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The recall of information from working memory: insights from behavioural and chronometric perspectives

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Abstract

In four experiments we test a recall reconstruction hypothesis for working memory, according to which reading span items can be recovered or specified from multiple memory representations. Each reading span experiment involves memoranda either embedded within or unrelated to the sentence content. This manipulation affected the timing of recall, with longer pauses accompanying items that are linked to processing. Levels of recall accuracy vary between these task formats, dependent on the orienting task for processing. Experiment 1 compares the chronometry of spoken recall for word span and reading span, in which participants complete an unfinished sentence. Experiment 2 and 3 confirm recall time differences without using word generation requirements, while Experiments 4 used an item and order response choice paradigm with nonspoken responses. We argue that verbal and manual recall timing offers an informative measure for understanding working memory.

Keywords

working memory; reading span; recall timing; recall method; short-term memory

Introduction

Working memory reflects the ability to hold in mind transient representations while simultaneously processing and assimilating ongoing events (Baddeley & Hitch, 1974). There are a wide variety of circumstances in which we are required to carry out mental operations and remember intermediate information (for instance, retain a carry item in mental arithmetic or a referent for an anaphoric pronoun) as well as situations in which current mental activities need to draw on past episodic knowledge (e.g., mapping the problem space for a current task using knowledge of related situations). They emphasise the importance of understanding active maintenance and transformation processes. Consequently, the concept of working memory has been the focus of considerable research.

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Although theories of working memory differ considerably (see Miyake & Shah, 1999), the most common method for assessing its capacity is to draw upon at least one of a family of tasks known as working memory (WM) span. Reading span was the first such task to be reported in adults (Daneman & Carpenter, 1980). Participants read a series of unconnected sentences, and the final word in each sentence yields a memorandum to be reported afterwards in serial order. In essence, an individual's reading span score reflects how many end-of-sentence words can be remembered whilst reading. Daneman and Carpenter (1980) showed reading span to be a very good measure of reading skill (see also Daneman & Merikle, 1986). The predictive prowess of WM span tasks (including alternatives such as operation span where the processing task involves arithmetic operations, Turner & Engle, 1989) provides empirical support for the conceptual idea that the processing-plus-memory requirements tap an important skill in complex cognition.

Several theories suggest, in different ways and to different degrees, that a competitive relationship between processing and memory activities is critical to measuring WM capacity. In other words, that the maintenance of information takes place in the face of distraction or interference from concurrent processing. For example, Case (1985) proposed that limited-capacity general-purpose cognitive resources were allocated to either processing or memory demands. Jarrold and Bayliss (2007) discuss evidence that combining or coordinating processing with memory places demands on WM, above and beyond those imposed by each requirement per se. Towse, Hitch and Hutton (1998) argued that processing activity produces informational degradation because memories are not actively or continuously maintained (in this respect, see also Barrouillet, Bernadin, & Camos, 2004). Kane and Engle (2003) suggested that controlled attention is important to preserve memory representations at the same time as the concurrent processing requirements.

We can see important insights to be gained from each of these accounts, and we do not intend here to arbitrate between them. Rather, our focus is directed towards the concept that links them; processing and memory are thought to be separable, even exclusive events. We certainly accept that processing can interfere with retention. Nonetheless, we present data that lead us to conclude that this is not the whole story; processing may also complement or support memory (for an early and seminal version of this perspective, see Craik & Lockhart, 1972).

Our core proposal that processing and memory need not always be thought of as completely separate events. Using behavioural and chronometric evidence, we propose that psychological models can be enhanced by considering a broader view of the WM representations that are present at the point of recall.

Chronometric analysis of memory recall – the timing of correct output sequences – has generally focused on short-term memory (STM) tasks such as word span, where a sequence of unrelated items are presented at a regular rate and then reproduced in their original order (e.g., Dosher & Ma, 1998; for an overview, Towse & Cowan, 2005). Whilst such research has been undoubtedly productive, given the body of evidence to distinguish STM from WM (e.g., Daneman & Carpenter, 1980; Engle, Kane & Tuholski, 1999), there is a clear motivation to investigate recall timing in WM. Cowan et al. (2003) did just this. They found children's reading span recall times were dramatically longer than has been obtained in STM studies, and that for both children and adults (but especially the former) response durations for listening span exceeded those of counting span and digit span. Cowan et al. also reported that WM response durations predicted children's word reading skills over and above the contribution of span scores per se: recall evidently incorporates processes relevant to children's cognitive development and attainment.

The particularly long interword pauses in reading span and listening span led Cowan et al. (2003) to two related conclusions. First, memory representations may not always be maintained in a highly accessible state during processing. If they had been, one would expect their rapid production during recall. Second, participants sometimes draw on memory of the sentence, in terms of thematic and semantic context, for the elicitation of the target items. Cowan et al. found that recall in counting span was less protracted than listening span, and attributed this to the lack of distinctive processing in the enumeration of visual displays, and thus the absence of a similar scaffolding process. Thus, reading span and listening span recall can involve the consideration of a much richer ensemble of (perhaps loosely encoded) memories of the trial episode than is the case for other tasks.

To capture these ideas we advance here a ‘recall reconstruction’ hypothesis for WM performance. The central proposal is that participants may bring to recall more than just representations of experimentally-assigned memoranda (i.e. target memory words). In the specific case of reading span, this can involve sentential information, which is combined with other representations over time. As a consequence, we propose that the memory sequence may not be continuously and actively maintained and consequently recall involves the resuscitation of degraded information.

According to this recall reconstruction perspective, WM potentially involves the intertwined and integrated aspects of processing and memory. Processing and memory activities need not inherently be in complete opposition to each other, dependent on the specific WM task. Consider an example sentence from Daneman and Carpenter (1980): “*The lumbermen worked long hours in order to obtain the necessary amount of wood*.” According to the position just outlined, later recall of “wood” might be facilitated by gist or episodic memory about lumbermen, or indeed associations made during reading to the implicit concept “trees”. An individual need not commit a sentence to memory verbatim, but relevant linguistic information could nonetheless be accessible, either to help reconstruct the word “wood” or to discount sentence-terminal words appropriate to other serial positions.

This recall reconstruction hypothesis is quite compatible with the evidence in children that recall pauses predict cognitive ability since item reconstruction using self-generated cues may be a source of skilled performance. Moreover, Saito & Miyake (2004) have pointed to a relationship between processing activity and memory within their representation-based interference account of WM. While they concentrated on how processing events can hinder memory, via overlapping representations that interfere, they similarly argue that the content of processing can be relevant to memory performance.

So far as we are aware, no studies have directly investigated the relationship between processing content and memory requirements in WM. However, Osaka, Nishizaki, Komori & Osaka (2002) investigated reading span, and for language-specific reasons underlined the word that was to be remembered. They either underlined a “focus” word –the most important word for sentence comprehension-or a non-focus word, which was less central. Recall was substantially and significantly better for focus words. While all their memoranda were thematically connected with sentence material, their data support a link between processing material and what is remembered.

Other indirect evidence can be marshalled in support of this idea. Copeland & Radvansky (2001) reported a reversed phonemic similarity effect in reading span, but a standard effect for operation span. They suggested that phonemically similar lists were at an advantage because recall was facilitated by the sentence context. Hitch, Towse & Hutton (2001: Fig. 2) reported that among children, the rate of forgetting on an operation span task (as a function of arithmetic processing time) was faster than the rate of forgetting on a reading span task (as a function of sentence processing time). Distinctive sentences may help to retard forgetting because they can be used in the reconstruction of target memoranda, in a way that less distinct arithmetic problems cannot.

In a series of experiments, we test the recall reconstruction hypothesis directly. Its validity is important because it addresses the widespread assumption that processing and memory are necessarily competitive components of WM tasks. Yet it also broadens the conceptual focus, encouraging theoretical models of WM to incorporate recall and not just maintenance processes (see also Unsworth & Engle, 2006). We therefore attempt to replicate the long reading span pauses found by Cowan et al. (2003) and test accounts of what underlies this phenomenon. The experiments substantially extend the analysis of Cowan et al. by providing converging paradigms to investigate recall timing, using spoken recall as well as non-spoken responses. This latter approach opens up new opportunities for studying the chronometry of recall and the nature of memory representations.

Experiment 1

To examine why reading span performance is characterised by long response durations, we manipulated the relevance of sentential processing for the memory items. For example, a participant might read the sentence “The rocket went into outer ___” and we would expect them to suggest “space” as the completion word. The memorandum could be either “space” or an unrelated word, such as “bridge”. In the former case, participants can use representations about the sentence (knowledge that it referred to a rocket for example) to inform their recall choice but drawing upon this additional information will slow down recall. In the latter case, with independent memory material participants might use alternative – and effective – maintenance processes, but they cannot easily draw on the processing content, and so correct recall should be more rapid. If the alternative maintenance strategies in the independent condition are less effective, then lower levels of recall will also be found. We also collected data from a STM task to form a point of comparison.

Method

Participants—Twenty-four Lancaster University students (22 women and 2 men) volunteered via departmental recruitment procedures and were paid £3. They were randomly assigned to the integrated and independent condition, as described below.

Stimuli—A corpus of 88 sentences (based on medium-length stimuli described in Towse, Hamilton, Hitch & Hutton, 2000) were randomly divided into two sets, “set A” and “set B”. Participants were assigned at random to receive the reading span sentences from either set A or set B, with the alternative end-of-sentence items used for word span stimuli. Sentences typically contained 8–10 words and had been formulated to elicit target completion words with a high probability among children (for example, "While I was sleeping I had a strange" typically leads to the completion response "dream").

Apparatus—Computer events were driven by an Apple Macintosh ibook G4 (programmed using the “Revolution” language running under OS X) with response latencies measured in (1/60 s) ticks. Visual displays used the 14 inch laptop screen. Audio recordings were captured directly to a minidisk player (Sony MZ-N710, with a Sony ECM-DS70P microphone).

Procedure—All participants completed a STM (word span) test, and either the integrated or independent word WM (reading span) test in counterbalanced order. Each task was explained prior to administration of experimental trials.

Reading span trials: On each trial, a set of (between 2 and 5) incomplete sentences appeared on screen, and participants were to read these sentences and generate a suitable word to complete them. Afterwards, they attempted to recall the memoranda in the correct serial order. An incremental-order test procedure was employed. Thus, trials commenced with 3 sets of 2 sentences. Provided at least one memory sequence was recalled correctly, an additional sentence was added to the series and 3 further trials were administered, up the maximum 5-sentence sets. Participants knew the list length prior to each trial.

In the integrated word condition, the completion words formed the memoranda (if a participant produced a non-expected completion word, this was adopted as the memory target). Once the participant completed the sentence, the experimenter immediately tapped a computer key to initiate the next experimental event, which occurred after a 1 second interval. Participants were instructed not to rehearse words during the reading phase and to begin reading each sentence immediately on its presentation.

In the independent word condition, participants also read sentences and supplied a completion word. This was followed (after .25 sec) by a .5 sec presentation centre-screen of a separate, unconnected word, which was the memorandum, and which participants read aloud. There was a subsequent .25 sec pause before the next experimental event commenced. The independent words for “set A” were taken from the “set B” pool, and vice versa.

Word span trials: Participants watched the visual presentation of a sequence of unconnected words. Each word was shown centre-screen for 0.5 sec, with a 0.5 second ISI. Initially there were 3 trials containing 2 memoranda, and sequence length increased by a single item, provided that at least one trial was successfully recalled, up to a maximum list length of 5 words.

Recall—Instructions asked participants to recall the word sequence to a trial as soon as (but not before) the computer produced the auditory recall signal. Participants were asked to limit their spoken response to the recall words only (to avoid other words such as “I think”, “then it was” or “and”) and were reminded of this if necessary during test administration. The experimenter recorded answers onto computer after the output sequence was complete.

Results

We examined the effect of task administration order (whether word span or reading span was administered first, for each stimulus pool set and task configuration) and found no significant effects on global timing measurements. We therefore collapse across order in subsequent analyses.

Participants undertook reading span trials where either the sentence interpretation led directly to the memoranda (the integrated word condition), or was unrelated (the independent word condition). Sentence reading times for these formats (M=3.39, SD=.31 and M=3.29, SD=.64 respectively) were equivalent, $t(22)=.47$, $p=.647$, $\eta^2=.009$. The number of correctly recalled words is reported in Table 1. Analysis confirmed memory accuracy was substantially greater for integrated words compared to independent words, $t(22)=5.01$, $p<.001$, $\eta^2=.533$[1].

To extract recall times, the portion of the sound files relating to each correct response sequence was selected and examined. In some cases, recall times were ignored because the participant restarted their list (e.g. “yellow… dream…. no, wait, door…yellow…dream”) or in some way gave an ambiguous recall with respect to timing issues.

[1]Where appropriate as here, probabilities have been corrected after adjusting degrees of freedom because of non-equal variances. In the case of analysis of variance, we report Greenhouse-Geisser values where warranted.

The computer produced both an auditory and visual recall cue. Auditory recall was segmented into three contiguous phases (see, for example, Cowan et al., 1998); the time between the recall signal and the start of recall (the preparatory interval); the time to articulate the relevant words (each word duration), and the gaps between words (interword pauses). A single trained researcher extracted timing values, for whom blind timings both correlate and correspond with those made by an independent coder (for a sample of 99 word and interval measurements, $r(97)=.993$). Specific recall time segments were screened for outliers by examining z-score distributions of each time measurement; where $z>2.58$, that trial value was not used in the compilation of recall times. Measures of stability are reported in Table 2. To make analysis easier to present, we focus on the three recall phases, combining individual values (e.g., the first and second word in two-item sequences).

Figure 1 shows the profile of recall durations. At list length 2, the mean pause between integrated words was longer than that between independent words, although this difference was only marginally significant, $t(22)=2.00$, $p=.058$, $\eta^2=.154$. At list length 3, the effect was in the same direction, but not significant, $t(14)=.57$, $p=.580$, $\eta^2=.023$, while at list length 4 there were too few data points in the independent condition for analysis. Combining data across list length 2 and 3, pauses in the integrated word condition were twice the length of the independent word condition, $t(22)=2.13$, $p=.045$, $\eta^2=.171$.

Preparatory intervals and word durations were longer before integrated words but comparisons at list length 2 and 3 were non significant ($ts<1.36$, $ps>.187$, $\eta^2<.078$). This dissociation in sensitivity is consistent with the notion that the separate recall segments can be differentiated (Cowan et al., 1998). We carried out additional analysis on STM recall, but since these are less relevant to the main experimental issue, they are reported in Appendix 1.

Discussion

Cowan et al. (2003) noted that WM recall could be differentiated from STM recall in terms of pause length. Furthermore, the longer recall was most evident for WM tasks that involved linguistic-based processing. The recall reconstruction hypothesis explains this finding by proposing that memory search processes might incorporate representations persisting from the sentences, and this takes time.

The present study experimentally evaluated this hypothesis by manipulating the link between sentential processing and memory items. When processing events can scaffold recall, pauses should be extended as a richer set of representations are evaluated. Indeed, gaps between words were longer when processing and memory were linked and more sequences were correctly recalled.

All other things being equal, one might expect that a difference in memory accuracy would work against the recall time difference that we found because with weaker memory representations, accessing the correct item should be more difficult. Thus, the evidence for more rapid correct recall in the independent condition is all the more telling.

To forestall possible mis-interpretation, we do not suggest that the processing event in reading span provides only a supportive environment for recall. Memory for the sentence ideas, or sentence words, may well degrade access to the designated memory item, offering alternative recall candidates and adding to the problem of discriminating between memoranda and activated non target representations (Saito & Miyake, 2004; see also below). Our argument is that the elicitation of recall words can be affected by memory for the processing material, and that this emergent property of the way reading span trials are often constructed is one contributory factor to the protracted recall of items reported here and elsewhere (Cowan et al., 2003).

Experiment 2

In the previous study, the processing task was to read aloud an incomplete sentence and generate a (constrained and thus predictable) word. This task format has been used among adults (Towse, Hitch & Hutton, 2000) but especially children (e.g. Leather & Henry, 1994; Towse et al., 1998), since the completion requirement helps to ensure that they adequately process the sentences. Yet, participants in the integrated condition remember a self-generated item, while those in the independent condition do not. Slamecka and Graf (1978) have demonstrated superior memory for generated items relative to read items, and so the procedure may influence recall.

In fact, self-generation of memoranda may affect recall by elaborating the processing that takes place and enriching the consequent representation, very much analogous to the sentence content. Therefore, any self-generation effect may overlap with recall reconstruction processes outlined here. Nonetheless, we removed the generation requirement in the next experiment, to determine whether it accounts for the findings.

Method

Participants—Twenty-eight Lancaster University students (22 women and 6 men) were paid £3 to complete reading span trials and ancillary tasks (not described here). They were randomly assigned to the integrated and independent condition.

Stimuli and Apparatus—We used the same apparatus as in Experiment 1. The sentence stimuli were the same too, except that they were presented in completed form; there were no missing words.

Procedure—Participants completed either the integrated or independent word task. In the former, each sentence appeared in black type with the final word in purple. In the latter, the completed sentence appeared in black type with the subsequent memory word shown in purple type. Rather than being required to read and complete each sentence, instructions asked participants to "read the sentences aloud and think about the sentence meaning as you do so."

Results

Sentence reading times for integrated and independent conditions ($\underline{M}$=2.95, $\underline{SD}$=.50 and $\underline{M}$=2.84, $\underline{SD}$=.33 respectively) were equivalent, $\underline{t}(26)=.71$, $\underline{p}=.488$, $\eta^2=.019$, and just slightly quicker than in Experiment 1 (sampling differences and the absence of sentence completion requirements could explain the discrepancy). In terms of the number of correctly recalled words, shown in Table 1, the integrated format enjoyed an advantage, but in this dataset it was not significant, $\underline{t}(26)=1.23$, $\underline{p}=.231$, $\eta^2=.055$. Notably, the difference from the previous study is that without the generation requirements, performance in the independent condition has improved whilst that in the integrated condition is similar.

As in Experiment 1, recall time outliers were screened prior to compilation of trial data[2]. Recall times are illustrated in Figure 2 (Table 2 reports stability measures). At list length 2, the pauses between integrated words were significantly longer than between independent words, $\underline{t}(26)=2.24$, $\underline{p}=.034$, $\eta^2=.162$. The difference for word durations was in the same direction but marginally significant, $\underline{t}(26)=1.96$, $\underline{p}=.061$, $\eta^2=.129$. The average list length 3 pause was significantly longer in the integrated condition, $\underline{t}(24)=2.54$, $\underline{p}=.020$, $\eta^2=.212$, and difference in the average pause across list lengths 2 and 3 was likewise significant, $\underline{t}(26)=3.08$, $\underline{p}=.005$,

[2]Two independent judges extracted timing measurements, using the same procedures as Expt. 1. Independent t-tests on all list-length 2 and list-length 3 segments indicated comparable judgements between coders (all ps>.10)

η^2=.267. At list length 4 there were few data points for meaningful analysis. There was no reliable difference in the word durations at list length 3, $t(24)=.22$, $p=.828$, $\eta^2=.002$. Preparatory intervals did not differ between the independent and integrated conditions (e.g. for the averaged preparatory intervals, $t(26)=.32$, $p=.751$, $\eta^2=.004$).

Discussion

The data offer further support for the recall reconstruction hypothesis. We again found evidence that recall pauses are longer when there is a connection between the memoranda and the processing context associated with them. There was also a trend for superior levels of recall in the integrated condition but this was not significant in the current dataset.

Thus, removing the word generation requirement did not eliminate the slow but accurate levels of recall in the integrated condition. The obvious point of change across experiments lies in the level of recall in the independent condition. Generating a word to complete a sentence, as opposed to just reading a sentence, makes it harder to then recall a separate word that follows. This could be because the generated, irrelevant word affects the encoding of the subsequent item or maintenance of items already encoded. Alternatively, just reading a sentence may be insufficiently demanding, permitting separate memorial operations to take place, though it is not clear why this would not also be true for the integrated condition. Regardless, data demonstrate that longer pauses are due to the processing-memory connection, not the processing task per se.

Experiment 3

Participants take reliably longer to produce words that are semantically linked to the sentence. However, whereas the difference in recall accuracy was significant in Experiment 1, it was not significant in Experiment 2. We therefore consider additional data. The set of sentences was taken from the corpus used by Friedman & Miyake (2004). Design configurations meant that the number of trials at each sequence length was also larger.

Method

Participants—Thirty-three Lancaster University students (27 women and 6 men) formed a subset of a larger experiment. They were paid £4 to complete the reading span trials and additional tasks (not described here), and were randomly assigned to the integrated and independent condition.

Apparatus and Procedure—The same apparatus as in Experiment 2 was employed. The core stimulus pool comprised 90 sentences selected from the Friedman & Miyake (2004) corpus. This was divided into two subsets (A & B) as before.

Participants completed either the integrated or independent reading span task. In the former, each sentence appeared in black type with the final word in purple and there was a 0.5 sec interval between sentences. In the latter, the entire sentence appeared in black type with the subsequent memory word shown in purple type for 0.5 sec. Participants were administered a total of 15 trials; 5 for each list length 2–4, in ascending sequence length order. Verbal instructions were the same as Experiment 2.

Results

Sentence reading times for integrated and independent conditions ($M=5.22$, $SD=.69$ and $M=4.86$, $SD=.56$ respectively) did not differ significantly, $t(29)=1.58$, $p=.125$, $\eta^2=.079$. The sentences were longer than those used in previous experiments, leading to extended reading times, but the pattern of performance is the same. In terms of the number of correctly recalled words, shown in Table 1, the integrated format again enjoyed an advantage, but in this dataset it was not significant, $t(31)=1.82$, $p=.078$, ηs=.097.

We then combined the number of correctly recalled words with the data from Experiment 2. The trial structure changed across experiments, and so the maximum possible number of recallable items differed, and indeed the number of words actually recalled reflected this, $F(1,57)=13.4$, $p=.001$, $\eta_p^2=.191$, Nonetheless it is the difference between sentence formats that is relevant here, and the analysis showed that more words were recalled from the integrated format, $F(1,57)=5.19$, $p=.027$, $\eta_p^2=.083$. There was no interaction between experiment and task format, $F<1$, $p=.804$, $\eta_p^2=.001$. Thus, the integrated format does lead to greater levels of recall, even without a word generation requirement in processing, though the effect is significant only with data aggregated across the two studies.

One judge (who contributed to measurements in Experiment 2) extracted timing measurements from auditory records of each correct reading span sequence, in the same manner as for previous studies. Once again, outliers were screened prior to compilation of recall times from individual trials.

Recall times are illustrated in Figure 3. At list length 2, the pauses between integrated words were significantly longer than between independent words, $t(31)=2.88$, $p=.010$, $\eta^2=.211$. Moreover, the word duration was significantly longer in the integrated condition, $t(31)=2.65$, $p=.012$, $\eta^2=.185$. At list length 3, the pause was also significantly longer in the integrated condition, $t(24)=2.37$, $p=.029$, $\eta^2=.190$ while the word durations did not differ, $t(24)=.079$, $p=.938$, $\eta^2<.001$. The difference in the pause averaged across list lengths 2 and 3 was significant, $t(24)=2.68$, $p=.017$, $\eta^2=.230$.

The preparatory intervals did not differ between the independent and integrated conditions for list length 2, $t(31)=.81$, $p=.425$, $\eta^2=.021$, but were longer in the independent condition for list length 3, $t(24)=2.19$, $p=.038$, $\eta^2=.167$. Although participants were asked to read aloud the independent word as soon as it appeared on screen, some were still articulating this item whilst the recall cues occurred, and consequently their ‘preparatory interval’ included additional reading, which can account for the longer intervals obtained.

Discussion

This study confirms and extends the results from Experiments 1 and 2. We again found that participants produced consistently longer pauses between recall words when these words were semantically related to the sentences that had been read, compared to when the words were unrelated to the sentences preceding them.

The difference in recall accuracy between the integrated and independent reading span conditions was clearly larger in Experiment 1 than in Experiment 2 and Experiment 3. Recall accuracy was roughly comparable in the integrated condition, regardless of whether participants either generated a sentence completion and final word. However, accuracy was relatively poor in Experiment 1 when participants generated a word to complete the sentence, and then remembered a separated item, rather than reading an entire sentence and then remembering a separate item. We conclude that the memory for the independent words must be fragile, and thus retention can be disrupted by competing representations such as a generated item. Yet this reinforces a central contention of the present paper: in reading span, participants arrive at recall with more than just the experimentally-defined memoranda in mind. ‘Processing’ and ‘memory’ may represent separate phases of the working memory span trial, but memory is not a neatly segregated and separate activity.

Experiment 4

We next undertook a conceptual replication of the preceding studies but chose not to use spoken output. Instead, participants compiled a recall sequence from a visually-presented set of choices, using a touch-screen device.

The use of manual responding offers a potentially complementary source of evidence about recall timing, avoiding the requirement that words be assembled into articulatory programs (see Chuah & Maybery, 1999; Maybery, Parmentier & Jones, 2002, for analysis of the timing of recall involving spatial stimuli). The approach yields a set of inter-response intervals, rather than word and pause times.

The experimental procedure returns to the ‘read-and-complete’ sentence processing procedure used in Experiment 1. However, the nature of the recall display represents an intermediate step between Experiment 1 and 2/3. In the integrated condition, the computer displays the sentence-terminal words (but in no particular order). The recall display also includes two types of error lure; a word from the processing sentence, since it is known that participants sometimes produce words from elsewhere in the sentence (Chiappe, Hasher & Segal, 2000; Friedman & Miyake, 2004), and a target answer from the preceding trial. Thus, the participant must overcome the impact of proactive interference from earlier trials (Lustig, Hasher & May, 2001), or at least make source-information judgements about current and past memories (Hedden & Park, 2003).

In the independent condition, then, the computer displayed the correct, (sententially irrelevant) words plus words from the sentences and from the previous trial. Notably, then, the recall display did not offer the sentence terminal word as a response candidate in the independent condition, which previous experiments suggest is source of difficulty arising from the sentence completion task. We used configurations in which chosen responses either disappeared from the recall screen or remained on screen, to ascertain the role of screen complexity on performance.

Method

Participants—Twenty-seven University of Missouri students (16 women and 11 men) participated for partial fulfilment of course credit requirements. One participant was subsequently excluded because they consciously ignored serial recall instructions.

Stimuli and Apparatus—Computer events were driven by an Apple Macintosh ibook (running “Revolution” programming language under OS X) with response latencies measured in (1/60 s) ticks. A Liyama touchscreen monitor (model INTH380-BS plus Keyspan RS232-USB Adaptor) displayed the experimental screen and recorded participants’ responses. Since this study draws on North American participants, some sentences were adjusted for idiomatic phrases as necessary (whereas English students are familiar with reference to eating “fish and chips” or playing with a “skipping rope”, American students are more attuned to the concept of eating “hamburger and fries” and playing with a “jump rope” respectively). We added to the set of memory word stimuli such that memoranda could be selected without replacement throughout the entire experiment.

Procedure—Except in the following respects, the procedure for the delivery of processing and memory followed Experiment 1. The experiment employed an incremental-order test procedure but administered all list lengths (i.e. length 2 – 5). Independent memoranda were presented for .75 sec before and after .125 sec interval. If a participant produced a non-expected completion word (completing “Food and water makes plants” with “live” instead of “grow”) the experimenter would volunteer the target word (in the case given, say “*or grow*”) before proceeding to the next experimental event[3]. Participants completed both a 'remain' and 'disappear' response selection condition, which were presented in counterbalanced order, with a minimal break between each.

Recall—Following the completion of the processing events, the computer presented a recall screen that comprised the target memoranda as well as incorrect words. For each correct word, there was also a 'processing-phase' lure; a word carrying semantic content that had appeared in the sentence (or very occasionally, when no suitable candidate was available, an associated prime word). There were two 'protrusion' lures, correct answers from the previous trial (the first trial employed two randomly selected words instead). Each of the ((list length * 2) + 2) response choices was assigned at random to one of 16 pre-specified locations across the screen. Participants identified their chosen recall sequence by tapping the word locations on-screen in the appropriate order. The computer recorded response latencies as well as recall selections.

In the 'disappear' condition, the chosen response was removed from the screen upon selection. In the 'remain' condition, responses continued to be visible after they had been chosen. In either case there was an auditory signal to confirm the computer's registration of the response selection. Participants were informed about the recall configuration at the start of the condition.

Results

Inspection of Table 1 indicates that participants were again able to recall more words from the integrated word condition (in both the disappear and remain condition) compared with the independent word condition. Analysis of variance confirmed a significant recall advantage in the integrated condition, $F(1,24)=16.2$, $p=.001$, $\eta_p^2=.402$, but no difference between the recall formats, $F<1$, $\eta_p^2<.001$, and no interaction, $F<1$, $\eta_p^2=.004$.

We did not anticipate reading time differences between the disappear and remain condition, since they differ only in recall screen dynamics, and they were equivalent ($M=3.50$ vs. $M=3.60$ respectively), $t(25)=.75$, $\eta^2=.022$. There were also no reliable reading time differences for integrated and independent words, for either the disappear or remain conditions ($ts(24)<.97$, $\eta^2<.038$).

Recall times were screened for outliers in the same manner as previously. Figure 4 describes pauses for correct sequences for each list length and response format. Graphs suggest list position effects (i.e. a speeding up in recall through the list) in *both* the disappear and remain conditions. Comparisons of the two response configurations indicated significantly quicker recall in the disappear condition at list length 3 only and no interactions – we therefore simply the following results by collapsing across this variable.

Analysis of the average inter-item recall durations for each list length broadly confirmed analysis from previous experiments. Although list length 2 and 3 differences were not significant [$t(24)=.26$, $p=.796$, $\eta^2=.003$ and $t(22)=.31$, $p=.756$, $\eta^2=.004$ respectively], at list length 4 the integrated word response pauses were significantly longer than independent response pauses, $t(20)=2.56$, $p=.029$, $\eta^2=.247$. There was also a difference at list length 5 but this was marginal, $t(14)=1.82$, $p=.090$, $\eta^2=.191$. We then combined the correct recall times for all available list lengths, and this confirmed the longer pauses in the integrated condition, $t(24)=2.74$, $p=.021$, $\eta^2=.238$. In the round, analyses show that the independent condition involves quicker recall, but with a response choice paradigm this paradigm is most salient at longer list lengths.

[3]This was necessary because recall items here were fixed prior to presentation, although it was used very rarely.

Analysis of recall errors—With the present paradigm, there are clear constraints on the nature of recall errors. Correct answers were present of course, but serial order errors could occur. In addition, participants could select a processing-phase word that had been part of the original processing, or a protrusion word taken from a previous trial. However, error probabilities are not constant across trials; at list length 2 for example, there is only one order error possible (the string A-B recalled as B-A), but at list length 3, there are 5 order error permutations. Furthermore, the number of protrusion error lures was a constant two items across list length (necessary to minimise recall screen complexity) and thus protrusions are less likely to occur through random selection at larger list lengths. For clarity and brevity, we present analysis of errors after combining data for the disappear and remain conditions.

In what follows we consider data based on performance up to and including the span-terminal level[4].

Table 3 reports the distribution of response choices. Errors are not randomly distributed: there are more order errors than processing-phase errors in both the independent condition, $t(12)=3.60$, $p=.004$, $\eta^2=.519$, and integrated condition, $t(12)=5.50$, $p<.001$, $\eta^2=.716$. Furthermore, although there are more opportunities for processing-phase lures than protrusion lures, error proportions for these two categories were not significantly different, either for the independent or integrated conditions, $ts(12)=.48$ & $-.03$ respectively, $\eta^2<.019$.

The type of errors that were committed varied with experimental condition. The proportion of protrusion errors was higher in the independent condition than integrated condition, $t(24)=2.63$, $p=.015$, $\eta^2=.224$, while the proportion of order errors was marginally higher in the independent condition, $t(24)=1.93$, $p=.069$, $\eta^2=.134$.

In the independent condition, there is no link between the processing material and the target memory word, and thus there is nothing to bind the processing episode to activation levels of words. Answers to previous trials are likely to retain activation, and thus may be chosen by the participant instead of the correct item. In contrast, when processing and memory are linked, the processing context may help rule out these protrusion lures, making source-monitoring decisions more accurate. In other words, an important function of the integration between sentences and words to be recalled is to make these words more distinctly tied to the present trial as opposed to previous trials.

Finally, we note that participants were tempted by the presence of processing-phase lures. All 13 participants in the independent condition selected this lure type at least once, and 12 / 13 participants in the integrated condition did so.

Discussion

This experiment addresses several issues. First, it offers data on recall timing on a complex memory task using motoric responses (to on-screen options) rather than spoken recall. Spoken recall measures have been highly important in increasing our understanding of memory phenomena (e.g., Cowan et al., 1992; Haberlandt, Lawrence, Krohn, Bowe & Thomas, 2005; Tehan & Lalor, 2000) but of course it is possible that some phenomena are properties of the specific methods of responding rather than general characteristics of recall. Spoken recall generally requires item and order information, yet the present methodology offers the possibility that item and order information can be teased apart (by varying the choices at recall). From a pragmatic standpoint, measuring spoken recall is a highly intensive process.

[4]In the ‘remain’ condition, it is possible to produce a ‘repeat’ error; many of these reflected registration issues for touch screen responses (e.g. immediate repetitions with an interval <0.5 sec). For simplicity, they were coded here as order errors.

Consequently, it is valuable to have convergent evidence from different, more easily registered, methods of recall to permit a more informed assessment of recall phenomena.

In these terms, the experiment has been a success. Recall processes are consistent and systematic. Moreover, participants are prone to confuse items in terms of their sequence order, and confuse them with no-longer-relevant items as well as items that they were exposed to but not asked to remember (see also Caretti, Cornoldi, De Beni & Romano 2005; Friedman & Miyake, 2004). There are both item and order constraints in WM.

General Discussion

We argue that sentence processing in reading span can contribute to recall performance because memory for the sentence persists into the recall period. Several theoretical views consider the processing-memory relationship in competitive terms, even where inherently they may not need to do so. For example, according to Daneman and Carpenter (1980) who first developed the reading span paradigm, the processing activity within a working memory span trial used general cognitive resources that were consequently denied to retention activities. Working memory span therefore reflected the balance of resources between processing and memory. The present data show instead that recall is partly a function of the compatibility between processing and memory, and that processing activity produces representations that affect recall, providing a source of both recall facilitation and interference. As a result, we argue that processing and retention in reading span are not as functionally distinct as considered hitherto.

The recall reconstruction hypothesis – long pauses in the recall of information from working memory that derive from memory search through the processing episodes – has resonances with performance on conceptual span task (Haarmann, Davelaar & Usher, 2003). Conceptual span tests involve the partial recall of presented information via category cues. Haarmann et al. (2003) report some overlap between reading span and conceptual span, even though the latter does not require the conventional ‘processing plus memory’ combination. The present data - which go beyond the more typical analysis of recall accuracy and errors – promotes the conclusion that both paradigms overlap in terms of recall processes, and may incorporate a link between encoding context and recall.

Support for the recall reconstruction hypothesis is drawn from data in four experiments that involve both spoken recall and manual item selection. These present convergent and complementary evidence in the form of recall timing together with information about recall accuracy and error types. They suggest that the correct recall of items embedded within processing operations is more time consuming than the recall of items unrelated to preceding processing events, even though the integrated format allows more items to be remembered than the independent format (so that, other things being equal, one might expect more rapid and highly accessible item production). That recall time differences are not significant at every list length (and some accuracy differences emerge only with a larger sample size) emphasises that (a) recall timing can be variable and recall reconstruction may not be required on every trial; (b) participants may be able to draw on other strategies to retain the memoranda that can in some situations be effective.

The response choice paradigm supports this basic finding that pauses are shorter in the independent condition although significant effects were not consistently found at each sequence length. We suspect that this technique places less stringent requirements on the participant to maintain the fidelity of item information (as opposed to order information), because the correct items are always present at recall. Items must be retained, because various types of lures are also present at recall. Nonetheless, perhaps imperfect representations are sufficient for successful reconstruction.

Conway et al. (2005) have reviewed the use of WM span tasks and point out that some reading span tasks in the literature have used the independent format while others have used the integrated format. While we are not aware of studies that have compared these configurations, it is important to recognise that we are not making commitments about which is the theoretically preferred form of the task, especially in the context of individual differences. One might wish to minimise the reconstructive element in recall, or one might wish to emphasise it. Nonetheless it is important to appreciate the implications of adopting either format.

We suggest that, during recall of information in reading span, reconstructive processes can operate on what are often degraded representations. These processes may include memory search and decision-making about target words that draw on ‘contextual’ information from a variety of domains or content. Contextual memories are complicated and multifaceted, and can offer support for target memories as well as generating interfering representations (Haarmann et al., 2003; Saito & Miyake, 2004). The present research also suggests that while the distinction between processing and memory in working memory span tests may be a useful research heuristic, these task components may functionally overlap for participants, so that processing activities and target memory words may actually become intertwined.

The present data show that WM theories can benefit from the incorporation of formal hypotheses about recall activities. Of course, when individuals produce a sequence of experimentally-defined items in WM tasks, they must arrive at the point of recall with some representations of these items. Yet we have shown that there is far more to response production than that. Before and during itself, they assemble or construct a memory list using some form of search process. They also strive to avoid non-target items that have some active representations (from preceding trials, and from the processing context). Finally, we argue that the present data reinforce the view that recall timing has an important place in advancing our understanding of immediate memory processes, especially but not only in an experimental context and when harnessed to information from recall accuracy.

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References

Baddeley, AD.; Hitch, GJ. Working Memory. In: Bower, G., editor. The psychology of learning and motivation: Advances in research and theory. Vol. Vol. 8. New York: Academic Press; 1974. p. 47-89.

Barrouillet P, Bernadin S, Camos V. Time constraints and resource sharing in adults' working memory span. Journal of Experimental Psychology: General 2004;133(1):83–100. [PubMed: 14979753]

Caretti B, Cornoldi C, De Beni R, Romano M. Updating in working memory: A comparison of good and poor comprehenders. Journal of Experimental Child Psychology 2005;91(1):45–66. [PubMed: 15814095]

Case, R. Intellectual development: birth to adulthood. New York: Academic Press; 1985.

Chiappe P, Hasher L, Siegel LA. Working memory, inhibitory control and reading ability. Memory & Cognition 2000;28(1):8–17.

Chuah YML, Maybery MT. Verbal and spatial short-term memory: Two sources of developmental evidence consistent with common underlying processes. International Journal of Psychology 1999;34:374–377.

Conway ARA, Kane MJ, Bunting MF, Hambrick DZ, Wilhelm O, Engle RW. Working memory span tasks: A methodological review and user's guide. Psychonomic Bulletin & Review 2005;12(5):769–786. [PubMed: 16523997]

Copeland DE, Radvansky GA. Phonological similarity in working memory. Memory & Cognition 2001;29(5):774–776.

Cowan N, Day L, Saults JS, Keller TA, Johnson T, Flores L. The role of verbal output time in the effects of word length on immediate memory. Journal of Memory and Language 1992;31:1–17.

Cowan N, Towse JN, Hamilton Z, Saults JS, Elliott EM, Lacey JF, et al. Children's working memory processes: A response-timing analysis. Journal of Experimental Psychology: General 2003;132(1):113–132. [PubMed: 12656300]

Cowan N, Wood NL, Wood PK, Keller TA, Nugent LD, Keller CV. Two separate verbal processing rates contributing to short-term memory span. Journal of Experimental Psychology: General 1998;127(2):141–160. [PubMed: 9622911]

Craik FIM, Lockhart RS. Levels of processing: A framework for memory research. Journal Verbal Learning and Verbal Behavior 1972;11:671–684.

Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior 1980;19:450–466.

Daneman M, Merikle PM. Working memory and language comprehension: A meta-analysis. Psychonomic Bulletin & Review 1996;3:422–433.

Dosher BA, Ma J. Output loss or rehearsal loop? Output-time vs. pronunciation time limits in immediate recall for forgetting matched materials. Journal of Experimental Psychology: Learning, Memory and Cognition 1998;24(2):316–335.

Engle, RW.; Kane, MJ.; Tuholski, SW. Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In: Miyake, A.; Shah, P., editors. Models of working memory. New York: Cambridge University Press; 1999. p. 102-134.

Friedman NP, Miyake A. The relations among inhibition and interference control functions: A latent variable analysis. Journal of Experimental Psychology: General 2004;133:101–135. [PubMed: 14979754]

Haberlandt K, Lawrence H, Krohn T, Bowe K, Thomas JG. Pauses and durations exhibit a serial position effect. Psychonomic Bulletin & Review 2005;12(1):152–158. [PubMed: 15945208]

Haarmann HJ, Davelaar EJ, Usher M. Individual differences in semantic short-term memory capacity and reading comprehension. Journal of Memory and Language 2003;48:320–345.

Hedden T, Park D. Contributions of source and inhibitory mechanisms to age-related retroactive interference in verbal working memory. Journal of Experimental Psychology: General 2003;132(1):93–112. [PubMed: 12656299]

Hitch GJ, Towse JN, Hutton UMZ. What limits working memory span? Theoretical accounts and applications for scholastic development. Journal of Experimental Psychology: General 2001;130(2):184–198. [PubMed: 11409098]

Jarrold, C.; Bayliss, D. Variation in working memory due to typical and atypical development. In: Conway, ARA.; Jarrold, C.; Kane, M.; Miyake, A.; Towse, JN., editors. Variation in working memory. New York: Oxford University Press; 2007. p. 134-161.

Kane MJ, Engle RW. Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop Interference. Journal of Experimental Psychology: General 2003;132(1):47–70. [PubMed: 12656297]

Leather CV, Henry LA. Working memory span and phonological awareness tasks as predictors of early reading ability. Journal of Experimental Child Psychology 1994;58:88–111. [PubMed: 8064220]

Lustig C, May CP, Hasher L. Working memory span and the role of proactive interference. Journal of Experimental Psychology: General 2001;130(2):199–207. [PubMed: 11409099]

Maybery M, Parmentier FBR, Jones DM. Grouping of list items reflected in the timing of recall: implications for models of serial verbal memory. Journal of Memory and Language 2002;47:360–385.

Miyake, A.; Shah, P., editors. Models of working memory. Cambridge University Press: New York; 1999.

Osaka M, Nishizaki Y, Komori M, Osaka N. Effect of focus on verbal working memory: Critical role of the focus word in reading. Memory & Cognition 2002;30(4):562–571.

Saito S, Miyake A. On the nature of forgetting and the processing-storage relationship in reading span performance. Journal of Memory and Language 2004;50:425–443.

Slamecka NJ, Graf P. The generation effect; Delineation of a phenomenon. Journal of Experimental Psychology: Human Learning & Memory 1978;4:592–604.

Tehan G, Lalor DM. Individual differences in memory span: The contribution of rehearsal, access to lexical memory, and output speed. Quarterly Journal of Experimental Psychology 2000;53A(4): 1012–1038. [PubMed: 11131811]

Towse, JN.; Cowan, N. Working memory and its relevance for cognitive development. In: Schneider, W.; Schumann-Hengsteler, R.; Sodian, B., editors. Young Children's Cognitive Development: Interrelationships among Executive Functioning, Working Memory, Verbal Ability, and Theory of Mind. Mahwah, NJ: Lawrence Erlbaum Associates; 2005. p. 9-37.

Towse, JN.; Hamilton, Z.; Hitch, GJ.; Hutton, U. Sentence completion norms among adults: A corpus of sentences differing in length (Technical Report No. CDRG 7). Royal Holloway: University of London; 2000.

Towse JN, Hitch GJ, Hutton U. A reevaluation of working memory capacity in children. Journal of Memory and Language 1998;39(2):195–217.

Towse JN, Hitch GJ, Hutton U. On the interpretation of working memory span in adults. Memory & Cognition 2000;28(3):341–348.

Turner ML, Engle RW. Is working memory capacity task dependent? Journal of Memory and Language 1989;28:127–154.

Unsworth N, Engle RW. Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. Journal of Memory and Language 2006;54:68–80.

Appendix 1: Additional analysis of data from Experiment 1

The STM task, measured as the number of correctly recalled words, was within the capacity of some participants (7 participants remembered all 42 words) while everyone remembered at least half of the words – see Table 1 for a breakdown. Since we focus on the timing of correct recalls, this high level of performance is advantageous in maximising the data density for analysis.

Several recall phenomena are evident from Figure 5. First, mean word articulation at approximately .4 sec, is similar to reading span data. Second, pauses between words are much shorter, but non-negligible, at less than .2 sec. Third, the preparatory intervals are (approximately three times) longer than interword pauses, consistent with the interpretation that they reflect a different mental activity. Data contrast with recall times for reading span trials that were noticeably longer (i.e. a different scale is used across Figures), and there are large, almost qualitative changes in the pattern of responding across list lengths.

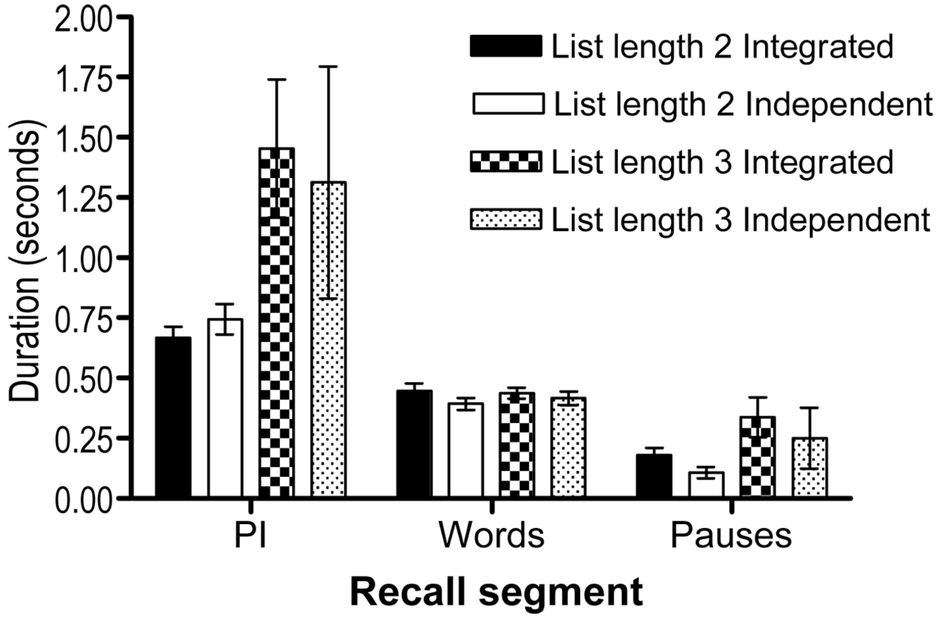

Figure 1.
Duration and standard error bars of correct sequences for reading span trials in Experiment 1, as a function of the phase of recall. PI = preparatory interval. Words = average duration of recalled items. Pause= interword pause duration (averaged at list length 3).

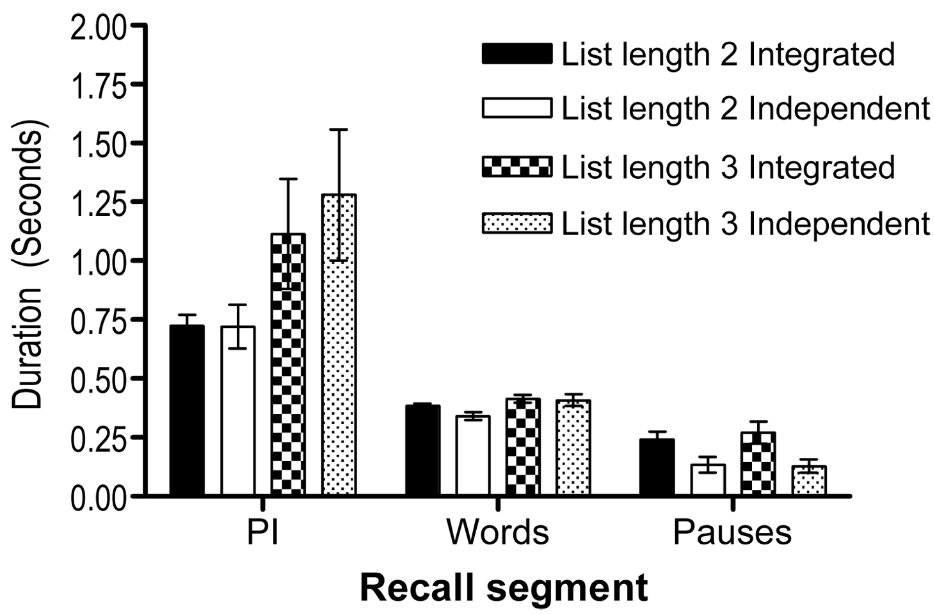

Figure 2.
Duration and standard error bars of correct sequences for reading span in Experiment 2, as a function of the phase of recall. PI = preparatory interval. Words = average duration of recalled items. Pause= interword pause duration (averaged at list length 3).

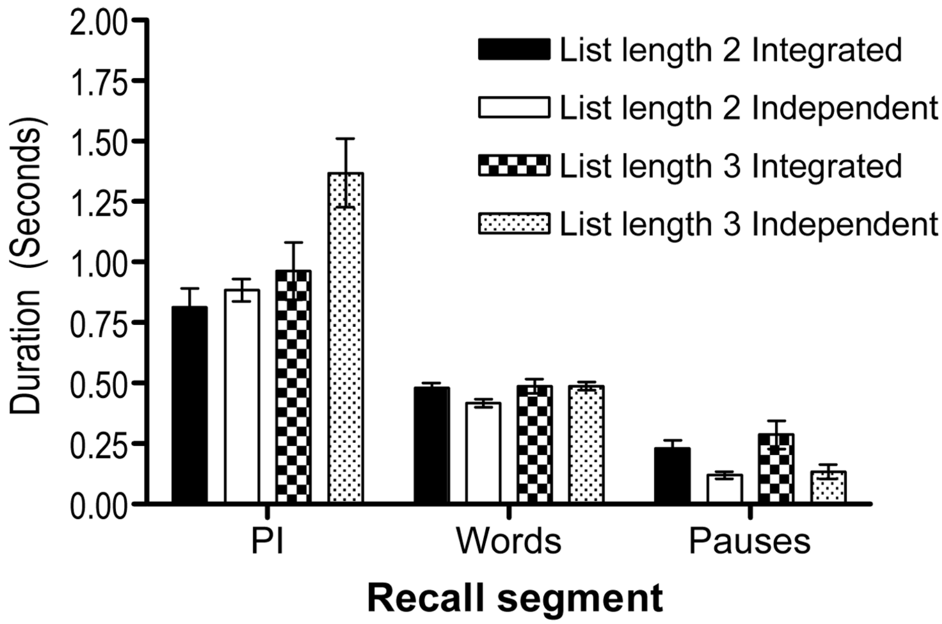

Figure 3.
Duration and standard error bars of correct sequences for reading span in Experiment 3, as a function of the phase of recall. PI = preparatory interval. Words = average duration of recalled items. Pause= interword pause duration (averaged at list length 3).

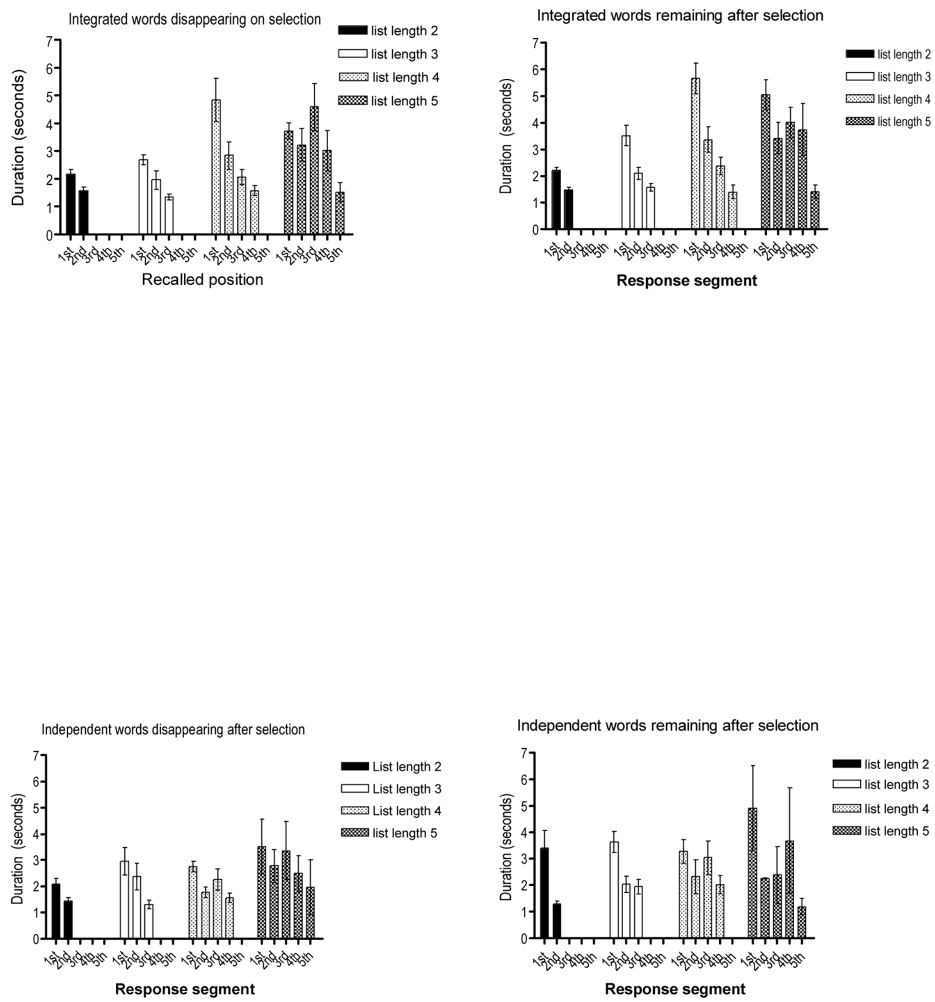

Figure 4.
Duration of recall delays between the correct selection of responses in Experiment 4, as a function of output position. Graph includes standard error bars. Top panel=data from integrated word condition (when response choices disappear after selection or remain after selection on the left and right respectively). Bottom panel=data from independent word condition (when response choices disappear after selection or remain after selection on the left and right respectively).

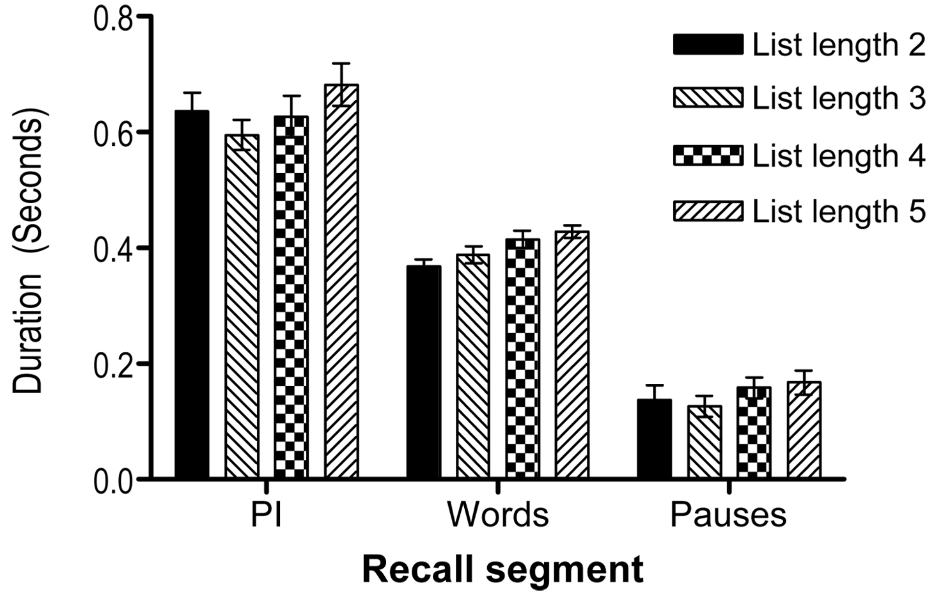

Figure 5.
Duration and standard error bars of correct sequences for word span trials in Experiment 1, as a function of the phase of recall and the sequence length. PI = preparatory interval. Words = average duration of recalled items. Pause= interword pause duration (averaged at list length 3 and beyond).

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Table 1

Memory performance reported as the number of correctly recalled words (range 0–42, except in Expt 3 where it is 0–45). Standard deviations in parentheses. Short-term memory (STM) trials in Experiment 1 differ only with respect to the working memory (WM) task that was also completed.

	Expt.1(STM)	Expt.1(WM)	Expt.2	Expt.3	Expt.4(dis.)	Expt.4(rmn..)
Integrated WM	38.3 (4.92)	27.2 (8.98)	31.3 (4.56)	25.9(5.91)	33.5 (6.25)	33.8 (5.21)
Independent WM	37.8 (3.32)	12.6 (4.56)	28.1 (5.40)	21.9(8.38)	24.6 (6.84)	24.2 (7.73)

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Table 2

Stability of recall timing: correlations between recall durations of list-length 2 & 3 in Experiment 1, 2, and 3 (asterisks represent significant correlations, at least p<.05).

	Expt.1 STM	Expt.1 WM	Expt.2 WM	Expt.3 WM	Expt.4 WM
Preparatory Intervals	r(22)=.661*	r(14)=.062,	r(24)=.535*	r(24)=.137	
Interword Pauses	r(22)=.571*	r(14)=.168,	r(24)=.484*	r(24)=.609*	
Word durations	r(22)=.766*	r(14)=.694*	r(24)=.626*	r(24)=.051	
Recall intervals					r(22)=.465*

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Table 3

Proportion of recall choices falling into different response categories in Experiment 4, for all trials up to and including span length. Standard deviations in parentheses.

	Response choice			
	Correct	**Order error**	**Proc.-phase error**	**Protrusion error**
Integrated	.802 (.112)	.134 (.070)	.032 (.021)	.032 (.045)
Independent	.626 (.118)	.212 (.129)	.076 (.034)	.086 (.058)