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Are forwards and backwards digit recall the same? A dual task study of digit recall

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Abstract

There is some debate surrounding the cognitive resources underlying backwards digit recall. Some researchers consider it to differ from forwards digit recall due to the involvement of executive control, while others suggest that backwards recall involves visuo-spatial resources. Five experiments therefore investigated the role of executive-attentional and visuo-spatial resources in both forwards and backwards digit recall. In the first, participants completed visuo-spatial 0-back and 2-back tasks during the encoding of information to be remembered. The concurrent tasks did not differentially disrupt performance on backwards digit recall relative to forwards digit recall. Experiment 2 shifted concurrent load to the recall phase instead, and in this case revealed a larger effect of both tasks on backwards recall relative to forwards recall, suggesting that backwards recall may draw on additional resources during the recall phase and that these resources are visuo-spatial in nature. Experiments 3 and 4 then further investigated the role of visual processes in forwards and backwards recall using dynamic visual noise (DVN). In Experiment 3 DVN was presented during encoding of information to be remembered, and had no effect upon performance. However, in Experiment 4 it was presented during the recall phase, and the results provided evidence of a role for visual imagery in backwards digit recall. These results were replicated in Experiment 5 in which the same list length was used for forwards and backwards recall tasks. The findings are discussed in terms of both theoretical and practical implications.

In immediate serial recall, participants are presented with series of stimuli and asked to recall them. Direction of recall is known to be an important determinant of performance, with participants typically achieving higher scores when recalling items in their original (forwards) order, relative to reverse or backwards order (e.g. Li & Lewandowsky, 1995; St Clair-Thompson, 2010, but see Anderson, Bothell, Lebiere, & Matessa, 1998). Studies have shown both primacy (advantage for early list items) and recency (advantage for late list items) effects for forwards recall, but minimal primacy and steeper recency for backwards recall (e.g. Bireta, Fry, Jalbert, Neath, & Surprenant et al., 2010; Li & Lewandowsky, 1995). Recall direction also interacts with the prevalence of traditional short-term memory effects, including those of word length, irrelevant speech, phonological similarity, and concurrent articulation (e.g. Bireta et al., 2010). Evidence suggests that the effects are either absent or greatly attenuated when participants are asked to recall items in reverse order (e.g. Bireta et al., 2010; Madigan, 1971; Tehan & Mills, 2007).

These studies of immediate serial recall have employed various stimuli, including letters (e.g. Li & Lewandowsky, 1995), words (e.g. Bireta et al., 2010; Tehan & Mills, 2007), and digits (e.g. Anderson et al., 1998; St Clair-Thompson, 2010). In the current study we focus on the recall of digits, because forwards and backwards digit recall form an integral part of all Wechsler Intelligence Scales and the Wechsler Memory Scales (Wechsler, 1955, 1981, 1997). These are among the most commonly used measures in psychological research and clinical evaluation. However, many theoretical approaches to short-term or working memory (e.g. Baddeley, 2000) assume a domain-specific store for verbal information, including letters, words, and digits. There is no a priori reason to suspect that different patterns of findings would emerge for different types of verbal stimuli.

Several approaches have been taken to account for differences between forwards and backwards recall. One dominant view explains the differences in terms of attentional demands. According to this view, both forwards and backwards recall employ short-term phonological storage (i.e. short-term memory). However, backwards recall is also considered to require an attention-demanding transformation of the digit sequence, thus classifying this task as a complex span measure of working memory (e.g. Alloway, Gathercole & Pickering, 2006; The Psychological Corporation, 2002, p6). Consistent with this suggestion, studies have revealed that backwards recall loads on to the same factor as working memory measures such as counting span and listening span, whereas forwards recall loads on to a separable short-term memory factor (e.g. Alloway et al., 2006; Alloway, Gathercole, Willis & Adams, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004). Backwards digit recall has also been found to be more sensitive to the effects of aging and brain dysfunction than forwards digit recall (The Psychological Corporation, 2002, pp 201-202), with this often attributed to the involvement of executive control (e.g. Reynolds, 1997). In addition, Gerton, Brown, Meyer-Lindenberg, Kohn, and Holt (2004) used PET to observe greater bilateral activation in the dorsolateral prefrontal cortex during backwards relative to forwards digit recall. It should be noted, however, that any explanation based on phonological representation would predict effects of related manipulations (e.g. phonological similarity) in both recall directions (Rosen & Engle, 1997), a prediction for which there has been some contrasting evidence (e.g. Bireta et al., 2010; Guerard, Saint- Aubin, Burns, & Chamberland, 2012).

A second approach assumes that differences result from two different types of representation, with forwards recall being more suited to a phonological code and backwards recall to a visuo-spatial code. For example, Li and Lewandowsky (1995) found that backwards recall, but not forwards recall, was impaired by presenting study items in random spatial locations. Intralist visual similarity was also beneficial to backwards but not forwards recall. Consistent with these findings there is also neuroimaging evidence for the involvement of visuo-spatial processes in backwards recall (e.g. Hoshi, Oda, Wada, Ito, & Tutaka et al., 2000; see also Gerton et al., 2004). Although this suggestion may seem to contradict multi-store models of memory (e.g. Baddeley, 2000), which assume that information is stored in domain-specific subsystems, there is evidence that recall of verbal information can be improved by the use of visual imagery (e.g. DeLa Iglesia, Buceta, & Campos, 2005), visual representation of a number line (e.g. Dehaene, 1992) or the presentation of digits within familiar visuo-spatial configurations (Darling, Allen, Havelka, Campbell, & Rattray, 2012; see also Mate, Allen, & Baques, 2012). It is possible that such visual strategies are employed more so for backwards than forwards recall because they can assist with the transformation of the digit sequence.

Other researchers, however, consider forwards and backwards recall to assess the same cognitive resources. For example, Rosen and Engle (1997) found that forwards and backwards recall did not differ in terms of predicting performance on standardized tasks. Some studies have also revealed that forwards and backwards recall load onto the same factor during factor analysis (e.g. Colom, Abad, Rebello, & Shih, 2005; Engle, Tuholski, Laughlin, & Conway, 1999).

Research investigating the cognitive underpinnings of backwards digit recall has therefore yielded mixed results. The present study aimed to further elucidate the cognitive resources involved in backwards digit recall using an experimental, dual-task approach. We began by employing an adaptation of the n-back technique (e.g. Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Jonides, Schumacher, Smith, Lauber, Awh, & Minoshima et al., 1997; Owen, McMillan, Laird, & Bullmore, 2005), which involves asking participants to track a series of visuo-spatial stimuli at a lag specified by the parameter n. Participants were tested at 0-back (essentially, simple visuo-spatial shadowing) and 2-back, as well as under baseline (no task) conditions. Comparing baseline and 0-back enables an examination of the role of visuo-spatial processing in backwards digit recall. In turn, a comparison of performance under conditions of 0-back and 2-back reveals the extent to which executive control is important. Two-back tasks have previously been shown to be highly demanding of executive resources (e.g. Owen et al., 2005). Furthermore, visuo-spatial 2-back has been effectively used as an executive-based concurrent task during encoding, showing greater disruptive effects on verbal working memory than 0-back (Baddeley, Hitch, & Allen, 2009). In the first experiment, participants completed visuo-spatial n-back tasks during the auditory presentation of digits to be recalled in either forwards or backwards order. In the second, the concurrent tasks were performed during the verbal recall stage. This approach allowed us to examine encoding and recall in turn, and identify at which stage (if any) visuo-spatial processing and attentional control become more important in backwards recall.

In three additional Experiments we further investigated the role of visuo-spatial resources in forwards and backwards recall. We did so by using Dynamic Visual Noise (DVN). DVN was developed by Quinn and McConnell (1996) as a procedure that can interfere with the encoding, maintenance and retrieval of purely visual information in working memory. It is known to influence visual imagery, but not tasks involving visual memory (e.g. Andrade, Kemps, Werniers, May, & Szmalec, 2002; Dean, Dewhurst, & Whittaker, 2008). This therefore allowed us to examine the role of visual imagery in backwards recall. In Experiment 3 DVN was presented during the presentation of digits to be recalled in forwards or backwards order, and in Experiment 4 DVN was presented during recall. Again this approach allowed us to examine at which stage (if any) visual processes become more important in backwards recall. In Experiment 5 we then replicated Experiment 4 but used the same list length for forwards and backwards recall.

Experiment 1

Method

Participants. Thirty undergraduate students took part in the study, receiving course credits. Their mean age was 21 years and 8 months (*SD* 9 months).

Materials. Sequences were constructed of 7 digits for forwards recall and 6-digits for backwards recall conditions. In all cases, digits did not repeat within a sequence. Different list lengths were selected for forwards and backwards recall due to better performance on forwards recall tasks (e.g. Engle et al., 1999; St Clair-Thompson, 2010). Visuo-spatial n-back stimuli consisted of a 3x3 grid square, with each of the nine locations squares measuring 4x4cm, and a 2cm diameter black circle occupying one of the locations on each trial. Stimulus presentation and recording of concurrent task responses was performed on a personal computer using E Prime software.

Design and Procedure. This experiment followed a 2x3 repeated measures design, manipulating recall direction (forwards, backwards) and concurrent task (no task, 0-back, 2-back). All conditions were blocked and order counterbalanced between participants. Each participant was tested in a single session lasting approximately 1 hour.

Each session started with 60 practice trials on each of the 0-back and 2-back tasks, performed in a counterbalanced order. In each trial the black circle appeared in one of the nine locations and remained present for 2 seconds. The next trial followed immediately, with the circle appearing in one of the eight remaining locations, chosen at random. In the 0-back condition participants had to respond by pressing a key on the 3 x 3 numerical keypad corresponding to the location presently occupied. In the 2-back condition the task was to respond to the location occupied two trials previously. In this condition participants were presented with two preparatory trials with the word "Wait" appearing below the 3 x 3 grid. On the third trial they began by responding to the location occupied in trial one, and so on for subsequent trials.

The baseline (no concurrent task) condition was divided into two phases, with five forwards and five backwards recall trials performed at the start, and a further five trials following completion of the concurrent task conditions. Ten trials for each of the four concurrent task conditions (forwards recall with 0-back and 2-back, and backwards recall with 0-back and 2-back) were presented in between the two halves of the baseline condition. These four conditions were blocked and were fully counterbalanced across participants.

On each trial in the baseline condition, participants were informed of whether they had to recall items in forwards or backwards order, and then a keyboard press triggered presentation of the series of digits through speakers at either side of the computer. Participants attempted to verbally recall the sequence immediately following its completion, either in their order of presentation (forwards recall) or in reverse order. In the concurrent task conditions, presentation of the series of digits was preceded by four concurrent task trials (plus two wait trials for the 2-back conditions). Participants were instructed to continue performing the n-back task as quickly and accurately as possible whilst listening to the series of digits being presented. The digits were again presented at the rate of one per second. Thus, two digits were presented during each n-back trial and four concurrent task trials were completed during the presentation of each digit sequence (for backwards recall the last n-back stimulus was presented after the final digit). On completion of digit presentation the screen turned blank and recall was attempted in either forwards or backwards order, as appropriate. Thus no concurrent task was performed during recall. Participants were instructed to state "pass" if they were unsure of a digit, allowing them to continue with recall of the remaining digits in the correct list position. Responses in the primary task were recorded on a digital recording device. Scores for forwards and backwards digit recall were calculated as the proportion correct for each serial position (e.g. see Bireta et al., 2010; Li & Lewandowsky, 1995). As recall direction has previously been shown to interact with serial position, it is important to establish whether the impact of concurrent tasks on forwards and backwards recall varies with position in the sequence.

Results

Forwards and backwards digit recall. Figure 1 shows the mean proportion correct across all participants at each serial position for the six conditions. Forwards recall is shown in the top panel, and backwards recall in the bottom panel. Serial position refers to the *presented* sequence order, thus for backwards digit recall serial position 1 is the final item to be recalled. Due to the different list lengths used for forwards and backwards recall the serial positions were then collapsed into three groups; early, middle and late, to allow for further analysis. For backwards digit recall, the means from 2 serial positions were placed in each category, while for forwards recall there were 3 serial positions in the middle category [1]. A 2 (direction) x 3 (concurrent task) x 3 (serial position) ANOVA revealed a significant main effect of direction of recall, $F(1,29) = 127.99$, $MSE = 4.34$, $p < .01$, $\mu^2 = .82$, with higher scores for forwards recall than backwards recall (means of .81 and .61 respectively). There was a significant main effect of concurrent task, $F(2,58) = 22.38$, $MSE = 1.20$, $p < .01$, $\mu^2 = .44$, with pairwise comparisons revealing significant differences between each concurrent task condition ($p < .05$ in each case). There was also a significant main effect of serial position, $F(2,58) = 109.22$, $MSE = 3.11$, $p < .01$, $\mu^2 = .79$, There was no significant interaction between direction of recall and concurrent task, $F(2,58) = 2.15$, $MSE = 1.64$, $p > .05$, $\mu^2 = .04$, or between concurrent task and serial position, $F(4,116) = 1.18$, $MSE = .94$, $p > .05$, $\mu^2 = .04$. There was a significant interaction between direction and serial position, $F(2,58) = 101.06$, $MSE = 1.17$, $p < .01$, $\mu^2 = .78$, resulting from diminished recency and extended primacy for backwards recall. However, there was no significant three-way interaction between direction, concurrent task and serial position, $F(4,116) = .38$, $MSE = .82$, $p > .05$, $\mu^2 = .02$.

Figure 1 about here

N-back performance. Concurrent n-back performance was based only on trials recorded during digit presentation i.e. excluding the pre-presentation trials. Performance and mean reaction times are displayed in Table 1. Using the percentage of correct responses there was a significant main effect of n-back task, $F(1,29) = 29.82$, $MSE = 62.48$, $p < .01$, $\mu^2 = .51$, with accuracy being substantially poorer in the 2-back task than the 0-back task (means of 88.83 and 96.71). There was no significant main effect of primary task i.e. direction of recall, $F(1,29) = .44$, $MSE = 42.24$, $p > .05$, $\mu^2 = .02$. There was also no significant interaction between n-back and primary task, $F(1,29) = .01$, $MSE = 34.59$, $p > .05$, $\mu^2 = .00$. For reaction times there was a significant main effect of n-back task, $F(1,29) = 13.42$, $MSE = 10832.28$, $p < .01$, $\mu^2 = .32$, with slower reaction times in the 0-back than in the 2-back task (means of 681.65ms and 612.05ms). There was no significant main effect of primary task i.e. direction of recall, $F(1,29) = 3.60$, $MSE = 8901.18$, $p > .05$, $\mu^2 = .10$. There was also no significant interaction between n-back and primary task, $F(1,29) = .09$, $MSE = 3911.30$, $p > .05$, $\mu^2 = .00$.

Table 1 about here

Discussion

The results revealed poorer performance on backwards digit recall than forwards digit recall. However, the results also suggest that these differences did not arise due to differential involvement of visuo-spatial or executive-attentional resources. Performance was poorer in the 2-back conditions than in the 0-back and no concurrent task conditions, presumably because 2-back requires a greater degree of executive control than 0-back (e.g. Baddeley et al., 2009; Owen et al., 2005). However, backwards digit recall was no more affected by the concurrent tasks than forwards digit recall. It is also important to note that differences between forwards and backwards digit recall were not reflected in performance on the concurrent tasks. Participants made more errors in the 2-back conditions than the 0-back conditions, but also responded more quickly. This latter finding was to be expected because in the 2-back task participants could prepare their next response during the 2 seconds that the stimulus remained on screen. However, there were no differences in performance on the n-back tasks between the forwards and backwards recall conditions.

The results of the experiment therefore suggest that backwards digit recall is not relatively more demanding of visuo-spatial or executive-attentional resources than forwards recall. In Experiment 1, however, n-back tasks were presented only during encoding of the digits to be remembered. Some studies have shown that prior knowledge of recall direction has no effect upon recall performance (e.g. Surprenant, Bireta, Brown, & Jalbert et al., 2011), suggesting that differences between forwards and backwards recall are due to retrieval rather than encoding processes. It is also well-established that encoding and retrieval phases of memory are not disrupted to the same extent by concurrent performance of a secondary task (e.g. Fernandes & Moscovitch, 2000; Naveh-Benjamin & Guez, 2000). In particular, one possible strategy during backwards digit recall is to delay the transformation of the digit sequence until all of the items have been presented (e.g. St Clair-Thompson, 2010). If this was the case then completing the n-back task during encoding would not be expected to be detrimental to performance. In contrast, performing the n-back task during retrieval would allow for any effects of the n-back tasks on sequence transformation to be observed. Experiment 2 was conducted to explore this possibility.

Experiment 2

Method

Participants. Thirty- seven undergraduate students took part in the study, receiving course credits. Their mean age was 20 years and 9 months (*SD* 8 months). None of the participants had taken part in Experiment 1.

Materials, design, and procedure. The tasks, structure of testing, and scoring procedures were the same as those used in Experiment 1, with one exception. This time, participants completed the 0-back and 2-back tasks during recall of the digits. Thus, digit sequences were presented in isolation, without concurrent load. In the no concurrent task conditions each series was followed by a 2 second delay and then a cue to recall the sequence. In the 0-back and 2-back conditions, participants were instructed that they could begin recalling the sequence when the second n-back location was displayed. Thus, they had started responding to the 0-back task or started storing locations for later recall in the 2-back task. Therefore, as in the no concurrent task conditions, this procedure resulted in a delay of 2 seconds between presentation and recall of digits in each condition. Participants ceased responding to the n-back trials following recall completion, and pressed the spacebar to hear the next series of digits.

Results

Forwards and backwards digit recall. Figure 2 shows the mean proportion correct at each serial position for the six conditions. Forwards recall is shown in the top panel and backwards recall in the lower panel. Again, due to the different list lengths used for forwards and backwards recall the position data were collapsed into three groups: early, middle and late. A 2 (direction) x 3 (concurrent task) x 3 (serial position) ANOVA revealed a significant main effect of direction of recall, $F(1,36) = 128.47$, $MSE = 6.16$, $p < .01$, $\mu^2 = .78$, with higher scores for forwards recall than backwards recall (means of .84 and.61 respectively). There was a significant main effect of concurrent task, $F(2,72) = 29.56$, $MSE = 1.55$, $p < .01$, $\mu^2 = .45$, with pairwise comparisons revealing significant differences between each concurrent task condition ($p < .05$ in each case). There was also a significant main effect of serial position, $F(2,72) = 98.84$, $MSE = 4.08$, $p < .01$, $\mu^2 = .73$. Of particular interest to the present study there was also a significant interaction between direction of recall and concurrent task, $F(2,72) = 10.74$, $MSE = 1.74$, $p < .01$, $\mu^2 = .23$. We explored this interaction further by conducting a one-way ANOVA comparing the concurrent task conditions for forwards recall, and a one-way ANOVA comparing the conditions for backwards recall. For forwards recall there was a significant main effect of task, $F(2,72) = 4.62$, $MSE = 3.21$, $p < .05$, $\mu^2 = .11$, and pairwise comparisons revealed significant differences between the no concurrent task and 2-back task conditions ($p < .05$). There was no significant difference between the no concurrent task and 0-back conditions, or between the 0-back and 2-back conditions ($p > .05$ in each case). For backwards recall there was a significant main effect of task, F (2,72) = 26.92, MSE = 6.73, , $p < .01$, $\mu^2 = .43$, with pairwise comparisons showing significant differences between the no concurrent task and 0-back conditions, and between the no concurrent task and 2-back conditions ($p < .01$). There was no significant difference between the 0-back and 2-back conditions ($p > .05$). There was also a significant interaction between direction and serial position, F (2,72) = 77.26, MSE = 1.56, $p < .01$, $\mu^2 = .68$. This resulted from a diminished primacy effect for backwards recall. There was no significant interaction between task and position, F (4,144) = 1.59, MSE = .81, $p > .05$, $\mu^2 = .04$, and no significant three-way interaction between direction, concurrent task and serial position, F (4,144) = .99, MSE = .77, $p > .05$, $\mu^2 = .03$.

Figure 2 about here

N-back performance. Performance and mean reaction times for the n-back tasks are displayed in Table 1. Using the percentage of correct responses there was a significant main effect of n-back task, F (1,36) = 25.13, MSE = 292.28, $p < .01$, $\mu^2 = .41$, with accuracy being substantially poorer in the 2-back task than the 0-back task (means of 63.15 and 71.68). There was also a significant main effect of primary task i.e. direction of recall, F (1,36) = 20.46, MSE = 131.34, $p < .01$, $\mu^2 = .36$, with accuracy being poorer for backwards recall than forwards recall (means of 63.15 and 71.68 respectively). There was no significant interaction between n-back and primary task, F (1,36) = .92, MSE = 124.85, $p > .05$, $\mu^2 = .03$. For reaction times there was a significant main effect of n-back task, F (1,36) = 8.83, MSE = 33823.32, $p < .01$, $\mu^2 = .20$, with slower reaction times in the 0-back than in the 2-back task (means of 883.28ms and 793.42ms). There was a significant main effect of primary task i.e. direction of recall, F (1,36) = 7.88, MSE = 25896.56, $p < .01$, $\mu^2 = .17$, with quicker reaction times for forwards recall than for backwards recall (means of 801.23ms and 875.47ms). There was no significant interaction between n-back and primary task, F (1,36) = 0.50, MSE = 6745.28, $p > .05$, $\mu^2 = .01$.

Discussion

As in Experiment 1, performance was significantly poorer on backwards digit recall than forwards digit recall. Furthermore, this experiment did reveal a significant interaction between recall direction and concurrent task. Further analysis demonstrated that this was due to effects of both visuo-spatial tasks (0-back and 2-back) on backwards recall, relative to baseline (no task) conditions, but no difference between 0-back and 2-back conditions (illustrating executive control). In contrast, for forwards recall, there was only an effect of the 2-back task. This suggests that differences between forwards and backwards recall occur during recall, rather than during encoding of the items to be remembered (Experiment 1), and also that backwards recall may have involved a degree of visuo-spatial resources.

Further differences between forwards and backwards recall were reflected in performance on the concurrent tasks. Performance on the n-back tasks was poorer during backwards recall than forwards recall. This provides some evidence for additional cognitive resources being employed for backwards recall, which then compromises performance on the n-back tasks. Importantly, however, there was no significant interaction between n-back task and direction of recall. Therefore, backwards digit recall did not differentially influence performance on the 2-back task relative to the 0-back task. The additional resources being employed for backwards recall therefore do not appear to be executive in nature, and rather appear to be common to both n-back tasks. This finding therefore provides further evidence for the role of visuo-spatial resources in backwards recall.

The results therefore support previous suggestions that backwards recall, but not forwards recall, relies partially on visuo-spatial processing (e.g. Li & Lewandowsky, 1995). It could be the case that when participants are required to recall a sequence in reverse order they use a visuo-spatial representation of the sequence from which they can read off the items to recall. However, the equivalent effects of concurrent tasks performed during encoding on forwards and backwards recall that were observed in Experiment 1 would appear to suggest that participants do not differentially use a visuo-spatial representation during encoding for forwards or backwards recall. Therefore it may be the case that digit encoding and storage are primarily phonological in nature with some form of visuo-spatial mental rotation employed at recall in order to reverse the sequence.

It is, however, important to note that although in the current study the interaction indicating the involvement of visuo-spatial resources was significant, the effect size was not large. In addition, the requirements of the visuo-spatial n-back task make the findings of visuo-spatial interference somewhat difficult to interpret. For example, when using dual-task paradigms there is always a concern about trade-offs in performance. In Experiment 2 accuracy on the n-back task was somewhat poorer during backwards recall then forwards recall, and participants also responded more slowly to the n-back task during backwards recall. In Experiment 1 there were no differences in accuracy between the forwards and backwards recall conditions. However, the difference in reactions times between the forwards and backwards recall conditions was nearing significance. Thus in Experiment 1 there may have been a hint of a small effect of performing concurrent tasks during encoding on backwards digit recall.

It is also worthy of note that the n-back task and both forwards and backwards recall share a requirement for serial order. It is, however, unlikely that the differential pattern of interference emerged because the n-back task involved a form of backwards recall. In the n-back task used in the current study participants were essentially recalling a spatial sequence in the same order that it was presented, at either a lag of 0 or 2 items. Thus the task could be considered to be more similar to forwards than backwards recall. Previous research comparing n-back with forwards and backwards recall, and simple and complex span, also reject the notion that the findings in Experiment 2 reflect increased similarity in basic task demands between n-back and backwards recall (e.g. Gevins & Smith, 2000; Jaeggi et al., 2010; Miller, Price, Okun, Montijo, & Bowers, 2009; Oberauer, 2005; Shelton, Elliott, Hill, Calamia, & Gouvier, 2009). Thus, we would claim that the results indicate a greater role for visuo-spatial support during backwards digit recall. Nevertheless, it is important to establish whether the same patterns of differential interference emerge using a different concurrent manipulation, that controls possible trade-off and ordering issues. We therefore conducted further experiments to examine the role of visuo-spatial resources in backwards digit recall. We did so by using DVN.

DVN involves presenting patterns consisting of small black and white squares that randomly switch colour over time, thus minimizing spatial and temporal components. It was established by Quinn and McConnell (1996; McConnell & Quinn, 2000) to allow selective interference with visual short-term memory. Quinn and McConnell (1996) found that DVN had minimal effects on storage of word lists when participants were instructed to use a rote rehearsal strategy, but caused substantial disruption when visual imagery of the same items was required. Subsequently, a growing body of evidence has indicated that DVN can interfere with the encoding, maintenance and retrieval of certain forms of purely visual information (e.g. Andrade et al., 2002; Dean et al., 2008) but not with spatial information (e.g. Darling, Della Sala & Logie, 2007; 2009; Dent, 2010). Furthermore, the passive nature of DVN interference, and the selective impact on visual imagery (and not verbal or spatial working memory) indicates that this manipulation places no demands on modality-independent central executive resources. Any disruptive impact of DVN can therefore be attributed to visual processing, and not a more general attentional contribution, or to any requirements of serial ordering also shared by the primary recall task. If participants do indeed employ visual resources during backwards recall, for example to assist with the transformation of the digit sequence, we would expect DVN to interfere with backwards recall relative to forwards digit recall. In Experiment 3 DVN was presented alongside forwards and backwards recall as concurrent interference during encoding.

Experiment 3

Method

Participants. 25 undergraduate students took part in the study, receiving course credits. Their mean age was 22 years and 0 months (*SD* 9 months). None of the participants had taken part in Experiments 1 or 2.

Materials, design, and procedure. Participants completed ten trials in each of four conditions (forwards recall with no concurrent task, backwards recall with no concurrent task, forwards recall with DVN during encoding, and backwards recall with DVN during encoding). The baseline (no concurrent task) conditions were divided into two phases, with five forwards and five backwards recall trials performed at the start, and a further five trials following completion of the concurrent task conditions. The concurrent task conditions were blocked and were fully counterbalanced across participants.

On each trial in the baseline condition, a keyboard press triggered presentation of the series of digits through speakers at either side of the computer. Participants attempted to verbally recall the sequence immediately following its completion, either in its order of presentation (forwards recall) or in reverse order. In the concurrent interference conditions a keyboard press triggered both the presentation of the digit sequence and presentation of DVN. The DVN consisted of a grid of 80 X 80 cells each measuring 2 x 2 pixels. At any one time 50% of the pixels were white and 50% were black. The pixels changed at random at a rate of 50% per second. The DVN was presented as an 8 second or 7 second movie for forwards and backwards recall respectively. The digit sequences began after 1 second, with one digit per second. Participants were instructed to look at the computer screen throughout the entire task. On completion of digit presentation the screen turned blank and recall was attempted in either forwards or backwards order, as appropriate. Thus no DVN was presented during recall. Scores for forwards and backwards digit recall were calculated as the proportion correct for each serial position.

Results

Figure 3 shows the mean proportion correct at each serial position for the four conditions. Forwards recall is shown in the top panel and backwards recall in the lower panel. Again, due to the different list lengths used for forwards and backwards recall the position data were collapsed into three groups: early, middle and late. A 2 (direction) x 2 (concurrent interference) x 3 (serial position) ANOVA revealed a significant main effect of direction of recall, $F(1,24) = 31.06$, $MSE = 7.42$, $p < .01$, $\mu^2 = .56$, with higher scores for forwards recall than backwards recall (means of .82 and.64 respectively). There was no significant main effect of interference, $F(1,24) = .42$, $MSE = .39$, $p > .05$, $\mu^2 = .02$. There was a significant main effect of serial position, $F(2,42) = 57.01$, $MSE = 1.98$, $p < .01$, $\mu^2 = .70$.. However, there was no significant interaction between direction of recall and interference, F

(1.24) = .03, MSE = .05, $p > .05$, $\mu^2 = .00$. There was a significant interaction between direction and serial position, F (2,48) = 81.27, MSE = 2.20, $p < .01$, $\mu^2 = .77$. This resulted from a diminished primacy effect for backwards recall. There was no significant interaction between interference and position, F (2,48) = .14, MSE = .66, $p > .05$, $\mu^2 = .01$, and no significant three-way interaction between direction, interference and serial position, F (2,48) = 2.11, MSE = .64, $p > .05$, $\mu^2 = .07$.

Figure 3 about here

Discussion

The results of Experiment 3 again revealed poorer performance on backwards digit recall than forwards digit recall. However, backwards digit recall was no more affected by DVN than forwards digit recall. The results are therefore consistent with Experiment 1, which suggested that backwards digit recall is not relatively more demanding of visuo-spatial resources than forwards digit recall. The findings of Experiment 2, however, suggested that backwards recall was more demanding of visuo-spatial resources during the recall phase, rather than during encoding of the items to be remembered. If this is the case then we would not expect DVN to interfere with backwards digit recall when presented during encoding, but rather we would expect it to interfere when presented during recall. Experiment 4 explored this possibility.

It is, however, worthy of note that in Experiment 2 although the interaction indicating the involvement of visuo-spatial resources in backwards recall was significant, the effect size was not large. There are a number of possible reasons for this finding. One is that the extent of visuo-spatial involvement is dependent upon participant's strategy use. Visuo-spatial imagery may be just one successful strategy for backwards recall (e.g. Hoshi et al., 2000), with some participants preferring verbal strategies such as articulatory rehearsal. It seems reasonable to assume that participants who employ visual strategies may be more affected by a concurrent visual task or DVN-based interference. Therefore in addition to exploring the effects of DVN during recall of digits, in Experiment 4 participants were also asked to report the strategies they employed during backwards recall, with these reports later classified as involving either visual or non-visual processes. The effects of DVN during recall of digits were examined overall, and then explored separately in two groups defined on the basis of strategic approach.

Experiment 4

Method

Participants. 30 undergraduate students took part in the study, receiving course credits. Their mean age was 20 years and 5 months (*SD* 9 months). None of the participants had taken part in Experiments 1, 2 or 3.

Materials, design, and procedure. The tasks, structure of testing, and scoring procedures were the same as those used in Experiment 3, with one exception. This time, participants were presented with DVN during recall of the digits. Thus, digit sequences were presented in isolation, without concurrent interference. In the no interference conditions each sequence was followed by a cue to recall the digits. In the DVN conditions, each sequence was followed by presentation of DVN, and participants were instructed that they could begin recalling the sequence as soon as the DVN was displayed. Participants stopped the DVN following recall completion, and pressed the spacebar to hear the next series of digits.

At the end of the testing session participants were then asked to describe the strategies they had employed during backwards digit recall. Responses were recorded on a digital voice recorder. These were then classified by an independent researcher who was blind as to the aims of the study, as involving either visual or non-visual processes. To be classified as using visual strategies participants reported that they had engaged in practices such as “picturing the numbers in my mind” or “imagining the numbers written down on a piece of paper”.

Results

Figure 4 shows the mean proportion correct at each serial position for the four conditions. Forwards recall is shown in the top panel and backwards recall in the lower panel. Again, due to the different list lengths used for forwards and backwards recall the position data were collapsed into three groups: early, middle and late. A 2 (direction) x 2 (concurrent interference) x 3 (serial position) ANOVA revealed a significant main effect of direction of recall, $F(1,29) = 120.33$, $MSE = 3.03$, $p < .01$, $\mu^2 = .81$, with higher scores for forwards recall than backwards recall (means of .83 and.62 respectively). There was no significant main effect of interference, $F(1,29) = 1.98$, $MSE = 1.31$, $p > .05$, $\mu^2 = .06$. There was a significant main effect of serial position, $F(2,58) = 107.08$, $MSE = 1.30$, $p < .01$, $\mu^2 = .78$.. Of particular interest to the current study there was also a significant interaction between direction of recall and interference, $F(1,29) = 6.97$, $MSE = 1.22$, $p < .05$, $\mu^2 = .19$. Further analysis revealed a significant effect of DVN on backwards recall, $F(1,29) = 4.15$, $MSE = 1.33$, $p = .05$, $\mu^2 = .13$, but not on forwards recall, $F(1,29) = 1.80$, $MSE = 1.32$, $p > .05$, $\mu^2 = .06$. Returning to the main analysis, there was a significant interaction between direction and serial position, $F(2,58) = 118.41$, $MSE = 1.66$, $p < .01$, $\mu^2 = .80$. Again this resulted from a diminished primacy effect for backwards recall. There was no significant interaction between task and position, $F(2,58) = 2.80$, $MSE = .34$, $p > .05$, $\mu^2 = .09$, and no significant three-way interaction between direction, interference and serial position, $F(2,58) = .47$, $MSE = .68$, $p > .05$, $\mu^2 = .02$.

Figure 4 about here

Further analyses then examined the pattern of findings as a function of participant's strategy use. Of the 30 participants 11 were classified as having used visual strategies, with the other 19 being classified as using non-visual strategies. A 2 (direction) x 2 (interference) x 3 (serial position) ANOVA was then conducted separately for each group of participants. The analyses revealed a similar pattern of findings for the two groups, with significant main effects of direction of recall and of serial position in each group ($p < .01$ in each case), but no significant main effects of interference ($p > .05$ in each case). However, regarding the interactions between direction of recall and interference condition, this was only significant in the group who had used visual strategies, $F(1, 10) = 9.35$, MSE

$= .49$, $p < .05$, $\mu^2 = .48$. In this group DVN caused greater interference for backwards recall (means of .68 and .60 for no concurrent task and DVN conditions respectively) than for forwards recall (means of .86 and .85). For the group who used non-visual strategies performance on backwards digit recall was still impaired somewhat by DVN (means of .62 and .59 for no concurrent task and DVN conditions for backwards recall, and means of .79 and .80 for forwards recall) but the interaction between direction of recall and interference condition was not statistically significant, $F(1, 18) = 2.45$, $MSE = 1.68$, $p > .05$, $\mu^2 = .12$. In both groups there were also significant interactions between direction and serial position, resulting from diminished primacy effects for backwards recall, but no significant interactions between interference and serial position nor significant three-way interaction between direction, interference and serial position.

Discussion

Consistent with the findings of Experiment 2 this experiment did reveal a significant interaction between recall direction and concurrent task. This provides further evidence that different processes are involved in forwards and backwards recall during the recall phase, rather than during encoding of the items to be remembered, and also that this process may involve a degree of visuo-spatial resources. The finding that backwards recall is affected more than forwards digit recall by DVN further suggests that the visuo-spatial processes involved in backwards recall are at least in part visual in nature, and may reflect a contribution of visual imagery (e.g. Andrade, Kemps et al., 2002; Dean et al., 2008).

Experiment 4 also revealed that one important factor determining the role of visuo-spatial resources in backwards digit recall is participant's strategy use. When all of the participants were considered together the interaction indicating the involvement of visual resources in backwards recall was significant. However, the effect size was relatively small (.19). When the participants were separated in to two groups based on their strategic approach to backwards recall, the interaction indicating the involvement of visuo-spatial resources was significant in the visual strategy group, with a large effect size (.48). However, it was not significant in the non-visual strategy group (effect size of .12). This finding will be revisited in the general discussion.

It is, however, important to note that in the present Experiment (and in Experiments 1,2, and 3), different list lengths were used for forwards and backwards recall (in order to minimize risks of floor and ceiling effects constraining performance in each direction condition). It is possible that this use of different sequence lengths (7-item sequences in forwards recall and 6 in backwards) may have influenced particular grouping or chunking strategies used in the two recall directions. Although there is no existing evidence to suspect that this particular difference in sequence lengths would make backwards recall any more amenable to visuo-spatial strategies, a further experiment was conducted to evidence a role for visuo-spatial resources in backwards but not forwards recall when the same list lengths are used.

Experiment 5

Method

Participants. 28 undergraduate students took part in the study, receiving course credits. Their mean age was 19 years and 2 months (*SD* 8 months). None of the participants had taken part in Experiments 1, 2, 3, or 4.

Materials, design, and procedure. The tasks, structure of testing, and scoring procedures were the same as those used in Experiment 4, with one exception. This time, participants were presented with series of 7 digits for recall in both forwards and backwards directions. Again, digit sequences were presented in isolation, without concurrent interference. DVN was then presented during recall. Thus, in the no interference conditions each sequence was followed by a cue to recall the digits. In the DVN conditions, each sequence was followed by presentation of DVN, and participants were instructed that they could begin recalling the sequence as soon as the DVN was displayed. Participants stopped the DVN following recall completion, and pressed the spacebar to hear the next series of digits.

Results

Figure 5 shows the mean proportion correct at each serial position for the four conditions. Forwards recall is shown in the top panel and backwards recall in the lower panel. For consistency, again the data were collapsed into three groups: early, middle and late. For both recall directions three serial positions were in the middle category. A 2 (direction) x 2 (concurrent interference) x 3 (serial position) ANOVA revealed a significant main effect of direction of recall, $F(1,27) = 90.13$, $MSE = 5.89$, $p < .01$, $\mu^2 = .77$, with higher scores for forwards recall than backwards recall (means of .84 and.59 respectively). There was a significant main effect of interference, $F(1,27) = 21.84$, $MSE = 1.48$, $p < .01$, $\mu^2 = .45$, with higher scores in no concurrent task than concurrent task conditions (means of .74 and .68 respectively). There was a significant main effect of serial position, $F(2,54) = 127.67$, $MSE = 1.86$, $p < .01$, $\mu^2 = .83$. Of particular interest to the current study, there was also a significant interaction between direction of recall and interference, $F(1,27) = 10.70$, $MSE = 1.04$, $p < .01$, $\mu^2 = .28$. Further analysis revealed a significant effect of DVN on backwards recall, $F(1,27) = 23.02$, $MSE = 29.50$, $p < .01$, $\mu^2 = .46$, but not on forwards recall, $F(1,27) = 2.97$, $MSE = 14.43$, $p > .05$, $\mu^2 = .09$. Returning to the main analysis, there was a significant interaction between direction and serial position, $F(2,54) = 146.01$, $MSE = 1.77$, $p < .01$, $\mu^2 = .84$. Again this resulted from a diminished primacy effect for backwards recall. There was a significant interaction between task and position, $F(2,54) = 6.42$, $MSE = .46$, $p < .01$, $\mu^2 = .19$, indicating that lower performance in concurrent task conditions was restricted to early and middle serial positions, and a significant three-way interaction between direction, interference and serial position, $F(2,54) = 7.72$, $MSE = .68$, $p < .01$, $\mu^2 = .22$, indicating that lower performance in the DVN condition in the early and middle serial positions only occurred in the backwards and not forwards recall conditions[2].

Figure 5 about here

Discussion

Consistent with the findings of Experiment 4, Experiment 5 revealed a significant interaction between recall direction and concurrent task. Participants performed significantly poorer on backwards digit recall as a result of DVN, but there was no significant difference in performance on forwards recall in the single and concurrent task conditions. This again suggests that different processes are involved in forwards and backwards recall during the recall phase, and that these processes involve a degree of visuo-spatial resources. The differences between forwards and backwards recall that were observed in Experiments 2 and 4 were therefore not simply a consequence of longer list lengths being used for forwards recall than for backwards recall. In addition, Experiment 5 revealed a significant three-way interaction between direction, concurrent task and list position, with larger DVN effects, only on backward recall, at the start and middle of presented lists (i.e. the end of the recalled sequence for backwards recall). This would indicate that visuo-spatial resources are more important at this phase of the sequence when reverse recall is required. This will be discussed in more detail, and in the context of the prior experiments, in the General Discussion.

General Discussion

The aim of the current study was to investigate the cognitive underpinnings of backwards digit recall. Experiments 1 and 2 revealed that, at least in adult participants, backwards digit recall places minimal additional demands on executive-attentional resources, relative to those involved in forwards recall. The basic effects of 2-back indicate a role for the central executive in encoding short sequences of verbal information (e.g. Aleman & Van ’t Wout, 2008; Baddeley et al., 2009), but this was no larger for backwards than forwards recall. Experiment 1 further revealed that performing a visuo-spatial task during encoding did not impair backwards recall relative to forwards recall, suggesting that it does not particularly rely on visuo-spatial resources either. Experiment 2, however did provide some evidence for a role of visuo-spatial processing resources in backwards recall. As this effect was only apparent when concurrent load was added during recall (Experiment 2), and not during encoding (Experiment 1), this suggests that participants use visuo-spatial processes during backwards recall during the response phase, rather than during digit encoding.

Experiments 3-5 further explored the role of visuo-spatial resources in backwards recall by using DVN. Experiment 3 revealed that presenting DVN during encoding did not impair backwards recall relative to forwards recall, suggesting that backwards recall does not particularly rely on visuo-spatial resources during the encoding phase. However, Experiment 4 then revealed an interaction between direction of recall and concurrent task, which consistent with Experiment 2 provides evidence for a role of visuo-spatial resources during the response phase of backwards recall. This was replicated in Experiment 5 using equal sequence lengths for forwards and backwards recall.

These results support previous suggestions that backwards but not forwards recall tends to draw partially on visuo-spatial processing (e.g. Li & Lewandowsky, 1995). The finding that DVN interferes with backwards recall further provides evidence that visual strategies are involved . DVN does not interfere with spatial information (e.g. Darling et al., 2007; 2009; Dent, 2010), and it is known to influence visual imagery, but not tasks involving visual memory (e.g. Andrade, Kemps et al., 2002; Dean et al., 2008), verbal memory (Quinn & McConnell, 1996), or central executive resources. Therefore it seems that the role of visual resources in backwards digit recall may well reflect participant's use of visual imagery during the recall phase of the task, in order to assist with transformation of the digit sequence. This is not to claim that visual imagery can *only* be used for backwards and not forwards recall. Instead, it appears that participants do not generally utilize such a strategy when required to recall digit sequences in their original order. It is, however, important to note at this stage that the exact role of visuo-spatial processes in backwards recall is not well understood. It could be that participants create a visual image to perform some kind of mental rotation of the digit sequence, or form a visual image of the sequence and then retrieve items by scanning the image starting from the final item that was presented.

The three-way interaction (between direction, DVN, and list position) observed in Experiment 5 may shed some light on this. This indicated that DVN had a larger effect on backwards recall at the start/middle of presented lists (i.e. the middle/end of recalled sequences). One possibility is that, for backwards digit recall, participants rely on phonological memory to recall the final few items in the sequence (as they were heard most recently). However, as reversed recall progresses towards the start of the presented sequence, this becomes a more difficult and unreliable strategy to use, and participants instead switch to a visual-based code to reverse the digits. While this is clearly a tentative post hoc account, patterns of interference from Experiments 2 and 4 would fit with this, as they indicate somewhat larger effects in the same sections of the sequence. The three-way interactions in these experiments were not significant, but this may reflect the slightly shorter sequences used for backwards recall than in Experiment 5. Thus, the final experiment replicated the critical interaction between direction and concurrent load from Experiments 2 and 4, and furthermore, the use of 7-item sequences enabled the three-way interaction to more clearly emerge in this study. Further research would however benefit from further examining the role of list length or task difficulty on the role of visuo-spatial processes in backwards recall, and from examining the effects on the likelihood of visuo-spatial processes being employed during other phases of the task, for example during encoding as well as recall.

Experiment 4 also indicated that visual imagery is just one possible strategy that can be used during backwards digit recall (see also Hoshi et al, 2000). Eleven of the 30 participants in Experiment 4 reported using visual strategies for backwards recall. Furthermore, for these participants there was a much greater decrement in backwards recall relative to forwards recall as a result of concurrent DVN. Participants who did not report using visual strategies commonly reported using the strategy of subvocal rehearsal, ceasing each rehearsal cycle when reaching the next digit to be recalled (see Li et al., 2012 for recent evidence of contribution of auditory-phonological STM to backwards digit recall). These participants did not show a significant decrement in backwards recall as a result of DVN. This finding suggests that the variable use of strategies across participants may have been responsible for the relatively small effect size of the interaction indicating a role for visuo-spatial resources that was observed in Experiment 2. This finding also suggests, more generally, that it is important for researchers to consider strategy use during short-term and working memory tasks.

It is also worthy of note that the design of the current studies may have minimised the impact of concurrent visuo-spatial tasks The current studies used auditory presentation of digits (due to the concurrent tasks being visuo-spatial in nature). In contrast, previous studies examining backwards digit recall (e.g. Bireta at el., 2010; Li & Lewandowsky, 1995) have used visual presentation of digits. The format used in the current study is likely to have increased the role for phonological coding, yet we still obtained some evidence for a role for visuo-spatial resources. Larger effects of concurrent visuo-spatial tasks may emerge with visual presentation, which may also encourage the use of visual codes and strategies (see Logie, Della Sala, Wynn, & Baddeley, 2000). Further research is therefore needed to explore the role of visuo-spatial resources in backwards recall using visual presentation.

These findings have implications for both theory and practice. They suggest that participants employ different processes, or strategies, during forwards and backwards recall (though not during encoding of these sequences). Models of immediate serial recall such as the Primacy Model (Page & Norris, 1998; 2003), assume that forwards and backwards recall are performed in the same manner. The findings of the current study suggest that such models require adjustment to explain backwards recall, by assuming that participants often employ different strategies or representations depending on the direction of recall. The findings also fail to support the suggestion by Bireta et al. (2010) based on SIMPLE (Brown, Neath, & Chater, 2007) of differential item/order trade-offs between forwards and backwards recall. Under this approach, participants focus more on order processing in the temporal dimension during backwards recall, and are thus less affected by manipulations that impact on item than on order. However, while 0-back may involve an ordering requirement (though not to the same extent as 2-back, which did not show an interactive interference effect), DVN has no such load, with its impact previously shown to be independent of the serial ordering requirement of primary memory tasks (Darling et al., 2009; Zimmer, Speiser, & Seidler, 2003). Instead, DVN directly affects visuo-spatial working memory representations (Dean et al., 2008). Therefore the item/ order trade off theory cannot account for the greater effects of DVN in backwards than forwards recall. The results also suggest that researchers and practitioners need to consider the cognitive resources underlying forwards and backwards digit recall. It is reported that backwards digit recall is a complex span task requiring executive resources (The Psychological Corporation, 2002, p6). However, the findings of the current study suggest that backwards digit recall for the most part behaves more like a simple span task, with relatively minimal additional processing required only at the recall stage, and only as a result of visual strategies. Therefore, at least in young adults, comparison of forwards and backwards digit recall appears to not be an appropriate method of examining central executive resources, and may instead at least partly reflect the strategic utilization of visual imagery.

Footnotes

[1] The analyses were also conducted with 3 serial positions in the early and late categories for forwards recall. The same pattern of results was found.

[2] The analyses were also conducted without grouping the serial positions. The same pattern of results emerged.

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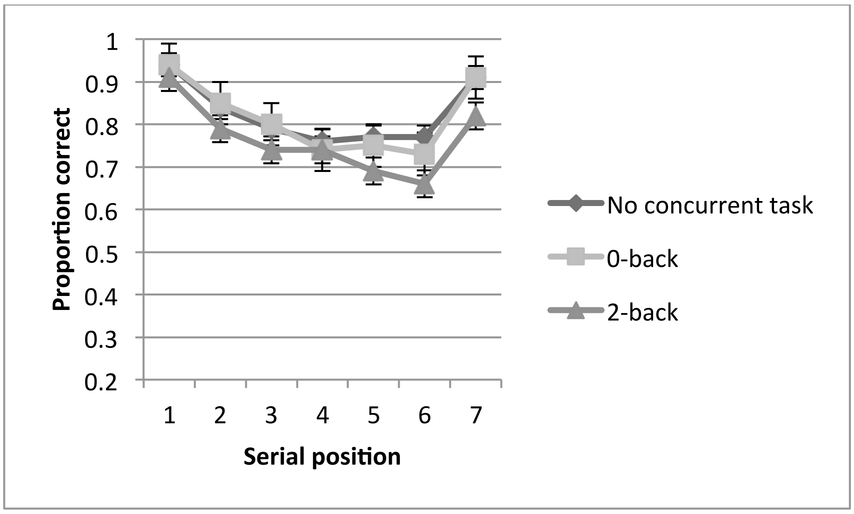
Table 1:

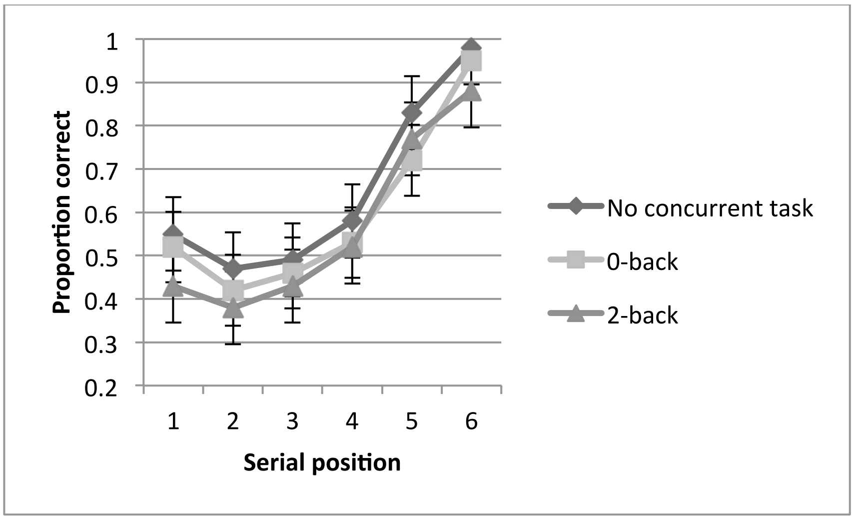
Mean scores and reaction times on the n-back task

	0-back		2-back	
	Mean	SD	Mean	SD
Experiment 1				
Scores				
Forwards digit recall	96.38	4.54	88.38	12.89
Backward digit recall	97.04	4.00	89.29	9.98
Reaction times				
Forwards digit recall	666.97	87.28	594.03	162.14
Backwards digit recall	696.33	71.57	630.07	90.01
Experiment 2				
Scores				
Forwards digit recall	77.84	11.63	65.51	17.24
Backward digit recall	71.08	11.70	55.22	20.12
Reaction times				
Forwards digit recall	850.95	156.78	751.51	244.83
Backwards digit recall	915.62	165.63	835.32	235.96

Figure 1

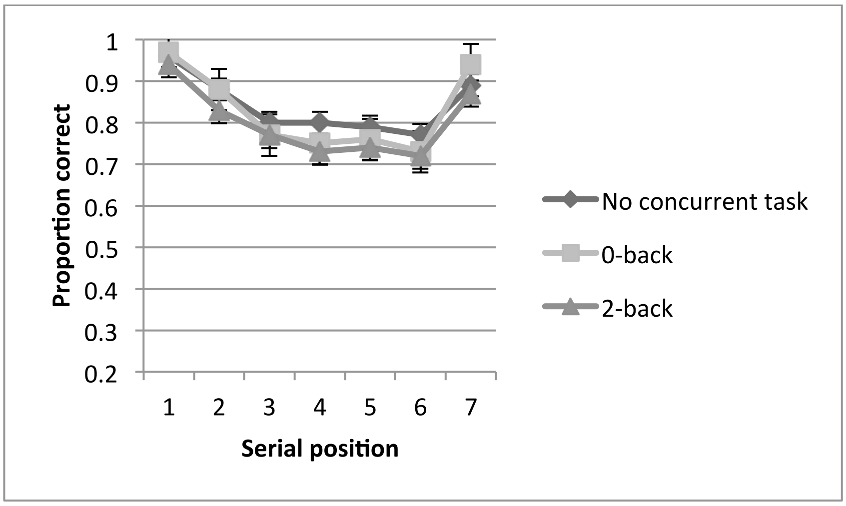


1a: Forwards recall

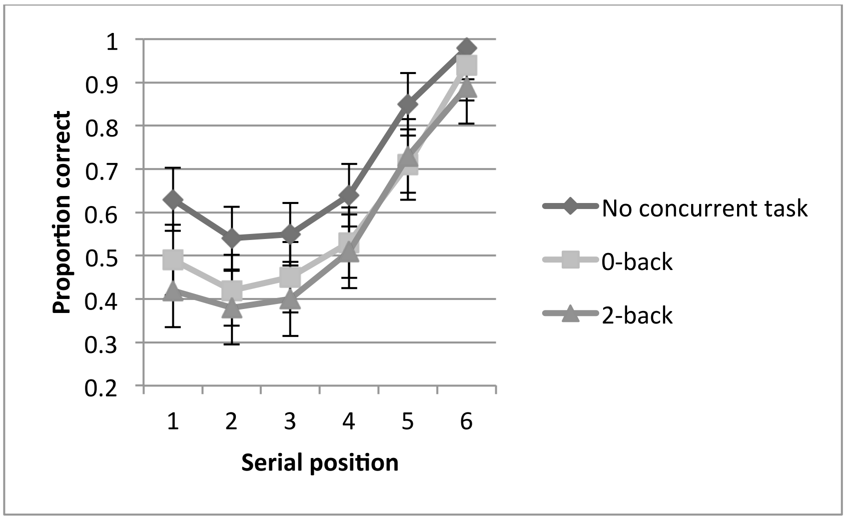


1b: Backwards recall

Figure 2

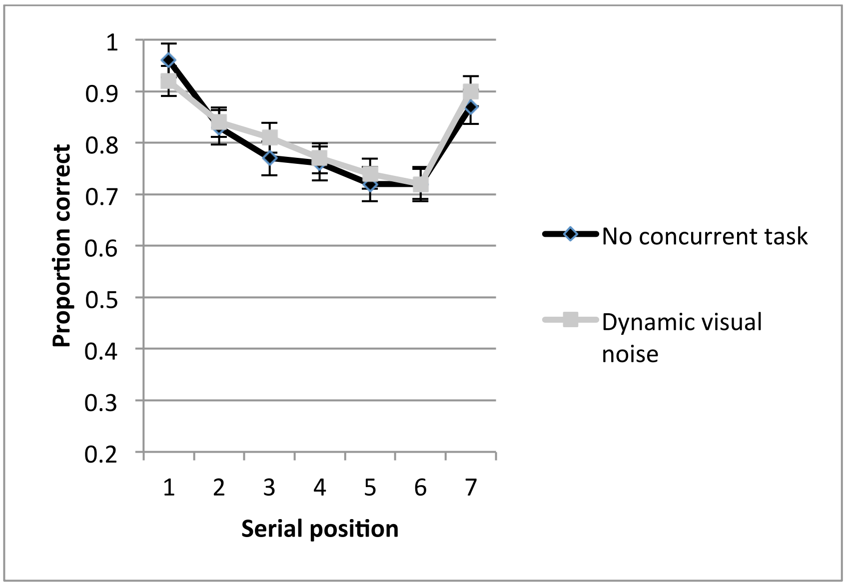


2a: Experiment 2 forwards recall

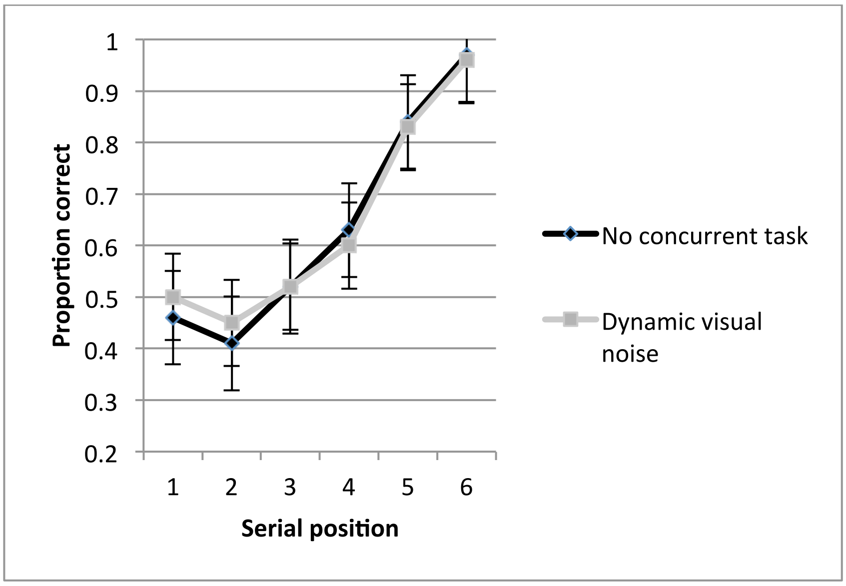


2b: Experiment 2: backwards recall

Figure 3

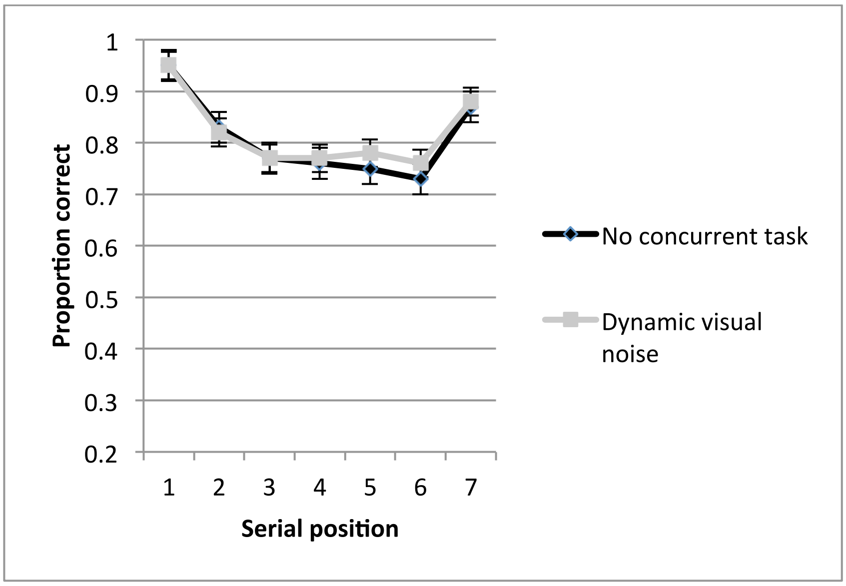


3a: Experiment 3 forwards recall

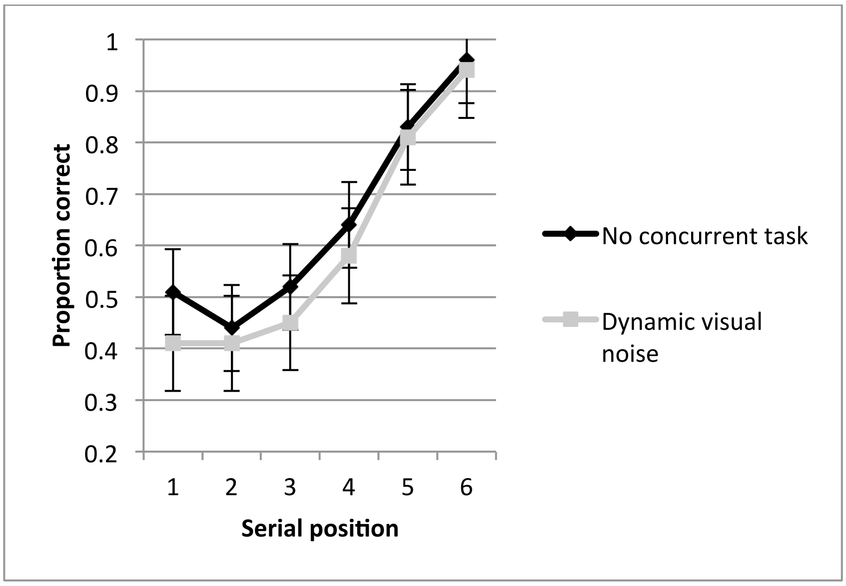


3b: Experiment 3: backwards recall

Figure 4

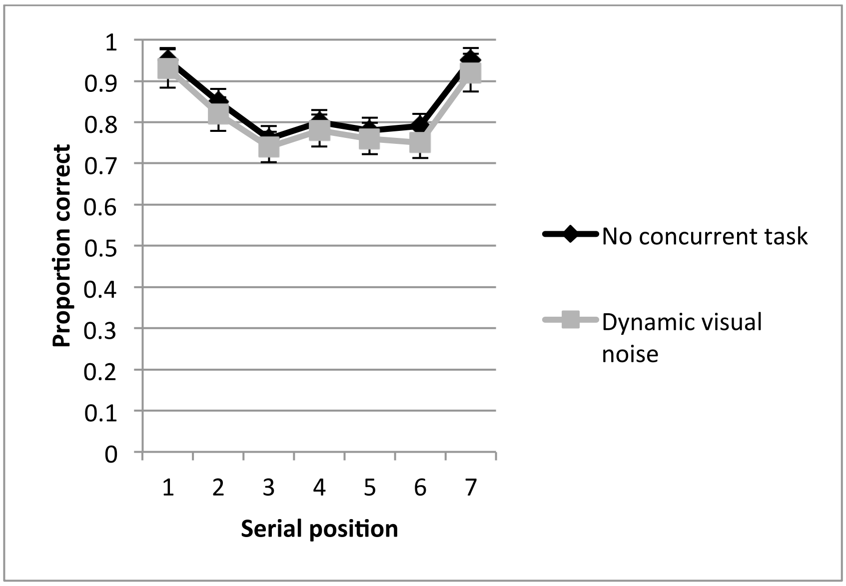


4a: Experiment 4: forwards recall

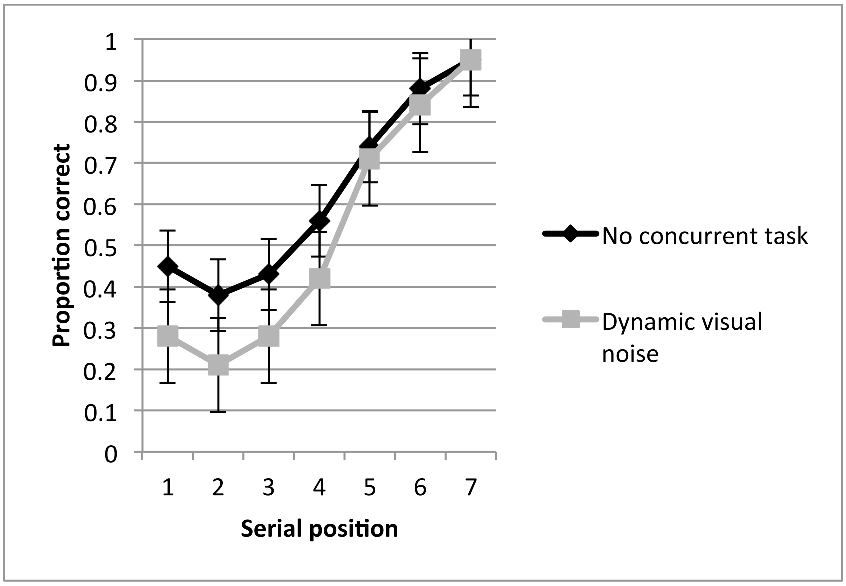


4b: Experiment 4: backwards recall

Figure 5



5a: Experiment 5: forwards recall



5b: Experiment 5: backwards recall