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The role of interference in moderating the relationship between working memory capacity and cued-recall

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The Role of Interference in Moderating the Relationship between Working Memory Capacity and Cued-Recall

by

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For my mother, Latife Akirmak. I will always miss you.

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ABSTRACT

Although much research has been done on how well working memory predicts processing of consciously activated information, research on the possible influences of working memory on automatically activated information is scarce (Barrett, Tugade, & Engle, 2004). Working memory capacity (WMC) may be related to how much information is activated automatically by either aiding ease of access to relevant information or by its role in inhibiting irrelevant thoughts and information (i.e., noise). The purpose of the present study was to examine the contribution of individual differences in WMC on implicit and explicit processes in cued recall. Participants studied target words and recall was cued by associatively related words. Target connectivity was varied in Experiment 1 and target set size was varied in Experiment 2. The cued recall memory test was conducted after various retention intervals (0, 10 and 20mins). In addition, memory span of all participants was measured with both operation and counting span tasks. Finally, all participants studied a second list of words under divided attention instructions. The present experiments examined 1) the influence of retention interval on cued recall performance, 2) the influence of individual differences in WMC on cued recall after various retention intervals and 3) the role of WMC and divided attention on implicitly activated knowledge (i.e., connectivity and set size effects). The findings revealed that working memory is related to intentional (explicit) types of processes, but not related to implicit processes outside of a person’s awareness. WMC also interacted with retention interval. This finding is compatible with an attentional interpretation of WMC that

assumes the high span advantage is apparent only when there is interference. Surprisingly, low span participants tended to outperform high span individuals on an immediate test. These findings are explained by differences in maintenance of information and rehearsal, and retrieval strategies.

Chapter One: Introduction

There is growing interest in individual differences in working memory capacity (WMC) and how well it predicts individual differences in cognitive tasks such as language comprehension, learning, memory, and reasoning (Kane & Engle, 2003; Kane, Poole, Tuholski, & Engle, 2006). WMC presumably reflects a general ability to focus and divide attention in response to task demands (Baddeley, 2000; Baddeley, 2001; Conway & Engle 1994; Cowan, 1995; Engle, 2002; Kane & Engle, 2003) WM has typically been connected with consciousness because of its role in regulating controlled attention or what we call explicit processing (Baddeley, 2001; Barrett, Tugade, & Engle, 2004), but research on its potential influence on implicitly activated information is scarce (Barrett et al., 2004). The influence of working memory may be related to how much information is activated implicitly by either aiding ease of access to relevant information in long-term memory or by working memory's role in inhibiting irrelevant information (i.e., noise). Alternatively, WM capacity may affect controlled processing without influencing the magnitude of implicit effects. The purpose of this study is to examine the extent to which individual differences in WMC influence implicit and explicit processes in an extra-list cued recall task.

In extra-list cued recall, participants study a list of to be remembered target words that can vary in different semantic features such as associative connectivity and associative set size (Nelson & McEvoy, 2005; Nelson, McEvoy, Janczura, & Xu, 1993). During test, related words are used as memory cues for recall (e.g. if "dog" is a studied word, "cat" might be used as a cue in the memory test). Targets and cues are related with each other via preexisting links that are formed through everyday language experience, and the cues are unavailable during the study episode and thus are extra-list. Research has shown that targets with smaller sets of associates and targets with densely connected associates are more likely to be recalled than those with larger sets and those with fewer connections. Such effects are known as set size and connectivity effects, respectively (Nelson, Goodmon, & Akirmak, 2007; Nelson, Fisher, & Akirmak, 2007). These effects are uninfluenced by explicit processing manipulations that have been shown to affect the magnitude of recall such as levels of processing, incidental as opposed to intentional processing, and study time (Nelson et al., 2007). Set size and connectivity effects are independent of the effects of explicit processing operations manipulated during encoding, suggesting that they are mediated by automatic processes. For this reason, extra-list cued recall is a good task for studying the effects of both implicit-automatic and explicit-intentional processing operations on memory. The influences of implicit operations can be assessed by the magnitude of set size and connectivity effects, and the influences of explicit operations can be assessed by variations in recall as a function of encoding operations and the conditions of testing, such as when the test is administered. The goal of the present study is to refine our understanding of the relationship between cued-recall and WMC and to determine whether WMC is related to both types of processing or to only explicit processing involving conscious attentional control.

Working Memory Span

WMC is operationally defined as the number of items that can be recalled during a complex memory span task and it is typically measured under conditions involving simultaneous storage and processing demands (Barrett et al., 2004; Daneman & Carpenter, 1980). Participants are asked to keep some information in an active and easily accessible state while at the same time switching their attention to another processing task (Baddeley & Hitch, 1974). For example, in the operation span task (OSPAN), participants may be presented: “Is (3x4)-4=8? (Chair)”. Their goal is to indicate whether the equation is true or false and to remember the word at the end of each problem for a future memory test. Similar span tasks exist that involve reading, digits, and spatial orientation (Baddeley, 1992; Kane & Engle, 2003). Individual differences in WMC predict performance in attention demanding cognitive tasks such as general intelligence tests (Gf) (Engle & Kane, 2004; Engle, Tuholski, Lahghlin, & Conway, 1999), the Stroop task (Kane & Engle, 2003), and the dichotic listening task (Conway & Kane, 2001).

Various factors may contribute to the predictive power of WMC but there is compelling evidence in favor of conceptualizing this capacity as an indicator of efficient use of executive attention (Engle, 2002). In this view, WMC provides a measure of individual differences in attention span and control. Span measures of working memory can be regarded as measures of abilities to keep attention focused and to keep distracting information from entering into consciousness and interfering with current goals (Kane & Engle, 2000; Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004). The ability to control attention is essential for controlled processing, because it presumably determines the extent to which irrelevant thoughts, feelings and behaviors are activated implicitly (Barrett et al., 2004). Controlled processing resolves conflicts between goal-relevant and goal irrelevant representations so that individuals can concentrate and focus on the relevant information (Barrett et al., 2004; Conway & Engle, 1994) and thus it determines how we consciously control our internal mental processes such as motivation and direction of information flow (Atkinson & Shiffrin, 1968; Cowan, 1988). Irrelevant stimuli that gain access to attention are believed to reduce performance on a variety of cognitive tasks (Hasher, Zacks, & May, 1999). Such distortions may derive from losing the focus of attention on the task due to momentarily intrusions, i.e.

noise. Controlled processing is assumed to prevent the noise from gaining access to and draining limited attention resources (Kane & Engle, 2003; Rowe, Valderrama, Hasher, & Lenartowicz, 2006).

In regards to interference effects, WMC was shown to be involved in susceptibility to interference (Kane & Engle, 2003). For example, high span individuals perform at higher levels than low spans in the Stroop task (Kane & Engle, 2003). They also demonstrate less output interference when generating category exemplars (Rosen & Engle, 1997), and they are less susceptible to the cocktail party effect in the dichotic listening task (Conway & Engle, 2001). Generally, the capacity of high spans to resist such interference effects is attributed to greater attentional control of memory representations (Kane & Engle, 2003), including information about context (Barrett et al., 2004; Conway & Engle, 2001; Engle, 2002).

Implicit and Explicit Processing in the Extra-List Cued-Recall Task

Words are associated with each other through the process of language experience in everyday life (Collins & Loftus, 1975). When a word is experienced, its associatively related concepts are implicitly activated. Such activation aids comprehension by providing immediate access to a word's associative meaning as determined by previous experience. A memory model that focuses on the influence of implicitly activated memories on episodic recall is Nelson et al.'s (1998) Processing Implicit and Explicit Representations (PIER2). According to PIER2, remembering a recently encountered word is a function of both explicit and implicit processes and their representations created during study. The explicit representation of a word is formed during controlled processing activities such as rehearsal whereas the implicit representation is produced by the covert activation of the word's associates and the links that bind them together (Nelson et al., 1998; Nelson, McKinney, & McEvoy, 2003;

Nelson & McEvoy, 2005). This research focuses on the influence of implicitly activated information on episodic recall by examining the effects of differences in the associative structures of various words in the extralist cuing task.

Not all words have the same associative organization. As measured with free association procedures, the associates of a given word differ in set size, connectivity, and in strength (Nelson et al., 1998). Set size is a normally distributed variable and small and large set size are operationalized as words having 8 or fewer associates and 17 or more associates, respectively (Nelson et al., 1998). The number of connections among a word's associates is called connectivity. Some words have a densely connected associative structure (2 or more links per associate) whereas the associates of other words are sparsely connected with each other (less than 1 link per associate). Finally, strength refers to the probability that one word brings a related word to mind.

Research has shown that set size and connectivity effects are obtained even when frequency (Nelson & Xu, 1995 cf. Nelson et al. 1998), concreteness (Nelson & Schreiber, 1992), and word ambiguity (Gee, 1997 cf. Nelson et al. 1998) are controlled experimentally or statistically (Nelson & Zhang, 2000). More importantly for present purposes, such effects are mediated via automatic processes (Nelson, Bennett, & Xu, 1997; Nelson, Schreiber, & McEvoy, 1992), and they are reduced by disrupting access to information about context. For example, the introduction of a retention interval during which participants solve math problems before the memory test reduces or eliminates set size effects (Nelson & Goodmon, 2003; Nelson & McEvoy, 2005; Nelson, Goodmon, & Akirmak, 2007). Likewise, connectivity effects diminish when participants experience interference between the study trial and the memory test (Nelson, Goodmon, & Akirmak, 2007). A recent study by Nelson et al. (2007) examined how the preexisting associative structure of an individual target word affects its cued recall when testing was delayed for retention intervals ranging from 0-20 minutes. During the interval, participants either solved simple math problems or they studied additional word lists. As the retention interval increased, probability of correct cued recall declined with these interference manipulations and the effects of connectivity diminished independently of the nature of the interfering task. Similarly, Akirmak (2007) showed that solving math problems or studying other lists reduced set size effects (also see Nelson et al., 1993). It seems that the magnitude of these implicit effects depends more on the length of the retention interval than the nature of the interfering activities.

The results of these experiments indicate that recovering context is important for both set size and connectivity effects as well as for overall levels of recall. The associates of the words that are activated during study appear to be bound to information encoded about the context of the learning experience (Nelson et al., 2007). Reducing access to the study context by increasing the retention interval diminishes implicit memory effects just as it reduces the effects of explicit processing activities. Thus, according to PIER2, memory for both implicit and explicit representations declines as a function of the length of the retention interval. In sum, the associates of the words need to be activated and maintained in an active state in order to obtain influences of word knowledge and if a disruption occurs during this state, associative set size and connectivity effects are reduced and often eliminated altogether across many studies (Nelson & Goodmon, 2003; Nelson & McEvoy, 2005; Nelson, Goodmon, & Akirmak, 2007). Findings indicate that this reduction in implicit and explicit effects is partially attributable to the loss of context information (Nelson & McEvoy, 2005; Nelson, Goodmon, & Akirmak, 2007). This view is consistent with the studies that attribute forgetting to failures to retrieve context accurately (whether physical or mental) (Lehman & Malmberg, in press; Sahakyan & Kelley, 2002; Smith & Vela, 2001). Mismatches between the study and test episodes reduce the likelihood of recall (Smith & Vela, 2001). For example, according to the contextual differentiation hypothesis, successful recovery of a target depends on reinstating information related to the encoding context during the test (Lehman & Malmberg, in press), thus making test context more similar to the study context by remembering information about the study episode. With longer retention intervals, the mismatch (i.e., difference) between study and test contexts increases proportionally.

Manipulations of retention interval can be considered as manipulations of the rate of context loss with higher amounts of context loss occurring after longer retention intervals (Nelson et al., 2007). Thus, for present purposes, retention interval is utilized to manipulate the difference between study and test contexts for list memory. When the memory test is immediate, study and test contexts are more similar to each other, because relatively short amounts of time have elapsed. Thus, implicit and explicit memory representations for to-be-remembered targets can be assumed to be intact and strongly present. In contrast, when the memory test is delayed, test context is less similar to the study context depending on the length of retention interval. The greater mismatch between study and test contexts may require more effortful cognitive processing to actively reinstate information about the study context after a delay.

Relation of Span to Cued Recall Performance

It is plausible that the ability to successfully reinstate context information differs across individuals. If memory representations involve context information and interference effects are partly due to context changes, there is a likely relationship between WMC and ability to remember context. Specifically, context losses may be more gradual for those with higher WMC. To this date, few studies have evaluated how the rate of context loss is affected by memory span (see Delanay & Sahakyan, 2007). If high span superiority in various cognitive tasks is partly due to their greater or more efficient context encoding or their strategies in resisting interference effects during context shifts, then magnitude of context loss is likely to be dependant upon memory span. One way to learn more about this relationship is to examine how high and low spans perform in a cued-recall task across different retention intervals. Access to context is reduced through manipulations of retention interval in which participants are asked to perform an unrelated task (Nelson et al, 2007). Individuals with higher WMC may have better and/or more access to the contextual cues from the study episode after an interfering task because having higher capacity may help them resist the disruptive effects of interference on remembering context information (Kane & Engle, 2003). If WMC plays a role in accessing and maintaining context information, higher capacity participants would be expected to have better cued recall than those with lower capacities, especially after an interfering task.

Another purpose of the present study is to examine whether WMC is related to interference occurring without the participant's awareness, such as implicit interference from target competitors (i.e., set size). Associates of the target that are not connected to the cue (i.e., target competitors) have been found to hinder recall (Nelson & McEvoy, 2002; Nelson & McEvoy, 2005). The present study explores whether high spans would show an advantage over low spans when the interference is implicitly generated by the words' associates. If span is related to implicitly generated interference via associates, then high spans are expected to show larger set size and connectivity effects, especially with the longer test delay. However, differences between high and low spans may not be evident when recall is evaluated in terms of implicit variables, because such effects are ostensibly automatic and likely to be independent of attentional manipulations. In fact, Nelson, Bennett and Xu (1997) found that the magnitude of target set size effects were equivalent under divided vs. undivided attention conditions. If WMC measures only explicitly controlled attention processes, it should not be a predictor of effects based on implicit processes such as set size and connectivity.

Two experiments evaluated these questions. Experiment 1 investigated the effects of associative connectivity and Experiment 2 investigated the effects of associative set size in the extra-list cued recall task. In both experiments, retention interval was varied at 0, 10, and 20 minutes and was filled with solving math problems, which acts as an interfering task prior to the memory test. Finally, in both experiments, WMC was measured for all participants and allowed to vary continuously. All participants were measured on two working memory tasks after they completed the cued recall task: operation span (OSPAN) and counting span (CSPAN). Variations in WMC and the duration of the retention interval were expected to affect probability of cued-recall. Specifically, high spans were expected to have higher cued-recall performance than low spans at longer retention intervals, because they are presumably better at maintaining context information in an active state during interference. However, such differences may not be evident on an immediate test because there is very little mismatch between the test and study contexts and the span advantage is more likely to occur when there is greater demands on retrieval (i.e., greater mismatch between study and test contexts) (Delanay & Sahakyan, 2007; Engle & Kane, 2002). In addition, if WMC is correlated with interference from implicitly activated information, then individuals with higher WMC would show larger connectivity effects in Experiment 1 and similarly, show larger set size effects in Experiment 2, with the difference between high and low span individuals most apparent at the longer delay. This hypothesis was tested by a regression analysis that evaluated the role of retention interval as a moderator on the relationship between working memory and implicit knowledge. Similarly, a regression analysis evaluated whether retention interval moderates a potential relationship between working memory and cued recall.

Finally, in order to further assess the role of attentional control in activating implicit knowledge in the cued recall task, attention at encoding was also experimentally manipulated. This manipulation was aimed at determining whether studying lists under full or divided attention conditions influence the magnitude of set size and connectivity effects. By doing so, it is possible to check whether the results of individual difference analysis in both experiments are in line with the results of a direct manipulation of attention. Participants in both experiments studied an additional list of words under divided attention after completing the first study-test portion of each experiment under undivided attention. The expectation was that if WMC is related to activation of implicit knowledge, then when attention is manipulated experimentally, participants learning under divided attention should display reduced set size and connectivity effects compared to when they learned under conditions of full attention. Furthermore, because memory has been shown to be better when attentional resources are focused on the studied items (Hasher et al., 1999) dividing attention during study is expected to diminish overall cued-recall.

Chapter Two: Experiment 1

Methods

General Design

Associative connectivity is varied within-subjects at high and low levels, and retention interval is a between-subjects variable with three levels (0m, 10m, 20m). Two working memory measures are obtained on each participant: operation span and counting span. All participants first received the full-attention cued recall memory test, followed by the divided-attention cued recall task, and then their span measures were obtained. The cued-recall tests were given before the WMC measures in order to eliminate potential proactive interference from the WMC tasks on cued-recall performance. The divided attention condition always followed the full attention condition because the primary interest in this project was the effects of WMC and retention interval on connectivity and set size effects in cued recall under full attention. For this reason the results of the divided attention conditions will be presented after Experiment 2.

Participants

The participants were recruited from University of South Florida undergraduates and were given course credit for their participation. Their age range was from 19-25 and they were from various ethnicities. There were 94 participants and they were randomly assigned to experimental conditions (i.e., to each retention interval condition) in replication blocks.

Measures of Associative Structure

There were two 24-item word lists used in Experiment 1 (Appendix A). The lists were taken from Nelson et al. (2007), and in each list, half of the words had high connectivity and half of them had low connectivity. Connectivity is operationalized as the number of connections among the associates of a target. Targets with high connectivity had an average of 2.98 (SD= .65) linking connections between their associates whereas those with low connectivity had an average of .77 (SD= .43) connections per associate. Printed target frequency was controlled for each level of connectivity and was set to a high level (M=308 times per million words). Similarly, other variables known to affect cued-recall were controlled at weak-moderate levels, including cue-to-target strength and target-to-cue strength, (M= .12, SD= .05 and M= .08, SD= .11, respectively), number and strength of cue competitors (M= 7.89, SD= 4.16 and M= .36, SD = .24) and number and strength of target competitors (M= 8.55, SD= 4.51 and M= .46, SD= .25), respectively.

Cued Recall Procedure

All participants received extra-list cued recall instructions in individual sessions. They were told that they would see a list of words and their task was to read each word aloud as it appeared and to remember as many as possible, but they were not told how their memory was going to be tested. They were then presented with 24 target words, each presented alone on a computer monitor for 3 seconds. During the cued recall test, participants were shown cue words, one at a time, that were meaningfully related with the words in the study list as measured by the Nelson, McEvoy, & Schreiber (1999) pool of word association norms. Participants were told each cue was related to one of the words they had studied and were asked to recall the targets with the help of these extra-list cues. They were told that they could guess when unsure. The cued-recall test was self-paced, and as soon as participants produced a response to the cue, the experimenter advanced the next cue until responses to all of the cues were collected.

In the immediate test conditions, participants were given cued-recall test instructions immediately after the last study word and then completed the test phase. Participants in the delayed test conditions received instructions for the interference task immediately after the last study word. They were told that they would complete a second important task that involved solving simple math questions (e.g., 13x56=??). Depending on the delay condition, participants solved these math problems for either 10 minutes or 20 minutes. Following this interference task, subjects received the cued recall test. After completing the cued recall test, each subject then studied and recalled an additional list of words under divided attention. The results of the divided attention condition will be presented after Experiment 2.

After the cued-recall phase of the experiment, the two working memory span measures were administered. The order of the working memory measures was counterbalanced and the measures were administered on a computer screen with the help of an experimenter.

Measures of Individual Differences

Operation Word Span. Participants solved simple math operations while trying to remember words for a later free recall test. Each operation-word pair was shown on the computer screen and the participant read them out loud. Then, they were asked to tell whether the equation was correct. They could respond by saying either “yes” or “no”. The main task was to remember the nouns that were presented next to the equations. An example would be “Is (5x4) – 5 =20? Chair”. The materials from the Kane, Hambrick, Tuholski, Wilhelm, Payne, and Engle (2004) study were used in this study.

The math operations always started with a multiplication or division that was followed by a subtraction or addition of another number. Participants read out the equation as soon as it appeared on the computer screen, indicated whether the equation was true or not, and then read the noun out loud. As soon as the noun was read, either another equation or a recall cue was presented to the participant. In response to the recall cue, the participant needed to recall each word, in order, from the preceding group, with group defined as the items presented since the last recall cue. Group sizes of the to-be-recalled nouns ranged from 2 to 5 math-word problems per trial (for 12 trials total). Operation span was measured by the number of words recalled in the correct serial order.

Counting Span. In this task, adopted from Kane, Hambrick, et al., (2004), participants tried to recall digits against background interference. Participants looked at a display that included 3 to 9 dark blue circles; 1, 3, 5, 7, or 9 dark blue squares; and 1 to 5 green circles on a gray background. The number of blue circles, blue squares, and green circles were balanced across displays. Participants needed to count out loud the number of dark blue circles in each display and once finished, they repeated the total number. For example, if there were 4 dark blue circles, participant would say “One, two, three, four…four”. When the participant repeated the final count, the experimenter would present another display or a cue to recall display totals from a preceding group of displays in the correct order. Group sizes for recall varied from 2 to 6 displays per trial and there were 15 trials in total. Counting span was measured by the participants’ memory of the final counts of the displays in the correct serial order.

Results

Preliminary analyses

Subjects who recalled zero items in the cued-recall task were not included in the analysis because recall was below chance as defined by free association in the absence of a study trial. Similarly, subjects who scored less than 85% correct on the operation span processing task were eliminated from the analysis as recommended by Kane et al. (2004). Table 1 contains descriptive statistics, alphas, and correlations among the focal variables. Analyses involved 84 subjects.

For computing correlations, connectivity effects were calculated by subtracting the probability of recalling low connectivity words from the probability of recalling high connectivity words. Working memory scores were computed based on partial credit scoring (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). Within a given item, proportion of words (OSPAN) or numbers (CSPAN) that were recalled in the correct serial position was determined and then all of these proportions were averaged together in order to calculate the working memory span score. As can be seen in Table 1, Operation Span (OSPAN) and Counting Span (CSPAN) were significantly related with each other in line with previous research (see Kane et al., 2004). However, probability of cued recall and connectivity effect difference scores were uncorrelated with either working memory measure. In order to explore the possibility that the correlation between WMC and cued recall may be reduced due to retention interval, regression analyses were employed. Specifically, moderated regression analyses were computed in order to determine the influence of retention interval on the WMC and cued recall relationships.

Table 1

Descriptive Statistics and Correlations among Measures in Experiment 1

		1	*2*	*3*	*4*
1	Operation Span	-			
2	Counting Span	.51**	-		
3	Probability of Cued Recall	-.06	.14	-	
4	Connectivity Difference Score	.03	.05	.03	-
	Mean	.76	.65	.31	.07
	SD	.14	.14	.14	.01

Note. N = 84; p**< 0.01 (2 tailed)

Regression Results

Retention interval is a categorical variable and was dummy-coded into two different variables named Short Delay and Long Delay in order to represent all 3 interval categories in the regression analyses as suggested by Cohen, Cohen, West, & Aiken (2003). 0min was coded as 0, 0; 10 min was coded as 1, 0; 20min was coded as 0, 1, respectively, for Short Delay and Long Delay. In the following tables, Short Delay refers to the difference between 0min and 10min, and similarly Long Delay refers to the difference between 0min and 20min. Immediate testing served as the baseline comparison for this analysis because interest focused on evaluating how the length of the retention interval moderates the WMC and cued recall relationships.

Relationships between working memory scores and cued-recall performance were tested by creating regression models in which OSPAN or CSPAN was entered as a predictor along with retention interval to predict the connectivity effect and probability of correct recall. The connectivity effect and probability of cued-recall were regressed upon either the main effects of OSPAN or the main effects of CSPAN scores along with main effects of Retention Interval in Step 1. To test for moderation effects, this step was followed by the appropriate OSPAN or CSPAN by Retention Interval interaction in Step 2. As recommended by Aiken and West (1991), the main effects of the span measures were centered before calculating the interaction terms (i.e., subtracted the mean from all observations, making the new 0 point equal to the mean to eliminate multicollinearity problems).

Operation Span. The hypothesis predicted that because length of the retention interval is correlated with level of interference, retention interval moderates the relationships between working memory scores and cued-recall performance. As indicated in Table 2, the OSPAN by Retention Interval interaction was not statistically significant when connectivity was the criterion variable revealing that OSPAN does not predict connectivity effects. In contrast, the OSPAN by Retention Interval interaction was statistically significant when probability of cued recall was the criterion variable. Specifically, the OSPAN by Long Delay interaction was significant (β=.45), $t(82)=3.27$, $p<0.05$ indicating that OSPAN scores affected correct probability of cued-recall differently between 0min and 20min conditions. The OSPAN by Short Delay interaction was in the same direction but was not significant, (β=.15), $t(82)=1.11$, p =.27. The R^2 change (.11) for the second step was statistically significant, $p<.01$ when cued recall was the dependant measure. The interaction is illustrated in Figure 1. Memory span was entered into the analysis as a continuous variable and for the purposes of understanding the figure, the ends of the scale are labeled as low and high on the X-axis. The lines represent the regression best fit lines for the given conditions. The OSPAN by Retention Interval interaction predicted memory performance when interference was highest as indexed by the 20m retention interval. However, OSPAN score was not a reliable predictor of performance when there was only 10m of delay and less interference. In the long delay condition, individuals with higher OSPAN scores showed better cued-recall performance. High spans performed better in the long delayed test. However the high span advantage was reversed in the immediate test. Simple slope calculations (Cohen et al., 2003; also see O'Connor (1998) for SPSS script) confirmed that high and low spans significantly differed in the 0min condition t(78)=-2.36, p<.05 and also in the 20min condition t(78)=2.29, p<.05. Finally, span had no effect after the 10m delay.

Table 2

Beta weights for the moderating effect of Retention Interval on OSPAN – Connectivity and Probability of Cued-Recall Relationships

		Criterion Variable	
		Connectivity	*Probability of Cued-Recall*
Step	*Predictors*	*B*	*B*
1	Operation Span	0.02	-0.58
	Short Delay	-0.11	-0.32**
	Long Delay	-0.25*	-0.32**
		R^2=.05; F(3,80)=1.31	R^2=.11; F(3,80)= 3.26*
		MSres=3.63	MSres= 10.02
2	Operation Span	0.02	-0.38*
	Short Delay	-0.12	-0.32**
	Long Delay	-0.25*	-0.30**
	Operate x Short	0.12	0.15
	Operate x Long	-0.12	0.44**
		R^2=.08; F(5,78)=1.26	R^2=.22; F(5,78)=4.34*
		MSres=3.61	MSres=9.02
		ΔR^2=.03	ΔR^2=.11*

Note. N= 84; p*<0.05; p**< 0.01

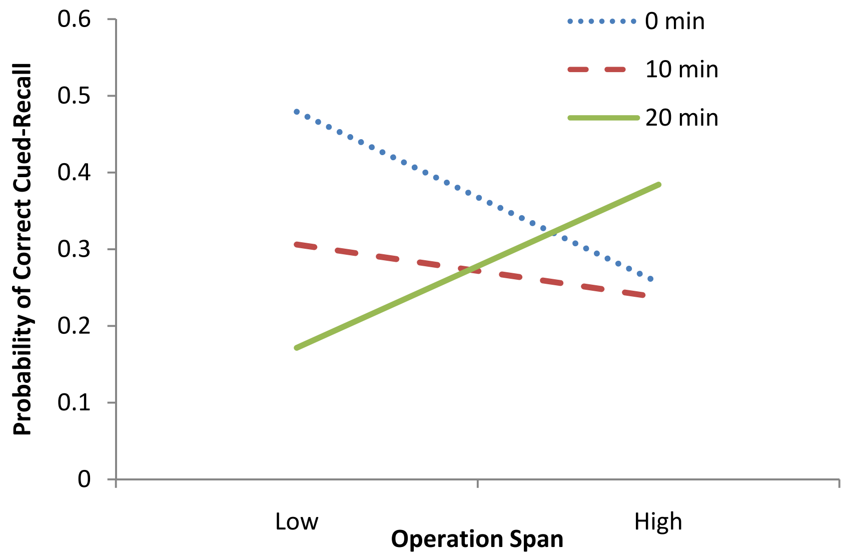


Figure 1. Operation Span by Retention Interval Interaction for Probability of Cued-Recall in Experiment 1

Counting Span. The predictions for CSPAN were in the same direction as OSPAN. As indicated in Table 3, the CSPAN by Reaction Interval interaction was not statistically significant when connectivity was the criterion variable. Thus, CSPAN was not related to the magnitude of connectivity effect. The OSPAN by Retention Interval interaction was significant when probability of cued recall was entered as the criterion variable. Similar to OSPAN results, the CSPAN by Long Delay interaction was reliable (β=.34), t(82)=2.32, p<0.05 and the CSPAN by Short Delay interaction was not significant (β=.08), t(82)=0.57, p =0.59. The R^2 change (.06) for the second step approached statistical significance, p=.06 when cued recall was the dependant measure. As can be seen in Figure 2, the CSPAN by Retention Interval interaction predicted memory performance when interference was highest as indexed by 20m of delay. After 20min of solving math problems, individuals with higher CSPAN scores had better cued-recall compared to individuals with lower CSPAN scores. Simple slope calculations confirmed that high and low span's cued recall significantly differed only in the 20min condition t(78)=-2.49, p<.05. None of the other differences were significant.

Table 3

Beta weights for the moderating effect of Retention Interval on CSPAN – Connectivity and Probability of Cued-Recall Relationships

		Criterion Variable	
		Connectivity	*Probability of Cued-Recall*
Step	Predictors	*B*	*B*
1	Counting Span	0.01	0.11
	Short Delay	-0.11	-0.32**
	Long Delay	-0.24	-0.30*
		R^2=.05; F(3,80)=1.29	R^2=.12; F(3,80)= 3.49*
		MSres=3.63	MSres= 9.94
2	Counting Span	0.19	-0.14
	Short Delay	-0.10	-0.33**
	Long Delay	-0.26*	-0.28*
	Count x Short	-0.05	0.08
	Count x Long	-0.26	0.34*
		R^2=.08; F(5,78)=1.38	R^2=.18; F(5,78)=3.36**
		MSres=3.58	MSres=9.49
		ΔR^2=.03	ΔR^2=.06 (p=.06)

Note. N=84; p*<0.05; p**< 0.01

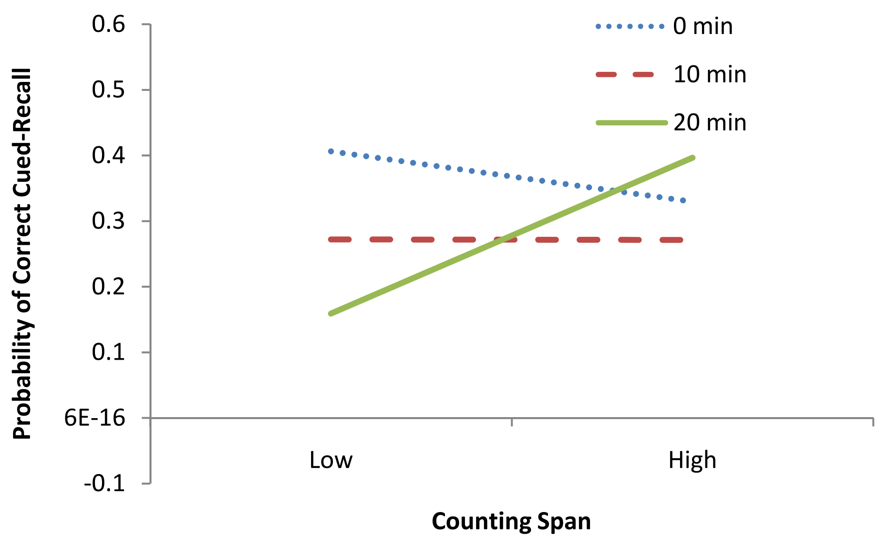


Figure 2. Counting Span by Retention Interval Interaction for Probability of Cued-Recall in Experiment 1

Supplementary Results

A composite score was created by averaging Operation and Counting Span scores in order to accurately classify individuals with high and low working memory capacities (see Conway et al. 2005 for a discussion). This composite score indicates individual's overall memory span. A median split was performed on this composite span score in order to create two categories that represented high WMC individuals (high spans) and low WMC individuals (low spans). Figure 3 illustrates probabilities of correctly recovering targets in the cued recall task. As can be seen, connectivity and retention interval had a significant main effect on recovering targets, but memory span did not consistently influence recall. In general, participants recalled more targets with high connectivity than low connectivity and probability of cued recall declined during the retention interval. A 2 (memory span) x 2 (connectivity) x 3 (retention interval) mixed-model analysis of variance of these data revealed that probability of correct recall varied with target connectivity, $F(1,78)=13.94$, $MSe=.013$, and with retention interval $F(2,78)=4.85$, $MSe=.032$, but memory span had no effect on cued recall ($F=1.43$, $p=.24$). An LSD of .07 indicated that participants recalled significantly more words at 0mn (.37) compared to 10mn (.27) and 20mn (.30).

Only one of the interaction effects met the .05 criterion for significance in this analysis. The main result of Experiment 1 indicated that probability of correctly recovering target information varied between high and low spans after different retention intervals. Memory span interacted with retention interval, $F(2,78)= 4.21$, $MSe=.032$. An LSD of .09 indicated that high span participants (.36) recalled more words than low span participants (.23) in the 20min condition but the other differences were not significant ($\Delta=-.06$ and $\Delta=.03$ respectively for 0min and 10min). The interaction between retention interval and connectivity was not reliable ($F=2.00$, $p=.14$). Nevertheless, as can be seen in Figure 3, the direction of the interaction was in the predicted direction with highest connectivity effect appearing in the immediate test (Δ=.11) and gradually decreasing over longer retention intervals (Δ=.7 and Δ=.2 respectively for 10 and 20min of retention intervals). A planned comparison with an LSD of .05 confirmed that connectivity effects were reliable at 0min and 10min, but not at 20min. The connectivity by span interaction ($F < 1$) and also the three way interaction of memory span, connectivity and retention interval ($F < 1$) were not reliable. These results indicate that connectivity effects do not change with memory span and are also unaffected by the combination of retention interval and span.

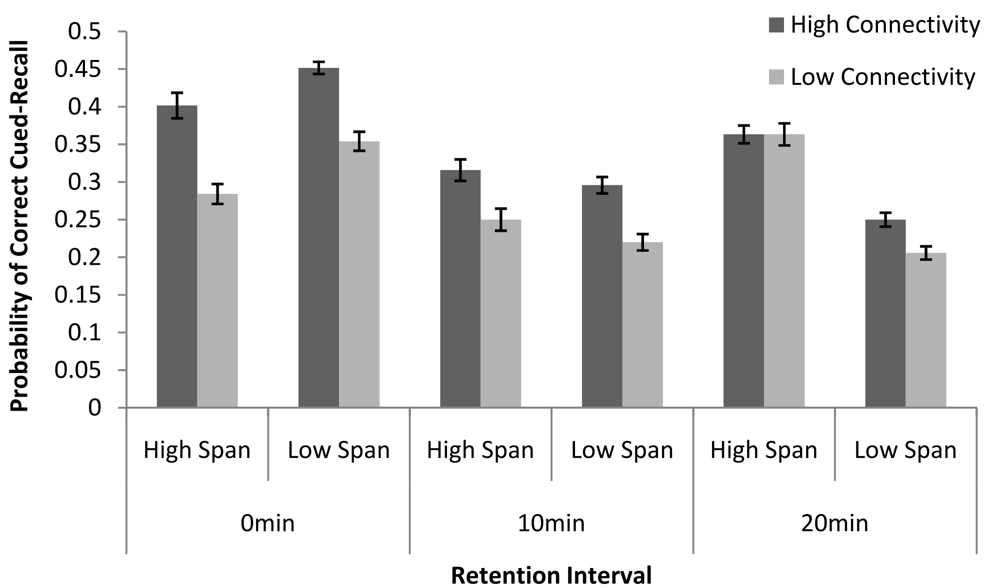


Figure 3. Probability of Correct Recall in Experiment 1 as a Function of Memory Span, Connectivity and Retention Interval

The results of Experiment 1 were consistent with general expectations in that recall was higher when targets were higher in connectivity, and overall recall gradually decreased when the retention interval was increased. There was a non-significant trend towards connectivity effects being smaller at longer retention intervals, and a planned comparison confirmed that the connectivity effect was not reliable in the 20min condition but was reliable in the 0min and 10min conditions. Furthermore, high spans had better cued recall than low spans only after 20min of delay as indicated by a significant two way interaction. Memory span had no effect on the magnitude of the connectivity effects.

The relationship between WMC and probability of recall was also tested by using moderation analyses in which a connectivity difference score or probability of correct recall served as dependent measures and OSPAN or CSPAN and retention interval served as predictors in regression equations. The results showed that none of the working memory measures or their interactions with retention interval reliably predicted the magnitude of the connectivity effect, in line with the ANOVA results which showed no connectivity by memory span interaction. Overall, these analyses indicate that connectivity effects were unaffected by OSPAN or CPSAN scores and their interaction with retention interval. In contrast, retention interval moderated the relationship between working memory and probability of cued recall. Moderation analyses indicate that probability of cued-recall in Experiment 1 is partly dependant upon participant's working memory scores and this relationship is only apparent when there is a relatively high level of interference. The relationship emerged only at the longest test delay, and this interaction was confirmed with ANOVA and moderation analyses. This finding is consistent with the hypothesis that when exposed to more interference, individuals with higher WMC perform better than those with low WMC. Furthermore, participants with lower OSPAN scores had better cued-recall than those with higher OSPAN scores when their memory was tested immediately.

Chapter Three: Experiment 2

Experiment 2 replicated the procedures of Experiment 1 with the difference that set size, rather than connectivity, was manipulated as a measure of implicitly activated knowledge. Set size is experimentally manipulated by varying target competitors, which increase directly with the size of the target's associative set. The main purpose of Experiment 2 was to evaluate whether memory span affects interference generated by implicitly activated knowledge (i.e., target competitors). Moreover, the moderating effect of retention interval on the WMC-cued recall relationship is further explored by using a different implicit memory variable.

Participants

The participants were recruited from the same source as Experiment 1 and were given course credit for their participation. Their age range was from 19-25 and they were from various ethnicities. There were 90 participants and they were randomly assigned to experimental conditions (retention intervals) in replication blocks.

Measures of Associative Structure

In each of two lists, half of the words had small set sizes and half of them had large set sizes (Appendix B). Set size effects would be apparent if more targets with small set size are recalled compared to targets with large set size. Target set size is highly correlated with the number and strength of target competitors, which have been shown to be the operative variable. Targets with small set size have fewer target competitors than large set size targets. A target competitor is an associate of the target that is not connected to the test cue within two associative steps. In Experiment 2, small set size targets had a mean of 4.25 competitors (SD=1.29) and large set size targets had a mean of 10.83 competitors (SD=3.98). The number of cue competitors (M=7.67, SD=6.05 and M=9.17, SD=4.73 respectively for few and many target competitors) was equated at each level of target competitors. In accordance with PIER2, the strengths of individual competitors for a given cue-target pair were summed in order to determine total competitor strength for that pairing. Target competitor strength averaged .78 for the words with many competitors and .32 for the words with few competitors. Cue to target strength and target to cue strength are known to affect extra-list cued recall, so in this experiment they were controlled at each level of target competitor strength at weak-moderate levels (M= .07, SD=.02; and M= .02, SD=.01, respectively). The word lists were taken from Akirmak (2007) master's thesis study.

Results

Preliminary analyses

Subjects who performed below the criterion levels (i.e., zero level cued recall and less than 85% correct on OSPAN processing task) were discarded from the analyses. Table 4 contains descriptive statistics, alphas, and correlations among the focal variables. Analyses involved 77 subjects.

Similar to Experiment 1, set size effects were represented as a difference score calculated by subtracting probability of correctly recalling words that have large set size from probability of recalling words that have small set size. As seen in Table 4, Operation Span (OSPAN) and Counting Span (CSPAN) were significantly related with each other. Correlation analyses showed that probability of correct recall and set size were unrelated to either working memory measure. However, moderation analyses were computed in order to evaluate the role of retention interval in the relationship between WMC and cued recall.

Table 4

Descriptive Statistics and Correlations among Measures in Experiment 2

		1	*2*	*3*	*4*
1	Operation Span	-			
2	Counting Span	.55**	-		
3	Probability of correct recall	.20	.12	-	
4	Set Size Difference Score	.14	.08	.18	-
	Mean	.70	.64	.36	.12
	SD	.13	.15	.17	.02

Note. N = 77; p**< 0.01 (2 tailed)

Regression Results

Similar to Experiment 1, retention interval was dummy-coded into Short Delay and Long Delay conditions in order to represent all 3 retention interval categories in the regression analyses. Relationships between working memory scores and cued recall performance were tested by creating regression models in which OSPAN or CSPAN was entered as a predictor along with retention interval to predict set size effects and probability of correct recall. The set size difference score and probability of cued-recall were regressed upon either the main effects of OSPAN or the main effects of CSPAN scores along with main effects of Retention Interval in Step 1. In order to examine moderation effects, this step was followed by the appropriate OSPAN or CSPAN by Retention Interval interaction in the second step of the regression analyses.

Operation Span. The hypothesis predicted that retention interval (i.e. level of interference) moderates the relationship between WMC (either OSPAN or CSPAN) and cued-recall performance (set size difference score or probability of cued-recall). As indicated in Table 5, the OSPAN by Retention Interval interaction was not statistically significant when the set size score was the criterion variable. Similarly, the OSPAN by Long Delay interaction was not reliable when probability of cued-recall was the dependant measure. However the OSPAN by Short Delay interaction approached significance level (β=.26), t(75)=1.85, p =0.07 indicating a trend for individuals with higher OSPAN scores to have better cued-recall than low span individuals in the 10m delay condition. The R^2 change (.04) for the second step was not significant, p=.12. However, as can be seen in Figure 4, individuals with higher OSPAN scores recalled significantly more targets only in the short delay condition. This result was confirmed with a simple slope analysis t(71)=2.84, p<.05.

Table 5

Beta weights for the moderating effect of Retention Interval on OSPAN – Set Size and Probability of Cued-Recall Relationships

		Criterion Variable	
		Set Size	*Probability of Cued-Recall*
Step	Predictors	*B*	*B*
1	Operation Span	0.14	0.19
	Short Delay	-0.02	-0.42**
	Long Delay	-0.08	-0.56**
		R^2=.03; F(3,73)=0.62	R^2=.31; F(3,73)= 11.04**
		MSres=4.36	MSres= 11.44
2	Operation Span	0.10	0.03
	Short Delay	-0.02	-0.41**
	Long Delay	-0.09	-0.56**
	Operate x Short	0.05	0.26
	Operate x Long	0.02	0.01
		R^2=.03; F(5,71)=0.38	R^2=.35; F(5,71)=7.70**
		MSres=4.47	MSres=11.09
		ΔR^2=.00	ΔR^2=.04

Note. N=77; p**< 0.01

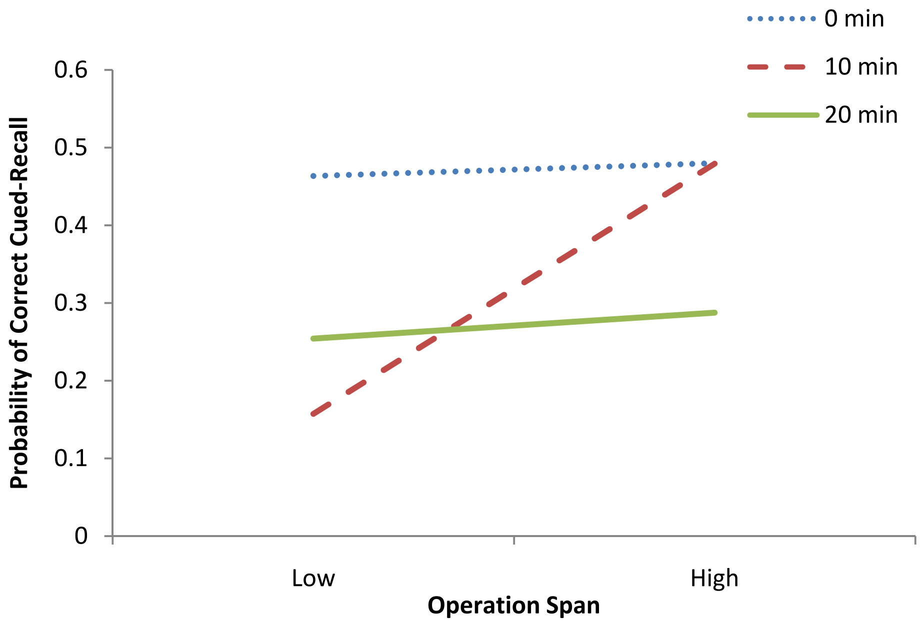


Figure 4. Operation Span by Retention Interval Interaction for Probability of Cued-Recall in Experiment 2

Counting Span. As can be seen in Table 6, the CSPAN by Retention Interval interaction was not statistically significant when the set size score was the criterion variable. Furthermore, when the probability of cued-recall was the dependant measure, the CSPAN by Short Delay interaction was reliable (β=.32), $t(75)=2.14$, $p<0.05$ but the CSPAN by Long Delay interaction was not significant (β=.22), $t(75)=1.45$, $p=0.14$. The R^2 change (.04) for the second step approached statistical significance, $p=.10$ when cued recall was the dependant measure. Overall, these results suggest that set size was not related to CSPAN or its interaction with retention interval. Nevertheless, as indicated by simple slope analysis, participants with higher CSPAN scores compared to lower CSPAN scores displayed a non-significant trend towards having better cued-recall scores only in the 10min condition, $t(71)=1.80$, $p=.08$, and none of the other differences were close to the criterion for significance (see Figure 5).

Table 6

Beta weights for the moderating effect of Retention Interval on CSPAN – Set Size and Probability of Cued-Recall Relationships

		Criterion Variable	
		Set Size	*Probability of Cued-Recall*
Step	Predictors	*B*	*B*
1	Counting Span	0.07	0.09
	Short Delay	-0.03	-0.44**
	Long Delay	-0.08	-0.55**
		R^2=.01; F(3,73)=0.25	R^2=.29; F(3,73)= 9.69**
		MSres=4.42	MSres= 11.89
2	Counting Span	0.07	-0.24
	Short Delay	-0.03	-0.45**
	Long Delay	-0.07	-0.56**
	Count x Short	-0.05	0.32*
	Count x Long	0.07	0.22
		R^2=.02; F(5,71)=0.25	R^2=.33; F(5,71)=6.97**
		MSres=4.51	MSres=11.47
		ΔR^2=.01	ΔR^2=.04

Note. N=77; p**< 0.01

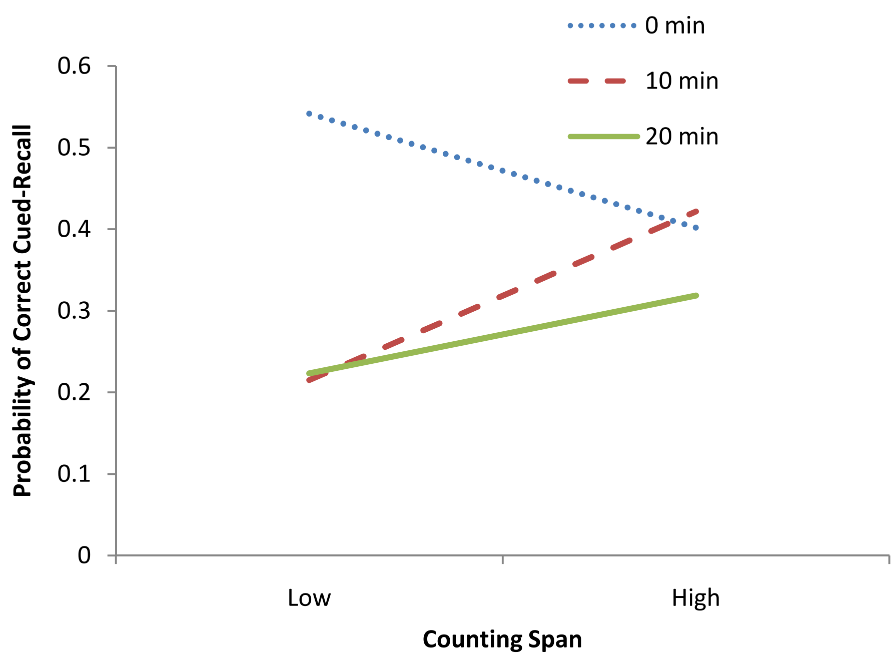


Figure 5. Operation Span by Retention Interval Interaction for Probability of Cued-Recall in Experiment 2

Supplementary Analysis

Figure 6 illustrates that set size effects were apparent during all retention intervals. Also, probability of correct recall declined during longer retention intervals. A 2 (memory span) x 2 (set size) x 3 (retention interval) mixed-model analysis of variance indicated that probability of correct recall varied with target set size, $F(1,71)=29.51$, $MSe=0.02$, and with retention interval, $F(2,71)=13.53$, $MSe=0.04$, but effects of memory span failed to reach significance level $F(1,71)=1.04$, $MSe=.04$, $p=.31$. An LSD of 0.13 indicated that recall at 0mn (.48) was significantly different than 10mn (.32) or 20mn (.27) and that the 10mn and 20mn conditions were not different than each other.

None of the interactions reached the .05 criterion for statistical significance. In contrast to Experiment 1, the memory span by retention interval interaction was not reliable, $F(2,71)=1.75$, $MSe=.04$, $p=.18$, high and low span individuals recalled equivalent numbers of targets at the various retention intervals. Moreover set size effects were reliably present across all retention intervals ($F < 1$) as confirmed by an LSD of .10. Finally, the three-way interaction among set size, memory span and retention interval was not significant ($F < 1$).

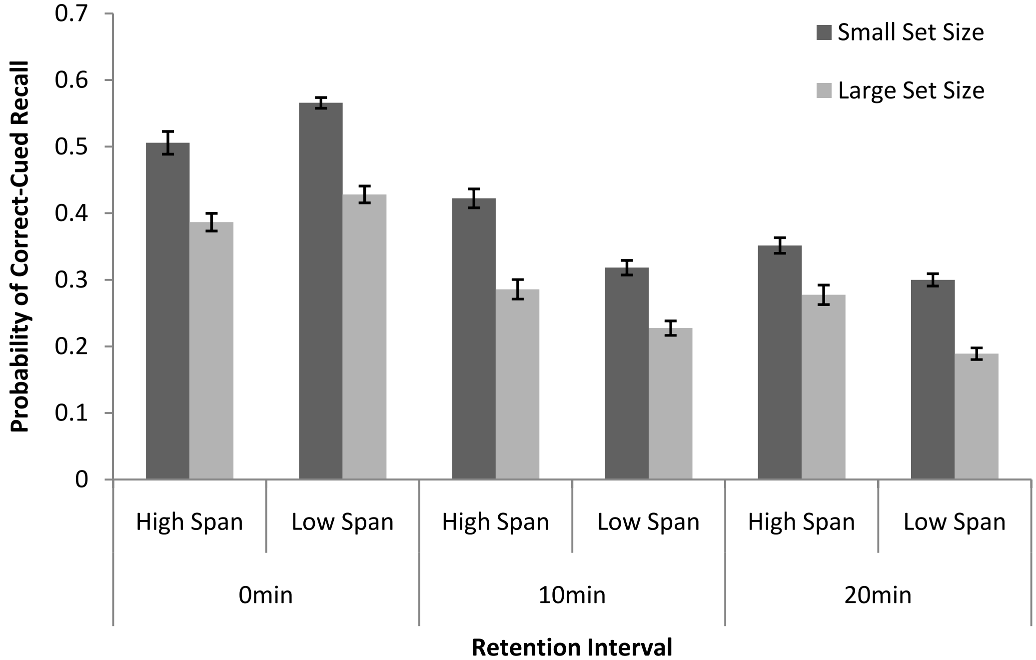


Figure 6. Probability of Correct Recall in Experiment 2 as a Function of Set Size, Memory Span and Retention Interval

The results of Experiment 2 revealed that targets with small set size were recalled better than targets with large set size, and probability of correct-cued recall was lower at longer retention intervals. Set size effects were present across all retention intervals as indicated by the non-significant Set Size by Retention Interval interaction. Similar to Experiment 1, none of the working memory measures or their interactions with retention interval was related with the implicit activation measure (i.e., set size). Contrary to the findings in Experiment 1, however, retention interval was not reliably moderating the relationship between working memory and probability of cued recall, although there was a non-significant trend towards individuals with higher working memory scores performing better than low WMC individuals when the retention interval was 10min (see Figure 4 and Figure 5).

Working Memory and Cued-Recall Relationship with the Pooled Data

Data from Experiment 1 and Experiment 2 were pooled in order to examine the relationship between working memory and recall in the extra-list cuing task ignoring the within-subjects variables (i.e., connectivity and set size). The analyses from Experiment 1 and Experiment 2 indicated that working memory was not related to either of the implicit activation measures, so set size and connectivity effects were dropped from this analysis. Experiment 1 results had revealed a reliable moderation effect of retention interval on the working memory and probability of cued recall relationship. Similarly, Experiment 2 results had shown a trend in the same direction but the differences failed to reach criterion level. In order to gain greater statistical power, data from both experiments were pooled together in this final analysis to further explore the working memory and cued-recall relationship. Separate moderation analyses were calculated for OSPAN by Retention Interval and CSPAN by Retention Interval interactions in predicting probability of cued-recall in the pooled data. Thus, probability of correct cued recall was the dependant measure and both working memory measures and retention interval served as the predictors.

As indicated in Table 7, the OSPAN by Short Delay interaction, (β =.23), $t(155)=2.29$, $p<.05$, and the OSPAN by Long Delay interaction, (β =.35), $t(155)=2.58$, $p<.05$ were reliable indicating that participants with higher working memory scores performed significantly better than those with lower scores when there were 10min or 20min filled delays before the cued-recall test. Furthermore, the R^2 change (.04) for the second step was reliable, $p<.05$. Simple slope analysis indicated that low spans had significantly better recall in the immediate memory test, $t(156)= -2.11$ $p<.05$, and there was a nonsignificant trend for high spans to be better in the long delayed test, $t(156)=1.57$, $p=.11$. As indicated in Table 8, the CSPAN by Short Delay interaction, (β =.23), $t(155)=2.23$, $p<.05$, and CSPAN by Long Delay interaction (β=.29), $t(155)=2.81$,

$p<.05$ were statistically significant. The R^2 change (.04) for the second step was also reliable, $p<.05$. Simple slope analysis indicated that high spans had significantly better recall in the long delayed memory test, $t(155)=2.22$ $p<.05$ and there was a nonsignificant trend for low spans to be better in the immediate test, $t(155)=-1.77$, $p=.08$. These interactions are illustrated in Figure 7. In line with the initial predictions, higher spans tended to perform better than lower spans at longer retention intervals, and interestingly, lower spans tended to have better recall on the immediate cued-recall test.

Overall, the pooled data analyses suggest that WMC is a predictor of extralist cued-recall. Specifically, participants with higher working memory spans had significantly higher cued-recall after 10 and 20 minutes of filled delay. These results support the hypothesis that higher spans perform better in cued-recall when there is greater interference. Additionally, there seems to be a trend toward participants with lower working memory scores compared to high working memory scores to perform better in the immediate test.

Table 7

Beta weights for the moderating effect of Retention Interval on OSPAN – Probability of Cued-Recall Relationship in the Pooled Data

		Criterion Variable
		Probability of Correct Recall
Step	Predictors	*B*
1	Operation Span	0.02
	Short Delay	-0.37**
	Long Delay	-0.43**
		R^2=.17; F(3,158)=10.95**
		MSres=11.49
2	Operation Span	-0.25*
	Short Delay	-0.38**
	Long Delay	-0.43**
	Operate x Short	0.23*
	Operate x Long	0.35*
		R^2=.21; F(5,156)=8.45**
		MSres=11.06
		ΔR^2=.04*

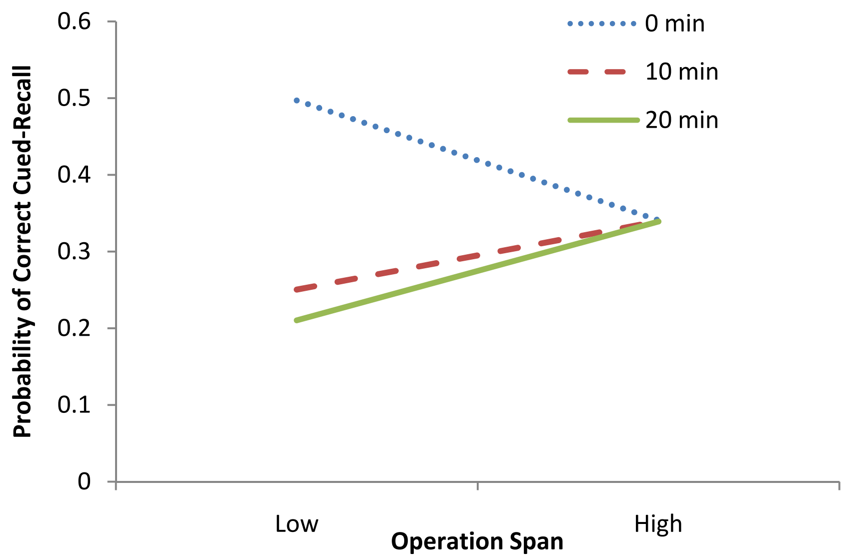
Note. N=161; p*< 0.05; p**< 0.01

Table 8

Beta weights for the moderating effect of Retention Interval on CSPAN – Probability of Cued-Recall Relationship in the Pooled Data

		Criterion Variable
		Probability of Correct Recall
Step	Predictors	*B*
1	Counting Span	0.08
	Short Delay	-0.37**
	Long Delay	-0.43**
		R^2=.19; F(3,157)=11.89**
		MSres=11.29
2	Counting Span	-0.23
	Short Delay	-0.39**
	Long Delay	-0.43**
	Count x Short	0.23*
	Count x Long	0.29*
		R^2=.23; F(5,155)=9.17**
		MSres=10.83
		ΔR^2=.04*

Note. N=161; p*< 0.05; p**< 0.01



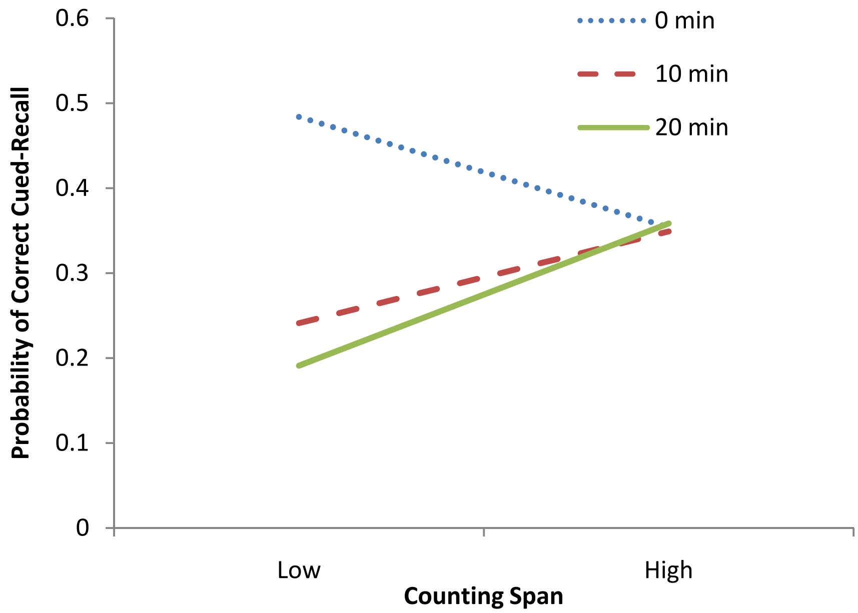


Figure 7. Retention Interval by Working Memory Measures Interactions in Combined Data Pooled (Experiment 1 & Experiment 2)

Supplementary Analysis

Data from Experiment 1 and Experiment 2 were combined together. Overall probability of cued recall was the dependent measure in this analysis. A composite working memory score was created in order to categorize participants as high and low in the span measure (see Experiment 1, p.17). Because there were sufficient observations when the data from both experiments were pooled together, a one thirds split was performed on the span data. The top third was categorized as high spans and bottom third was categorized as low spans. As can be seen in Figure 8, probability of cued recall decreased during retention intervals and this decrease in recall was dependant upon participant's memory span. A 2 (memory span) x 3 (retention interval) between-subjects ANOVA showed a significant main effect of retention interval, $F(2,101)=11.64$, $MSe=.08$, but no main effect of working memory span ($F < 1$). An LSD of .09 showed that level of recall was significantly better in the 0min (.42) condition compared to 10min

(.28) and 20min (.29). Furthermore, the memory span by retention interval interaction was reliable, $F(2,101)=5.27$, $MSe=.08$. An LSD of .11 indicated that high spans (.35) remembered significantly more words in the 20min condition than low spans (.23). Also, there was a trend for low spans (.46) to recall more words in the 0min condition than high spans (.38) but this difference was not reliable.

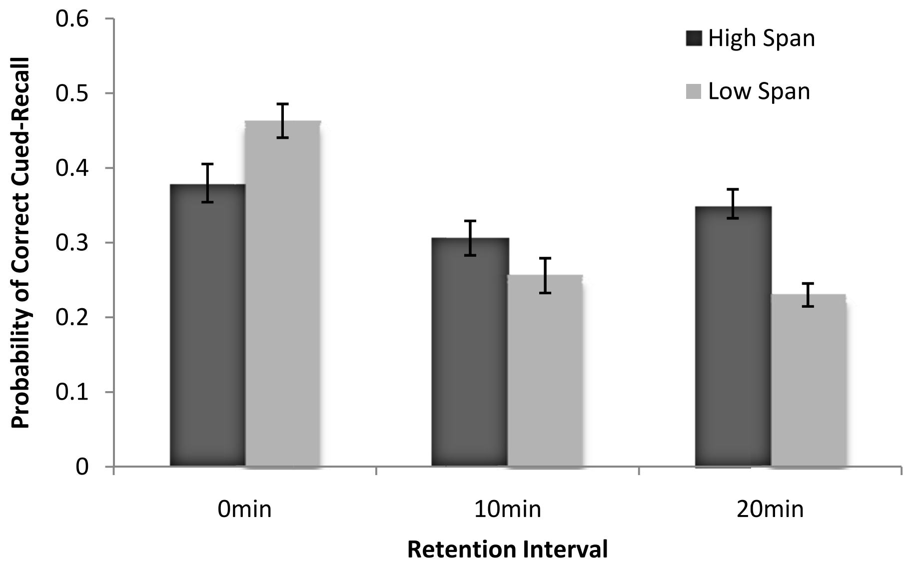


Figure 8. Memory Span by Retention Interval Interaction in Pooled Data (Experiment 1 & Eperiment 2)

Chapter Four: Experimental Manipulation of Attention

Assuming the premise that the predictive power of working memory comes from attentional processes, then it is expected that varying attention experimentally will have an effect on cued-recall performance. Based on the attention interpretation of working memory, attention was varied in the above studies as an additional condition to provide pilot data to determine the feasibility of further work. The goal was to determine whether attention during encoding (e.g., full or divided) affects probability of cued recall and the magnitude of set size and connectivity effects. Participants in Experiment 1 and Experiment 2 studied an additional word list after being tested on the initial list. All the participants studied this second list of words under divided attention instructions after having studied the first list under full attention conditions. As can be seen in Table 9, participants in Experiment 1 studied an additional list from Experiment 2 whereas participants in Experiment 2 studied an additional list from Experiment 1 after which they received an immediate cued-recall test. The nature of the manipulation was arranged so that the effects of attention could be compared on the same lists, which made the attention variable a between subjects variable. However, the order of the lists was confounded with the attention manipulation.

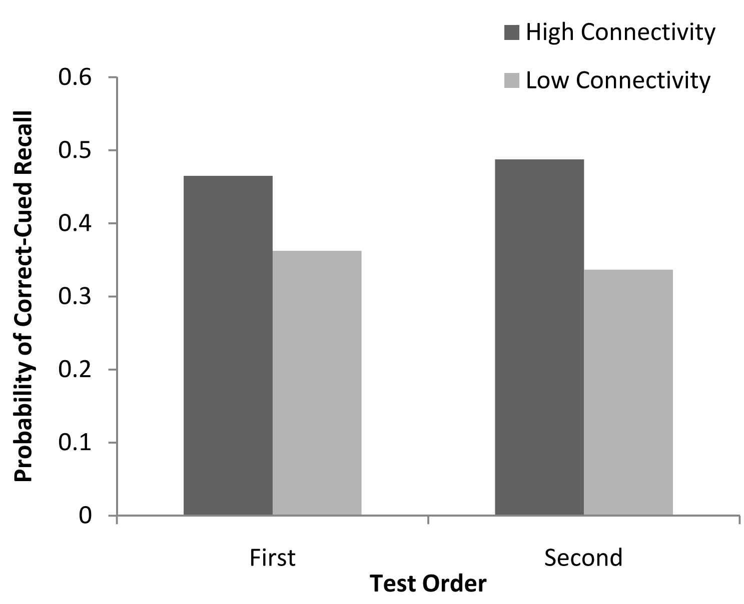
As a precaution, a pilot study on these lists was conducted and as can be seen in Figure 9, list order had no effects on probability of cued-recall or on effects of the implicit variables. A 2 (connectivity) x 2 (list order) mixed-model ANOVA indicated that there was a main effect of connectivity, $F(1,51)=26.47$, $MSe=.02$. The main effect of list order ($F < 1$) and the interaction between connectivity and list order ($F < 1$) failed to reach significance. A similar analysis indicated that set size effects were significant, $F(1,51)=16.4$, $MSe=.02$, and that neither list order ($F < 1$) nor the interaction between set size and list order ($F = 1.73$, $p=.20$) were reliable. Thus, list order is unlikely to affect the magnitude of set size or connectivity effects.

Table 9

Experimental Manipulation of Attention in the Study

	Attention	
Experiments	*Full*	*Divided*
Experiment 1	**Connectivity Lists**	*Set Size Lists*
Experiment 2	*Set Size Lists*	**Connectivity Lists**

Note. Cued-recall performances written in bold font were compared to each other. Similarly, cued-recall performances written in italic font were compared to each other.



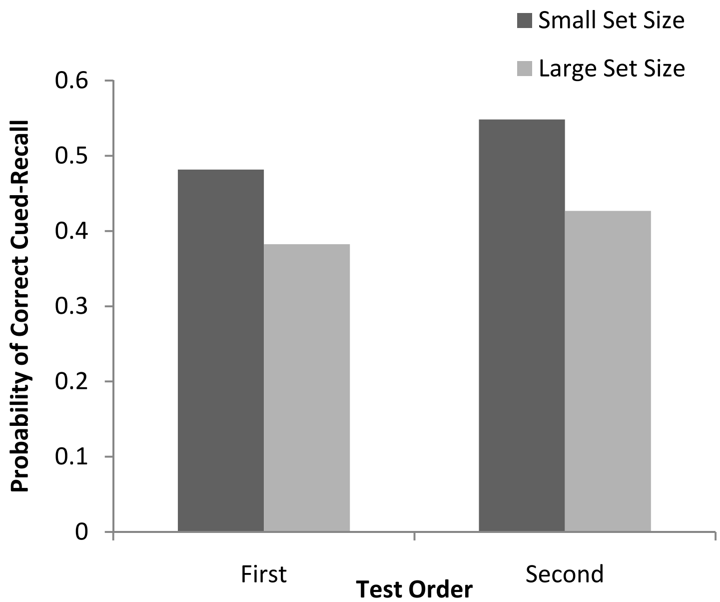


Figure 9. Set Size by Test Order and Connectivity by Test Order Interactions

Results

Separate 2 (implicit variable) x 2 (attention) mixed-model analyses of variance were performed for Connectivity x Attention and Set Size x Attention manipulations. Findings reported in Figure 10 show that probability of correct recall varied as a function of both connectivity and attention. Recall was more likely when target connectivity was high (.33) compared to low (.24), $F(1,55)=24.34$, $MSe=.01$. Similarly, participants correctly recalled significantly more words when they fully attended the lists (.37) compared to when they divided their attention (.20), $F(1,55)=26.19$, $MSe=.03$. The Connectivity by Attention interaction was not significant indicating that connectivity effects did not change as a function of attention during encoding ($F < 1$). An LSD of .06 indicated that connectivity effects were present in both divided and full attention conditions.

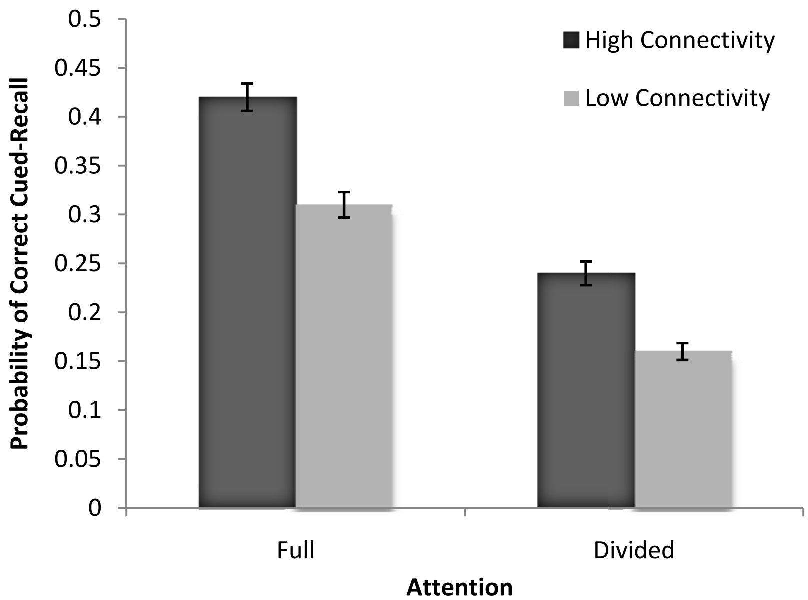


Figure 10. Probability of Correct Recall as a Function of Attention and Connectivity in the Present Study

According to the findings reported in Figure 11, probability of recall varied as a function of set size and attention. Targets with small set size were more likely to be recalled (.37) compared to targets with large set size (.28), F(1,55)=21.67, MSe=.01. Participants recalled more words correctly under full attention condition (.48) compared to divided attention condition (.17), F(1,55)=79.54, MSe=.03. Finally, the set size by attention interaction was not reliable, F(1,55)=3.02, p =.07. An LSD of .06 indicated that set size effects were present in both divided and full attention conditions. This finding replicates previous findings that found no effect of attention on the magnitude of set size effects (Nelson, Bennett, & Xu, 1997).

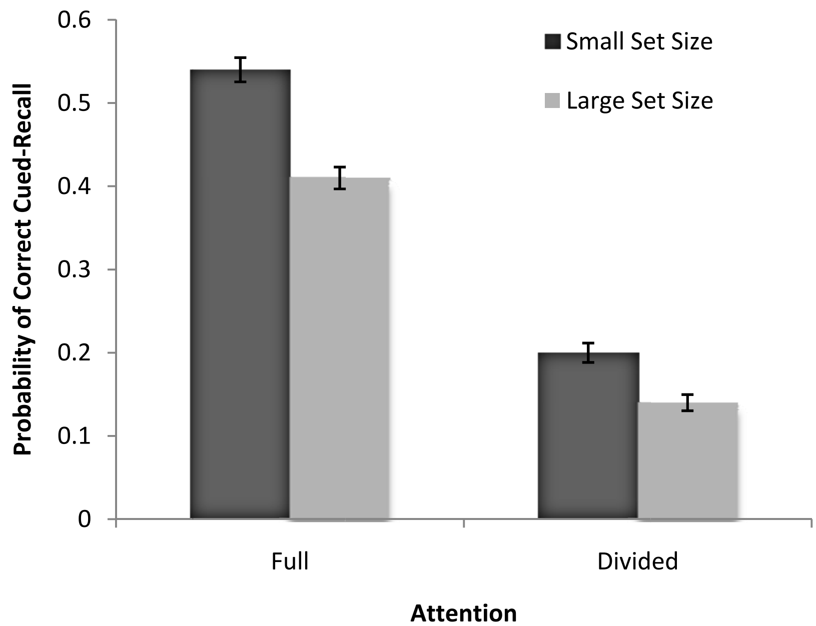


Figure 11. Probability of Correct Recall as a Function of Attention and Set Size in the Present Study

The present study's results indicated that connectivity and set size effects can be obtained in spite of dividing attention to a different task, i.e., counting numbers backwards by threes. In general, results from the attention manipulations in Experiment 1 and Experiment 2 showed that recall was better when targets had small set size and high connectivity compared to targets with large set size and low connectivity, respectively. Also, participants recalled significantly fewer words under divided attention conditions. One of the main findings was that neither set size nor connectivity interacted with attention manipulations. Set size and connectivity effects were reliably present under both divided and full attention conditions. There were trends for implicit effects to be smaller under divided attention instructions, but such reductions were probably due to floor effects under divided attention instructions. Overall, the results suggest that attention did not influence the magnitude of set size and connectivity effects, but it reduced the overall probability of correct cued-recall. Set size and connectivity effects seem to be independent of attention manipulations during encoding. Attention manipulations, however, influenced overall probability of correct cued-recall. In line with the initial expectations, participants recalled fewer words under divided attention compared to full attention instructions.

Chapter Five: General Discussion

The results of Experiment 1 and Experiment 2 indicate that probability of cued recall decreases as a function of retention interval. What is theoretically more interesting is that this decrease in recall was influenced by memory span, with high span participants having better recall for the to-be-remembered targets during longer retention intervals than low span individuals. The findings of both experiments and also the pooled data analyses reveal that memory span aids target recovery during the delays before the cued recall memory test. More specifically, participants with higher span scores (both OSPAN and CSPAN) had better cued recall memory than participants with lower span scores. Surprisingly, the recall advantage for high spans tended to be reversed on an immediate cued recall test. In addition, and in line with previous literature, recall was higher for targets with many connections and targets with fewer competitors. However, these implicit effects were unaffected by memory span. Thus, the magnitude of connectivity and set size effects were comparable for high and low span individuals. Finally, the connectivity and set size effects were present under divided and undivided encoding conditions.

These findings show that memory span has differential effects on cued-recall memory depending on the length of the retention interval. The high span advantage that has been documented in many studies was only apparent after a delay before the memory test. During the immediate memory test, high span superiority was either lost or reversed. Low spans displayed a tendency to perform better in the immediate test condition. In addition, the influence of memory span was evident only on overall probability of cued recall after a delay, suggesting that the influence was limited to explicit memory processing. Processing of implicitly activated knowledge, as measured by connectivity and set size effects, was not influenced by span differences. Furthermore, the present study revealed that connectivity and set size effects did not depend on the degree of attentional processing during encoding. Thus, such effects seem to be implicit and outside of the participant's awareness. However, cued recall performance declined when attention was divided between the memory encoding task and a secondary task in line with the previous literature (Hasher et al, 1999). Taken together these findings indicate that memory span is related to explicit – intentional types of processing, and individual differences in memory span do not affect automatic effects (i.e., processing implicitly activated information in long term memory).

Theoretical Implications

The high span advantage appearing only on a delayed test is consistent with the working memory literature on susceptibility to interference. According to previous findings, individual differences in working memory should be present only under circumstances where there is distraction or interference (Barrett et al, 2004, Engle & Kane, 2003). During the interfering task, participants need to hold memory representations in an active state in order to access or retrieve them later during the test (Baddeley & Hitch, 1974). According to the attention interpretation, working memory capacity regulates the maintenance of these representations during distractions (Engle & Kane, 2002). The results of Experiment 1 confirm this interpretation by showing that the span advantage is present only after longer retention intervals. During the retention interval, participants are engaged in an unrelated math task which creates interference for the memory of the study list. High spans seem to be more likely to switch or maintain attention to the encoding context during the retention interval. In other words, they may be overtly or covertly thinking back about the episode in which they studied the target words. Evidence suggests that when such processing is discouraged by study instructions promoting mental context change between study and test, the span advantage is reversed (Delanay & Sahakyan, 2007). Thus, high spans' memory representations may be more sensitive to remembering context information regarding the learning episode. In contrast, low spans' memory for the list of words declines rapidly during the retention intervals, maybe because low spans are less likely to think about the study episode during the retention interval. For this reason, low spans' memory representations are more prone to task disruptions.

Such decreases in memory representations can be attributed to disruptions due to changes in context. According to Lehman and Malmberg (in press) forgetting is correlated with the amount of context change. According to their context differentiation hypothesis, as study and test episodes become separated in time, the amount of mismatching contextual features increases proportionally. Such mismatches are one of the main reasons for the observed forgetting over time. The present study's results are consistent with such a view in that forgetting is attributed to changes in context information via delays before the memory test. Probability of correct recall declined in Experiment 1 and Experiment 2 as a function of retention interval. Importantly, the main contribution of the present study to the literature is that loss of context information during various delays is moderated by working memory capacity. Participants with higher working memory capacity are better able to cope with the noise generated by the interfering task compared to those with lower working memory capacity. Such advantage is likely due to high spans' efficiency in maintaining context information during the interference period. Such efficiency may be due to greater attentional control which enables high spans to switch back and forth between the study context and the interpolated processing task (i.e., solving math problems) with minimal costs compared to low spans who may have maximum costs for doing the same attention switch. Thus, the present study is one of the first studies that show effects of context loss are attenuated by high working memory capacity.

However, better maintenance of context information also implies that the high span advantage should also be apparent in the immediate cued recall test. Present findings suggest that such an interpretation is not sufficient to explain the results obtained in the immediate test. The efficiency of context maintenance by high spans can only explain why the span advantage appears during the delayed tests but it fails to account for why low spans tend to perform better in the immediate test. Due to the nature of the cross over interaction, these differences in recall between high and low spans should depend on a process separate from the loss of context interpretation.

One candidate explanation is the differential strategy selection between high and low spans. The effects of strategic processing such as grouping (Hitch, Burgess, Towse, & Culpin, 1996) and covert rehearsal (Baddeley, 2001; McCabe, 2008) have been shown to influence working memory span with high spans being more likely to employ these sorts of processing strategies during the working memory tasks. Similarly, Turley-Ames and Whitfield (2003) showed that low spans benefit from explicit instructions of efficient strategy use. In their study, low spans increased their working memory scores after they were taught to use a rehearsal strategy (Turley-Ames & Whitfield, 2003) compared to no rehearsal training. Thus previous research underscores the importance of efficiency and type of rehearsal strategies as a major determinant of individual differences in memory span. Span advantage is most likely to derive from knowledge of rehearsal strategies and also self initiation of these efficient methods to remember information.

It is plausible that high spans are more likely to use these rehearsal strategies not only in working memory tasks but also in similar cognitively demanding tasks, namely cued recall. Strategy selection can play a role during different phases of information processing such as encoding, maintenance of information or retrieval. The present study only manipulated the conditions surrounding the maintenance of information by introducing various retention intervals before the memory test. High span superiority is likely to be due to more efficient rehearsal during this delay period. The present findings suggest that high spans are likely to use efficient rehearsal strategies in cued-recall as indicated by their superior memory performance in the delayed test. In the same line, high spans may know more efficient strategies to deal with disruptions and thus they may employ them more often during this maintenance period. In general, this interpretation assumes that high spans are more likely to initiate elaborative rehearsal than low spans. In addition, a supplementary analysis on the number of math problems solved in the interfering task in the present data indicated that high and low spans attempted to solve about equal number of math problems during the retention intervals ($M=28.92$, $SD=7.27$ for high spans and $M=27.46$, $SD=9.73$ for low spans). Because the number of problems solved among high and low spans is about the same, it can be assumed that both high and low spans devoted equivalent amount of time to rehearsing target words in the list. Thus, maybe the quality of the rehearsal not the quantity is driving high span superiority in the delayed cued recall tests. High spans may be more likely to engage in elaborative rehearsal but low spans may just be engaging in maintenance rehearsal during the cued recall task.

Strategy selection can also occur during encoding. High spans may be more likely to bind the item information with the context information and thus they have better cued recall memory than low spans. However this view cannot explain why low spans tended to outperform high spans in the immediate test. If high spans have better encoding strategies, then they are expected to do better in the immediate cued recall test as well. However, the results of the present study revealed that low spans tended to do better in the immediate cued recall test. Thus, an explanation based on the differences of encoding strategies is insufficient to account for the present findings.

Alternatively, participants may have different retrieval strategies. For example, high and low spans were found to use different response strategies for semantic questions (Barrett et al., 2004). Low spans were found to respond faster to questions about syntactically ambiguous meanings, thus, relying more on automatic responses to sentences. In contrast, high spans were believed to be maintaining different meanings of the sentences in mind which resulted in slower reaction times (MacDonald, Just, & Carpenter, 1992). Existence of such differences in strategic recall is also plausible for the cued recall task. Because of the nature of the cued-recall task, participants can rely on automatic influences of word knowledge when the test is immediate but can switch to a more explicit strategy when the test is delayed because effects of implicit activation are reduced. Hence, there can be individual differences in the choice of a retrieval strategy in the cued recall task. Low span participants are more likely to rely on automatic influences of words (Rosen & Engle, 1997). They may base their responses more on priming in long term memory. In contrast, high spans may be more likely to employ explicit retrieval strategies and rely less on priming effects. Since priming effects are highest on the immediate test, low spans cued recall memory is likely to be better than high spans. In contrast, because high spans rely more on explicit processes, they are more likely to evaluate their responses longer than low spans. Thus, choosing an intentional retrieval strategy seems to impair cued recall in the immediate test. More empirical work is needed in order to evaluate the validity of this interpretation.

Overall the results of the present study may suggest that working memory is related to strategy selection during retention or during the retrieval of information. Present findings are consistent with the interpretation that the choice of explicit retrieval strategies can impair immediate cued recall performance and the choice of efficient rehearsal strategies during the maintenance of information can facilitate delayed cued recall performance. Thus, individual differences in memory span may be due to the differences in rehearsal and maintenance strategies employed by high and low spans. More work is needed in order to determine the antecedents of high span superiority in these cognitive tasks. Future studies can examine the role of strategic processing by evaluating the encoding, retention and retrieval conditions individually. In order to determine the effects of encoding conditions, levels of processing can be manipulated for the studied items. An interfering task which blocks or minimizes the amount of rehearsal for the target items is likely to evaluate the role of rehearsal during the retention period. Also, participants may be explicitly instructed to rehearse the target items during the delay. Finally, participants' reaction times can be measured for the criterion test in order to determine whether they are responding fast - under the influence of implicit processing or they are responding slowly - due to more uses of explicit retrieval strategies.

Working Memory and Implicitly Activated Knowledge

The present study found no relationship between working memory and the magnitude of connectivity and set size effects. The magnitude of these effects is not influenced by dividing attention during encoding. The results showed that connectivity effects are uninfluenced by attentional considerations. Previously, set size was shown to be independent of attentional manipulations involving different types of encoding operations (Nelson et al, 1997) and the present study adds to the literature by showing that both set size and connectivity effects are implicit and automatic. Moreover, high spans and low spans show equivalent amounts of implicit effects. Such results are in line with the attentional view of working memory capacity. Because the predictive power of working memory is assumed to be driven by executive attention and attention control, working memory should not be a predictor for the effects that do not depend on attentional processes. The present findings gave support to this view by showing that WMC is related to overall memory scores after retention intervals, however WMC is not a reliable predictor of connectivity and set size effects. Working memory seems to be related to explicit and intentional uses of attention and it is not related to the automatically processed information.

The findings also suggest that even though working memory is a predictor in many interference tasks, it s not a reliable predictor when the interference is generated implicitly. Set size effects depend on target competitors. These competitors are activated outside of the awareness of participants and effectively drive cued-recall down by producing noise (Nelson & McEvoy, 2005). However, the findings of Experiment 1 and Experiment 2 indicated that WMC was not related to either set size or connectivity effects. Thus, these effects are present in the same magnitude in spite of working memory capacity differences. Theories of working memory need to take into account that WMC is related only to explicitly generated interference and not to implicitly generated interference.

Limitations

Even though the results were in the same direction in general, there were differences in the results of Experiment 1 and Experiment 2 results. Particularly, Experiment 1 showed memory span differences in the long delay. In contrast, Experiment 2 showed a trend for such differences in the short delay. These differences are likely to derive from the small sample size used in Experiment 2. In order to increase statistical power, more participants are needed. Nevertheless, the results of the pooled data (Experiment 1 and Experiment 2 combined) analyses were clear by reliably showing that working memory capacity is related to cued-recall performance over different retention intervals.

Difference scores were used in the regression analyses for connectivity and set size effects. The use of difference scores is likely to shrink the range of the scores and thus affecting the correlation values. Nevertheless, the regression analyses using difference scores were also in the same direction as the results of the ANOVA analyses in showing that memory span is not related to implicit effects. Thus, the absence of memory span by implicitly activated knowledge interactions is unlikely to be due to an artifact of the use of difference scores. However, in a future study, set size and connectivity effects can be manipulated at larger magnitudes. In the present study, they were about 10% range and this magnitude may not be enough to detect the possible differences associated with memory span.

Conclusion

The purpose of the present study was to evaluate how working memory differences affect cued recall performance in the face of interference. It was found that WMC has a complex relationship with cued recall. Specifically, recovering target information after short and long delays benefits from having a higher memory span. In contrast, in the immediate memory test the high span advantage is lost and surprisingly showed a tendency to be reversed. This interaction was explained by individual differences in the maintenance of context information and in the selection of rehearsal and retrieval strategies. Implicitly activated information as measured by connectivity and set size effects do not seem to interact with memory span. Overall the findings of the present study suggest that working memory capacity is related to explicit – intentional uses of executive attention. In contrast, WMC does not seem to be related to implicit – automatic processes.

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Appendices

Appendix A: Experiment 1 Word Lists

List 1

TEST CUES	**TARGETS**[1]
BIBLE	RELIGION
DEAF	HEAR
EXPENSE	COST
HUGE	LARGE
JURY	TRIAL
MOOD	FEELING
NEVER	AGAIN
PURPLE	COLOR
REGULAR	NORMAL
SISTER	MOTHER
STAR	SUN
VARY	DIFFERENT
BENCH	TABLE
BOUNDARY	LINE
CORRECT	RIGHT
CURIOSITY	INTEREST
FALL	DOWN
HIDE	FIND
HOUR	TIME
HUNGRY	FULL
INDIVIDUAL	SINGLE
REAR	FRONT
WISE	OLD
SLAVE	LABOR

List 2

TEST CUES	**TARGETS**
BORROW	TAKE
BRAT	CHILD
BIBLE	RELIGION
CAB	CAR
DECIDE	THINK
EDUCATION	COLLEGE
SALARY	PAY
TELEVISION	RADIO
TONE	VOICE
TREASURE	ISLAND
WEATHER	TEMPERATURE
UNUSUAL	NORMAL
BLONDE	HAIR
BOMB	NUCLEAR
CALCULATOR	NUMBERS
CORE	CENTER
DESK	TABLE
EDITOR	CHIEF
INDIVIDUAL	SINGLE
JUSTICE	PEACE
MORNING	EARLY
PEST	CONTROL
WORKER	LABOR
YEAR	TIME

[1] The first 12 targets have *high* and the last 12 targets *low* connectivity

Appendix B: Experiment 2 Word Lists

List 1		**List 2**	
TARGETS[2]	**TEST CUES**	**TARGETS**	**TEST CUES**
LAST	FINAL	HAMMER	WRENCH
INSECT	MOSQUITO	LAUNDRY	DETERGENT
DECAY	DECOMPOSE	CANOE	RIVER
YOUTH	ADOLESCENT	DICTIONARY	ALMANAC
MINUTE	MOMENT	GEM	RUBY
SIGHT	VIEW	ISOLATED	SECLUDED
GLUE	STICKER	ORCHESTRA	CELLO
INTELLGENT	WISDOM	AFFECTION	HUG
SAND	ISLAND	STOP	HESITATE
CORRECT	ERROR	AIRPORT	BAGGAGE
PEPPER	SPICE	MOM	PARENTS
JOG	EXERCISE	RICH	FORTUNE
AWAY	DISTANT	DECORATION	ORNAMENT
APARTMENT	BALCONY	COLD	FEVER
BRAIN	NERVE	ARCHITECT	BLUEPRINT
ORIGINAL	UNIQUE	GLASS	PANE
COAT	VEST	INSURANCE	AGENCY
WIRE	CABLE	METER	MEASUREMENT
MONSTER	BEAST	HALL	LOBBY
STRING	KNOT	WRITE	NOTEBOOK
STEAK	GRILL	CASTLE	DUNGEON
INNOCENT	VICTIM	METAL	SCRAP
DUCK	QUAIL	SCULPTURE	CLAY
AWKWARD	CLUMSY	EXPERT	NOVICE

[2] The first 12 targets have *small* and the last 12 targets *large* set size

About the Author

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