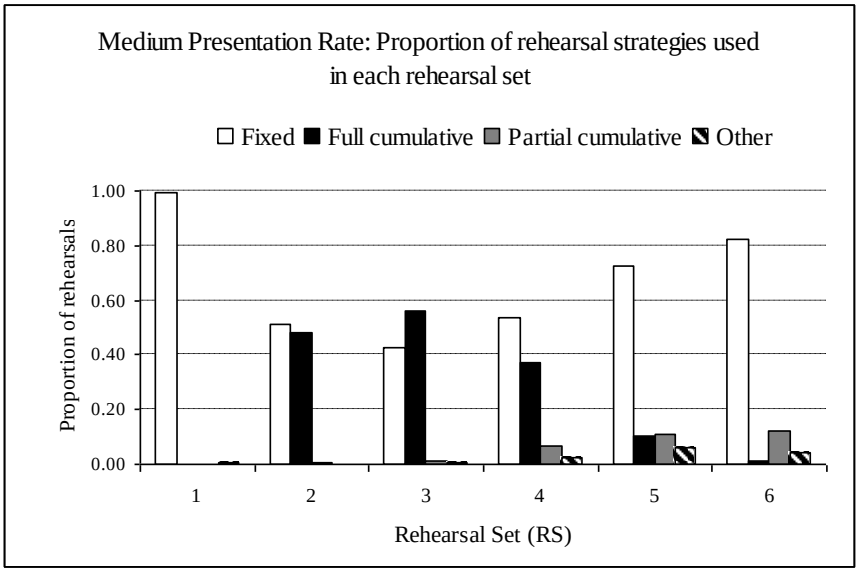

Effect of Presentation Rate: Overt rehearsal
Fast
Medium
Slow
Proportion correct
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1
2
3
4
5
6
Serial position

Figure 2


Fast Presentation Rate: Proportion of rehearsal strategies used in each rehearsal set
Fixed
Full cumulative
Partial cumulative
Other
Proportion of rehearsals
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Rehearsal Set (RS)


Medium Presentation Rate: Proportion of rehearsal strategies used in each rehearsal set
Fixed
Full cumulative
Partial cumulative
Other
Proportion of rehearsals
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Rehearsal Set (RS)

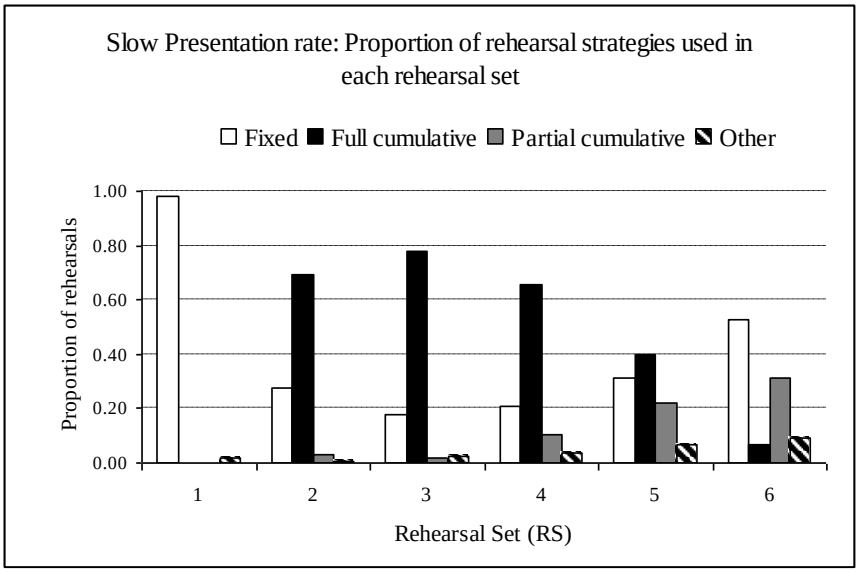
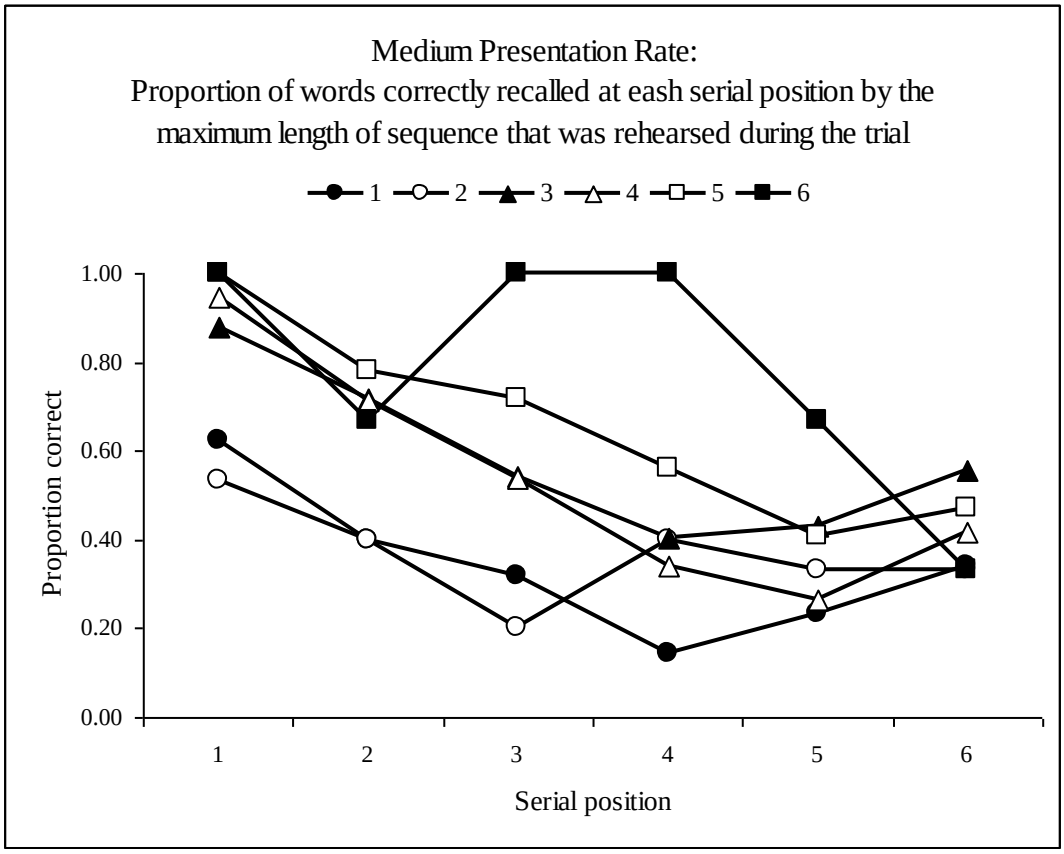

Slow Presentation rate: Proportion of rehearsal strategies used in each rehearsal set
Fixed
Full cumulative
Partial cumulative
Other
Proportion of rehearsals
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Rehearsal Set (RS)

Figure 3.


Medium Presentation Rate:
Proportion of words correctly recalled at eash serial position by the maximum length of sequence that was rehearsed during the trial
1
2
3
4
5
6
Proportion correct
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Serial position

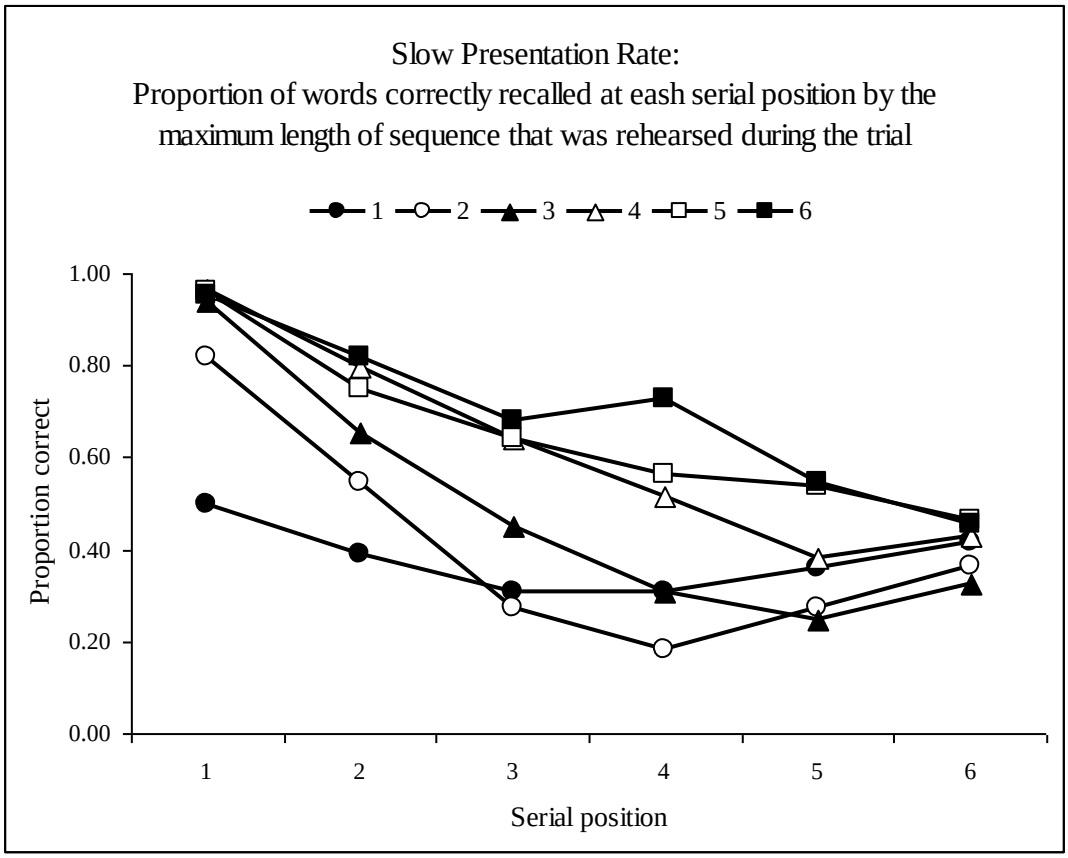

Slow Presentation Rate:
Proportion of words correctly recalled at eash serial position by the maximum length of sequence that was rehearsed during the trial
1
2
3
4
5
6
Proportion correct
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
Serial position

Figure 4

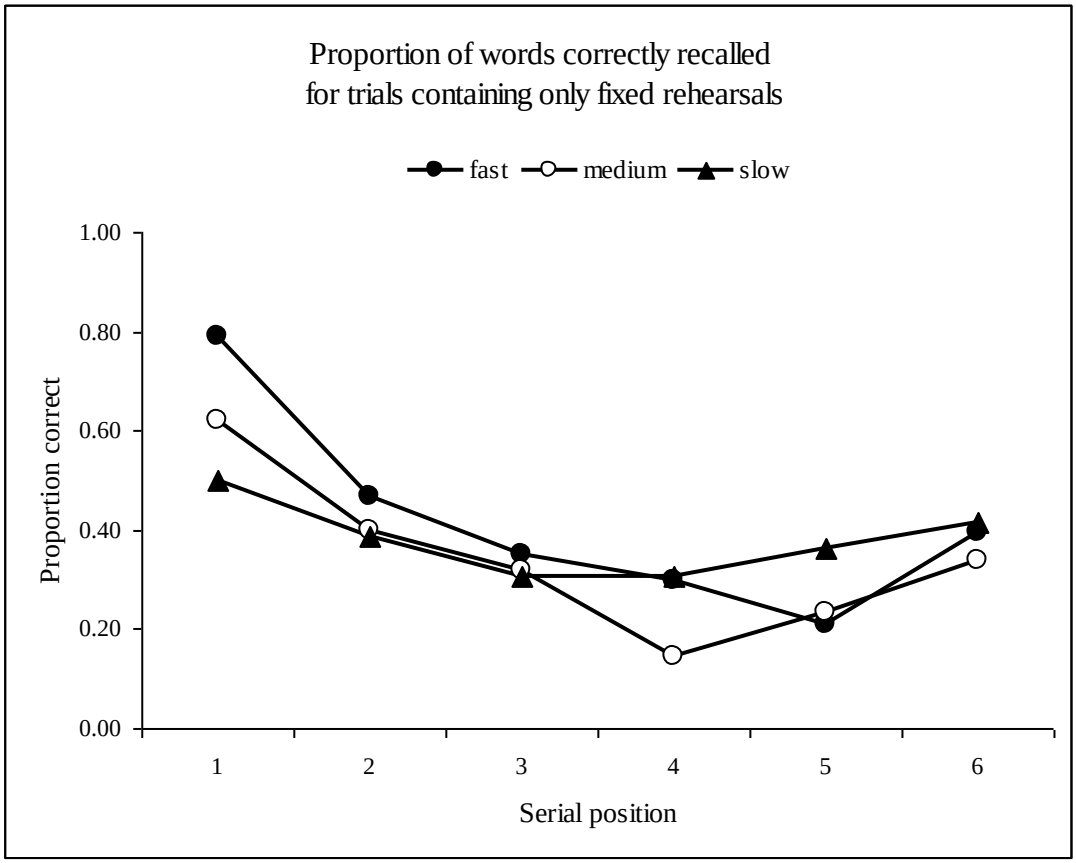
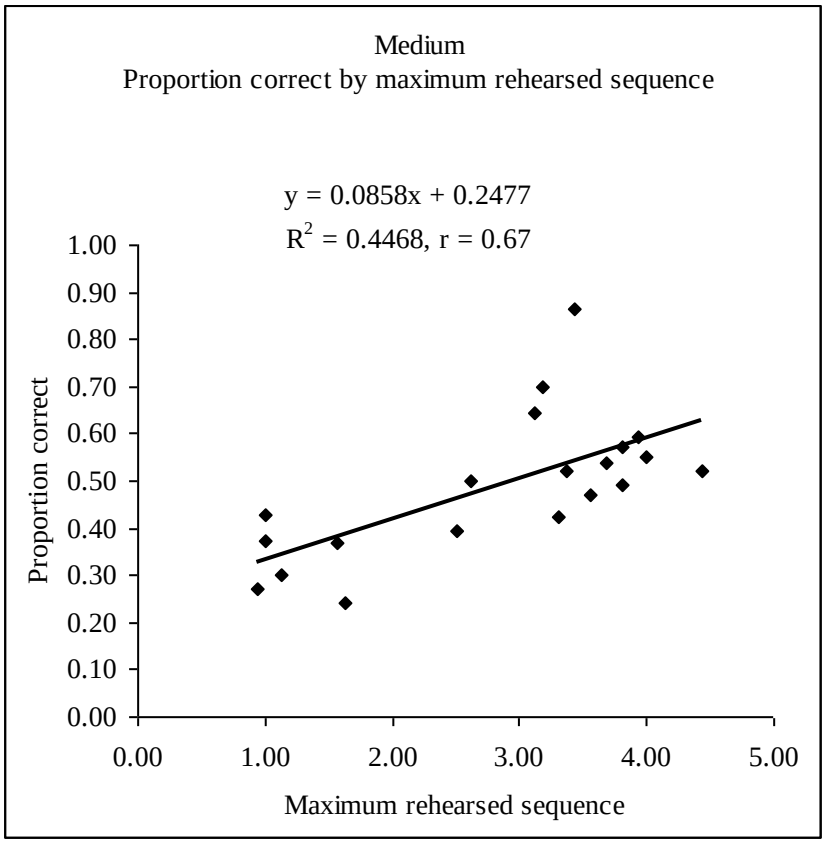
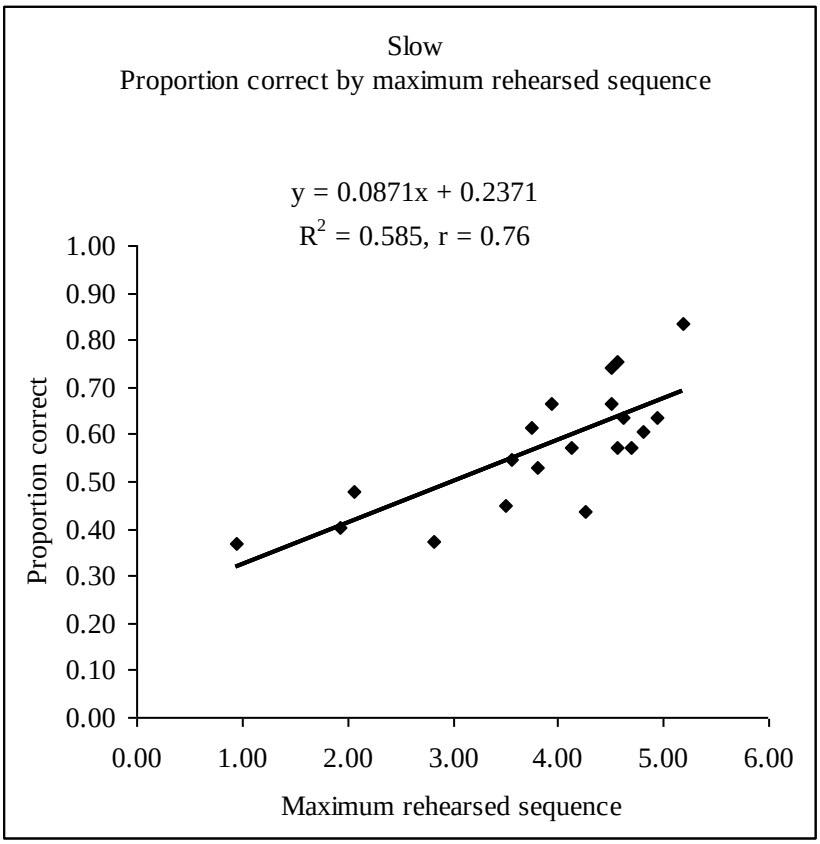

Proportion of words correctly recalled
for trials containing only fixed rehearsals
fast
medium
slow
1.00
0.80
0.60
0.40
0.20
0.00
Proportion correct
1
2
3
4
5
6
Serial position

Figure 5


Medium
Proportion correct by maximum rehearsed sequence
y = 0.0858x + 0.2477
R2 = 0.4468, r = 0.67
Proportion correct
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
1.00
2.00
3.00
4.00
5.00
Maximum rehearsed sequence


Slow
Proportion correct by maximum rehearsed sequence
y = 0.0871x + 0.2371
R2 = 0.585, r = 0.76
Proportion correct
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Maximum rehearsed sequence