Unexpected costs of high working memory capacity following directed forgetting and contextual change manipulations

By: PETER F. DELANEY AND LILI SAHAKYAN

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Abstract:

Greater working memory capacity is usually associated with greater ability to maintain information in the face of interruptions. In two experiments, we found that some types of interruptions actually lead to greater forgetting among high-span people than among low-span people. Specifically, an instruction designed to change mental context resulted in significant forgetting for high-span people but minimal forgetting among the low-span people. Intentional forgetting instructions also resulted in greater forgetting among higher working memory capacity participants than among lower working memory capacity participants. A candidate explanation called the intensified context shift hypothesis is proposed which suggests that high-span people are more context dependent than low-span people.

Article:

In most tasks, the most relevant information should be kept active during processing while irrelevant information may be ignored or forgotten. The mechanisms that meet the need for active, selective storage during processing are referred to as working memory (WM) while *working memory capacity* (WMC) refers to quantitative measures of the ability to maintain relevant information while performing unrelated tasks. One of the prominent views of working memory is that WMC reflects control of attention by applying activation or suppression to memory representations (Engle, Tuholski, Laughlin, & Conway, 1999).

Memory representations are likely to contain information not only about studied items, but also about the context in which they were acquired. Context may be conceptualized as information that is not directly relevant to accomplishing the task, but that is nonetheless present during processing. Physical environment, internal states, and extra-task thoughts are part of contextual information that accompanies item processing. Some of these contextual cues are continuously present during study, such as the physical environment, whereas others are transitory and change throughout the task, such as the mood or extra-task thoughts. It is widely established that when the test context and the learning context mismatch, forgetting is observed (for a review, see Smith & Vela, 2001).

Context is becoming an important construct in memory research and is part of many formal memory models. For example, Mensink and Raaijmakers (1988) have shown that contextual fluctuation over time can account for a variety of interference effects (and many other memory phenomena). Interestingly, research exploring interference phenomena from an individual differences perspective shows that WMC mediates susceptibility to interference. For example, high-span people are better than low-span people at resisting proactive interference (Kane & Engle, 2000), show less output interference when retrieving category exemplars (Rosen & Engle, 1997), and show smaller fan effects (Bunting, Conway, & Heitz, 2004; Cantor & Engle, 1993; Conway & Engle, 1994). Typically, ability to resist interference among high-span people is attributed to better attentional control applied to memory representations. If memory representations contain contextual information, and fluctuations of context can account for interference effects, then it is possible a relationship exists between WMC and control of context.

Given the theorized links between WMC, context, and interference, we sought to explore the relationship between the amount of forgetting following context change and WMC. The specific task we used to manipulate context was invented by Sahakyan and Kelley (2002) to help test their context-based account of list-method directed forgetting (invented by Bjork, LaBerge, & LeGrand,1968). Typical list-method studies involve presenting participants a list of study items (List 1), following which half of the participants are told to keep remembering the items for a later memory test, while the other half are told to forget those items (e.g., "that list was just for practice"). Then another list (List 2) is then studied, and participants receive a final free recall test on both lists. People show reduced access to List 1 items following a forget instruction than following a remember instruction – a phenomenon known as the "costs" of directed forgetting. Sahakyan and Kelley (2002) collected retrospective reports that indicated that the forget instruction led some participants to focus their thoughts on something other than the study material (by thinking of something else). Participants often reported thinking of past or future events, such as their upcoming wedding or the chores they had planned to do. Sahakyan and Kelley (2002) proposed that engaging in diversionary thoughts allowed participants to sample new contextual elements, which are in place when the second list is encoded. At the time of the final test (which follows the study of List 2), the available contextual cues match List 2 better than List 1. The mismatch between the study and test contexts in the forget group produces impaired List 1 recall.

To test the context based explanation of directed forgetting, they employed a context-change manipulation aimed at changing mental context after the study of List 1. They told the participants after List 1 to keep remembering it for a later test but also to think back to their childhood home, mentally visualize it and describe it for 45 sec. The context-change instruction was hypothesized to produce a directed-forgetting-like effect, namely a reduction of List 1 memory. Consistent with the predictions, they obtained forgetting of List 1 items following both context-change and forget instructions, which did not differ from each other. Importantly, when Sahakyan and Kelley (2002) mentally reinstated the original learning context at the time of the final test, they observed significant reduction of forgetting in the forget group as well as the context change group, lending support for the involvement of context in both directed forgetting and the context-change task. The effects of context-change instructions have been replicated in Sahakyan and Delaney (2003) even when encoding strategy was controlled.

The present studies approached the directed forgetting and context change tasks from an individual differences perspective. Normally, when told to keep remembering information during the processing of an irrelevant task, we should expect people with high working memory spans to remember more information than low-span people. In fact, this is the basis of the span tasks often used to measure WMC (e.g., Daneman & Carpenter, 1980; Engle et al., 1999). Furthermore, one would generally expect that if high-span people tried to forget things, they should be better at it than low-span people. There is some limited support for this claim, as Brewin and Beaton (2002) showed that high-span people are better than low-span people at avoiding thinking about topics that they are instructed to suppress. Thus there are good reasons to expect that high- span people may respond differently to a context change instruction (when they are supposed to keep remembering) or to a forget instruction (where they are supposed to forget) compared to low-span people. That is, we predict that high-span people will be more resistant to context change and therefore will have *better* List 1 recall than low-span people following context change tasks. Also, we predict greater directed forgetting effect in high-span people (and therefore, *worse* List 1 recall) compared to low-span people.

However, these predictions would contradict the context change account of directed forgetting because they imply that the two types of instructions (forget and con text change) behave differently. On the other hand, if the effects of the forget instruction and the context change instruction rely on similar mechanisms as Sahakyan and Kelley suggested, then we should predict similar effects of the two types of instruction on List 1 memory. Therefore, the effects of the directed forgetting and context change instructions on List 1 memory should be similar – either high-span people should show *better* memory for List 1 following either instruction, or they should show *worse* memory for List 1 following either instruction (compared to low-span people).

EXPERIMENT 1

In this study, we explored the direction and degree of correlation between WMC and free recall following directed forgetting and context change instructions (compared to a remember control instruction). The standard list-method directed forgetting paradigm was employed in which people studied two lists and received the instruction (remember, forget, or context-change) between the lists. No special instructions were provided to participants as to how lists should be learned. At the end, memory for both lists was tested using a free recall test.

Method

Participants. Participants were I32 introductory psychology students tested individually.

Materials. Two lists of I5 medium-frequency words were drawn from the Francis and Kucera (I982) norms. Each list appeared equally often as the first or second study list.

Procedure. Participants were presented with the first list of I5 words at 5 sec/word, and were instructed to learn and memorize them for a later memory test. After the study of List I, one-third of the participants were told that the list they had studied was only for practice, that there was no need to remember it, and to try to forget the words (the *forget* condition). One-third of the participants were told that the list they had studied included only the first half of the items, and that they should remember them for a later memory test (the *remember* condition). The remaining participants received the remember instructions, but additionally engaged in one of Sahakyan and Kelley's (2002) mental context-change tasks (the *context-change* condition). The context-change task lasted 45 sec and involved imagining walking through their parents' house and describing it to the experimenter, including details about furniture and its location. To equate the amount of time between the two study lists, participants in the forget and remember conditions performed speeded reading for 45 sec. They were instructed to ignore the content of the passage and the punctuation marks and read aloud as fast as possible as we were measuring their reading speed. Actually, the purpose was to preclude rehearsal in the remember control group without dramatically changing mental context. Prior pilot work with this task showed that it produced less forgetting than the forget or the context change instructions.

Everyone then studied List 2, which was always followed by the remember instruction. Final recall was preceded by a 90 sec retention interval filled with arithmetic problems. Recall was carried out on separate sheets of paper, starting with List I followed by List 2, with 60 sec allotted for recall of each list.

Finally, participants completed the standard operation span (OSPAN) task measuring WMC (e.g., Kane, Bleckley, Conway, & Engle, 200I; Turner & Engle, I989). OSPAN involved verifying arithmetic equations while trying to remember words. Each trial consisted of several paired equations and words (e.g., IS (9/3) + 2 = 5 ? DRILL), presented one at a time. Participants read the equations aloud, verified them, and read the to-be-memorized word. They were not allowed to pause or rehearse. After the trial ended, they wrote down the words in the order of presentation. The OSPAN score was calculated by summing the number of words on correct trials. A trial was correct if *all* the presented words from that trial were recalled in the right order.

Three trials of each length (from two to five equation/word pairs) were presented. Participants were unaware in advance of the number of words on a given trial. The possible range of scores was from 0 to 42.

Results and Discussion

Participants' OSPAN scores ranged from 4 to 32, with a mean of 13.30 (SD = 6.60), with low skew (0.68) and kurtosis (0.25). The OSPAN scores deviated significantly from normality, Shapiro–Wilk's $W(132) = .960, p < .01$. However, converting the OSPAN scores to z scores did not affect the pattern of the results, so for simplicity we have used the untransformed values.

Global analysis of costs. Proportion List 1 recall was analyzed by instruction (remember, forget, or context-change) using a one-way ANOVA to verify that the contextual change manipulation was effective, replicating Sahakyan and Kelley's (2002) findings. The effect of instruction was significant [$F(2,129) = 17.48$, $MS_e = .027$,

$p < .001$]. Tukey's HSD post hoc tests showed that the remember group recalled a larger proportion of words from List 1 ($M = .4 1$, $SD = .15$) than the forget ($M = .2 1$, $SD = .20$) or context-change ($M = .27$, $SD = .14$) groups, which did not differ.

Individual differences analyses. We employed regression to examine the proportion of List 1 recall variance captured by instruction, WMC, and the Instruction X WMC interaction. Instruction was represented as two contrast-coded variables that reflected orthogonal contrasts. Following the procedure recommended by Jaccard and Turrisi (2003), we first simultaneously entered the main effects and then determined if the interaction term explained significant additional variance. The total model was significant [$F(5,126) = 10.52, p <.001$], explaining 29% of the variance. We detected a significant instruction X WMC interaction [$F(2,121) = 6.55$, $p < .005$, $\Delta R^2 = .07$]. Thus, the effect of instruction was moderated by WMC.

We next fit separate regression lines to the proportion of List 1 recall for each instruction. Figure 2 shows the best-fitting regression lines for each condition and Table 1 gives relevant statistics and regression coefficients. In all three conditions, WMC accounted for significant variance. In the remember condition, higher working memory capacity was associated with higher recall. However, in the context-change and forget conditions, participants with higher WMC recalled *fewer* List 1 words than participants with lower WMC. Context change instructions hurt high-span people more than low-span people, reversing the usual positive relationship between WMC and retention.

Finally, Table 2 shows the mean List 1 recall for each instruction for the top and bottom third of participants based on their OSPAN scores. The mean OSPAN scores were 20.8 ($SD = 4.96$) for the high-span group and 6.7 ($SD = 2.62$) for the low-span group.

Analyses of benefits. Our primary interest in the present study was in List 1 memory. However, both forget instructions and context-change instructions often lead to better List 2 memory than remember instructions (known as the "benefits"). We have argued elsewhere that directed forgetting benefits emerge because participants in the forget condition (and disrupted context condition) adopt more efficient study strategies when they encode List 2 compared to List 1. The choice of better study strategy is often driven by self-evaluation of the efficiency of current encoding (e.g., Sahakyan & Delaney, 2003, 2005; Sahakyan, Delaney, & Kelley, 2004). Because both the forget instruction and the mental context change instruction disrupt ongoing rehearsal, participants in these conditions may be more inclined to reflect on their performance and change strategies. The remember group participants, on the other hand, may be less willing to disrupt ongoing rehearsal and are therefore less likely to change study strategy between the two lists. However, when participants in a remember group give a quick judgment about how many words they will recall on the test, they improve memory for List 2 to the level of the forget group participants (Sahakyan et al., 2004).

In the present study, the speeded reading task inserted after List 1 study also interrupted rehearsal in the control

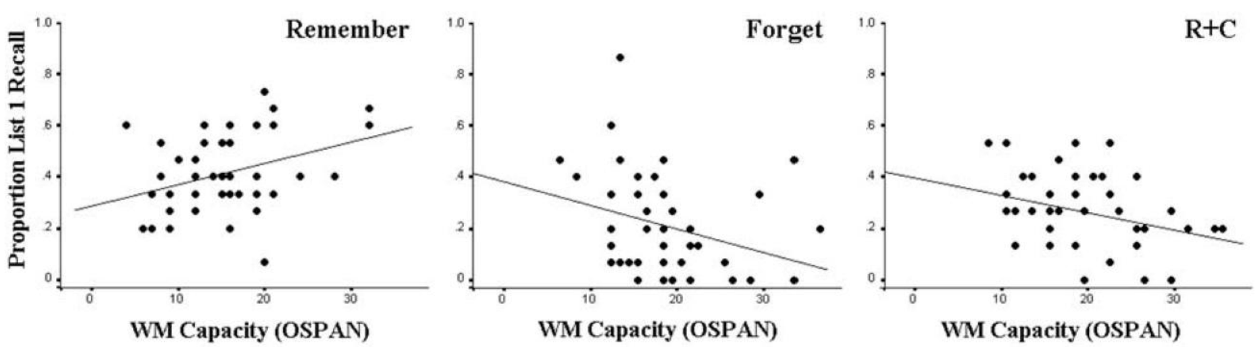

Figure 1. Proportion of List 1 words recalled as a function of working memory capacity (operation span) and instruction (forget, remember, or context change), Experiment 1. Lines show best-fitting linear regressions.

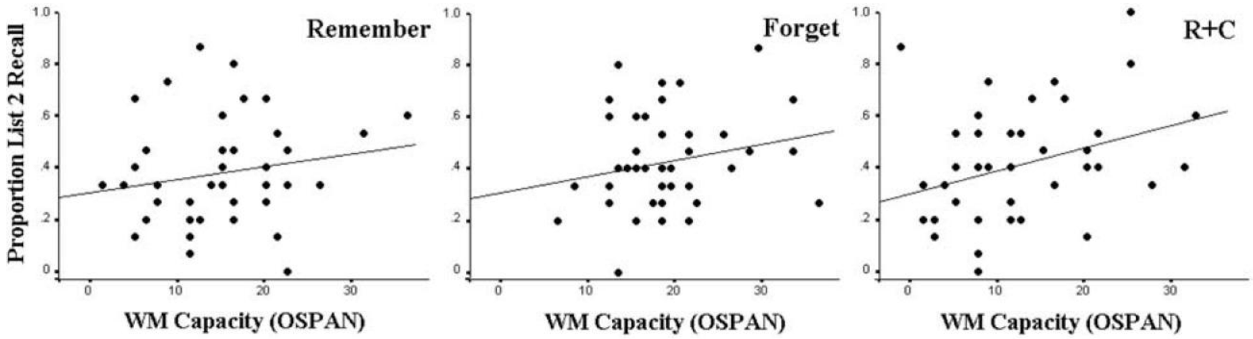

Figure 2. Proportion of List 2 words recalled as a function of working memory capacity (operation span) and instruction (forget, remember, or context change), Experiment 1. Lines show best-fitting linear regressions.

remember group, and therefore we did not expect strategy change rates to differ across conditions. A one-way ANOVA on List 2 recall found no significant effects of instruction ($F < 1$). The mean List 2 recall was .38 (SD = .20) for the remember condition, .40 (SD = .22) for the context-change condition, and .42 (SD = .19) for the forget condition.

We also used regression analysis to examine the proportion of variance in List 2 recall as a function of instruction, working memory, and the Instruction X WMC interaction. Figure 3 shows best-fitting regression lines for each instruction and the relevant statistics and regression coefficients are displayed in Table 1, and Table 2 shows the List 2 recall rates for the top and bottom third of CSPAN scorers for each instruction. The total model approached significance [$F(5,126) = 2.11$, $p = .07$]. Only WMC was a significant predictor of recall [$F(1,126) = 8.44$, $p < .005$], capturing 6% of the variance. The best-fitting line was $p(R) = .31 + (.008 * \text{WMC})$, indicating that higher- span people tended to recall more List 2 words than lower- span people did. Neither instruction nor the instruction X WMC interaction were significant (both Fs < 1). Taken together, the results suggest that higher-span people recalled more List 2 items regardless of instruction.

Conclusions. Participants were told to keep remembering a studied list in two conditions and to forget a studied list in another condition. In the context-change condition, participants' attention was diverted from the main task of memorizing words with another meaningful activity (thinking of their parents' house). The context change manipulation resulted in worse recall of List 1 items for high-span people than for low-span people. In contrast, high-span participants in the control remember condition (that did not undergo dramatic changes in mental context) recalled more List 1 items than low-span participants. Finally, the directed forgetting manipulation behaved like the context change instruction in that high-span people showed poorer List 1 recall following directed forgetting instructions compared to low-span people.

Table 1
Statistics and Regression Coefficients for Each Instruction Condition: Proportion of Words Recalled Regressed on OSPAN Score, Experiment 1

	df	*F*	R^2	Slope (*B*)	Intercept
List 1					
Remember	42	5.84*	.12	.01	.29
Context change	42	5.02*	.11	−.01	.35
Forget	42	4.17*	.09	−.01	.32
List 2					
Remember	42	1.70	.04	.01	.29
Context change	42	5.27*	.11	.01	.27
Forget	42	2.05	.05	.01	.35

Note—All F tests have 1 as the df numerator and the number in column 2 as the df denominator. *$p < .05$.

EXPERIMENT 2

The results of Experiment 1 were sufficiently surprising that we felt a need to replicate the greater forgetting among high-span people than among low-span people following a context-change task.

One motivation was to explore whether the WMC and forgetting interaction observed in Experiment 1 could be specific to OSPAN or whether it generalized to other WMC measures. Because OSPAN and list learning both involve word learning, similar encoding strategies might apply to both tasks. People select different encoding strategies to learn lists of words and often change to more effective encoding strategies when they study multiple lists (Delaney & Knowles, 2005; Sahakyan & Delaney, 2003). Because we conducted our working memory task (OSPAN) after the word memory task, and because OSPAN also involved word learning, perhaps those who selected better encoding strategies during learning also did better on OSPAN because they used the same better encoding strategies in OSPAN. If so, then the measure of span would have been contaminated.To address this possibility, we used a different span task called the counting span (CSPAN) that has been previously used by Engle et al. (1999). CSPAN does not involve word memory and therefore we would not expect strategy transfer between the list learning and CSPAN tasks. However, there is ample evidence that OSPAN and CSPAN are highly correlated and that they reflect WMC (Engle et al., 1999).

Alternatively, even if participants did not transfer strategies between the OSPAN and list-learning tasks, perhaps high-span people generally tend to select different encod-

Table 2
Proportion of Words From Each List Recalled, by Span Group and Instruction, Experiment 1

	Remember		Forget		Context Change	
	M	*SD*	*M*	*SD*	*M*	*SD*
List 1						
High-span group	.54	.17	.36	.18	.36	.27
Low-span group	.50	.15	.47	.18	.50	.17
List 2						
High-span group	.39	.19	.47	.19	.51	.23
Low-span group	.34	.18	.39	.21	.31	.20

ing strategies than low-span people. If so, then the greater vulnerability of higher-span people to context changes could be because the particular encoding strategies they selected were more vulnerable to context change than the encoding strategies selected by lower-span people. To address this concern, we controlled encoding strategy in Experiment 2. Following Sahakyan and Delaney (2003), participants studied each list by creating a story using all of the words on the list.

Method

Participants. Participants were I08 undergraduates who were tested individually.

Materials. The Experiment I materials were used.

Procedure. The procedure followed Experiment I, except we included an encoding strategy instruction and changed the task used to measure WMC. Participants were instructed to create a story using all of the items on each list, creating the story aloud to ensure compliance. Two participants who failed to follow instructions were replaced.

WMC was assessed using the counting span (CSPAN) task, which is analogous to OSPAN except that instead of equation/word pairs, there are randomly arranged screens of dark blue circles, dark blue squares, and light blue circles. Participants counted the number of dark blue circles aloud and memorize the final total for each screen. After each trial, they recalled the totals in order. The CSPAN score was the sum of the recalled totals for all correctly recalled sets. Three sets of each length (from two to six screens) were presented in an unpredictable order. The possible range of scores was from 0 to 60.

Results and Discussion

Scores on the CSPAN task ranged from 7 to 46, with a mean of 25.3 (*SD* = 8.62), with low skew (.03) and kurtosis (-0.53). The distribution of the CSPAN scores was approximately normally distributed [Shapiro–Wilk's $W(109) = .988, p = .46$].

Global analyses of costs. A one-way ANOVA on proportion correct List 1 recall revealed instruction effects [$F(2,105) = 5.77$, $MS_e = .034$, $p < .005$]. Tukey's HSD post hoc tests revealed that the forget group (*M* = .41, *SD* = .18) and the context-change group (*M* = .42, *SD* = .21) both recalled significantly fewer items than the re- member group (*M* = .55, *SD* = .16). The forget and con- text-change groups did not reliably differ. These results closely replicated an earlier strategy control experiment from Sahakyan and Delaney (2003).

Individual differences analyses. We used regression analysis to examine the proportion of List 1 items recalled as a function of WMC, instruction, and their interaction. Instruction was represented as two orthogonal contrast- coded variables. As in Experiment 1, we first entered the two main effects and then tested whether the interaction term explained additional variance. The total model was significant [$F(5,102) = 5.3\ 1$, $p < .00\ 1$], accounting for 21% of the variance. A significant instruction X WMC interaction emerged [$F(2,102) = 3.9\ 1$, $p < .05$, $\Delta R^2 = .06$], indicating that the effect of instruction depended on WMC.

To follow up the interaction, we fit separate regression lines to the proportion of List 1 items recalled for each of the instructions (forget, remember, and context-change). Best-fitting regression lines are shown as Figure 3 and relevant statistics and regression coefficients are given in Table 3. Higher WMC was associated with greater forgetting following the context-change instruction and the intentional forgetting instruction. WMC was not a significant predictor of List 1 recall in the remember group.

Lastly, Table 4 gives the mean List 2 recall for each instruction for the top and bottom third of participants based on their CSPAN scores. The mean CSPAN scores were 34.9 (*SD* = 4.2) for the high-span group and 15.8 (*SD* = 4.2) for the low-span group.

Analyses of benefits. The "benefits" of forget and context-change instructions on List 2 recall are not found when encoding strategies are controlled (Sahakyan & Delaney, 2003). Therefore, we did not expect benefits. The proportion of List 2 items recalled in the forget (*M* = .65, *SD* = .14), context-change (*M* = .63, *SD* = .15), and remember (*M* = .61, *SD* = .14) groups did not differ ($F < 1$).

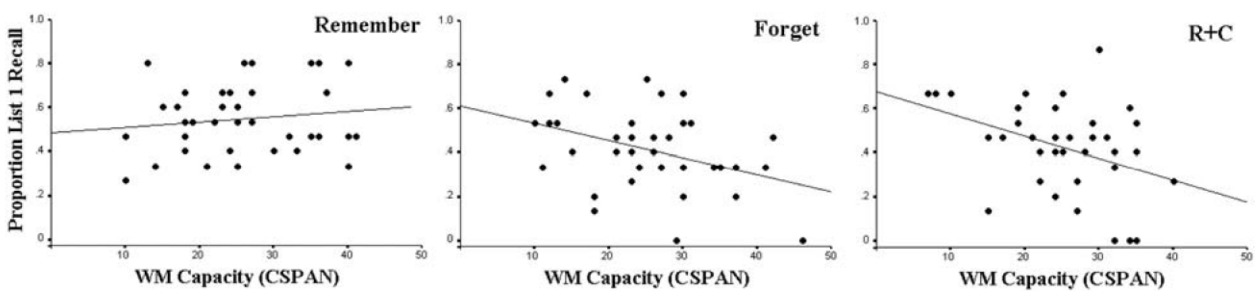

Figure 3. Proportion of List 1 words recalled as a function of working memory capacity (counting span) and instruction (forget, remember, or context change), Experiment 2. Lines show best-fitting linear regressions.

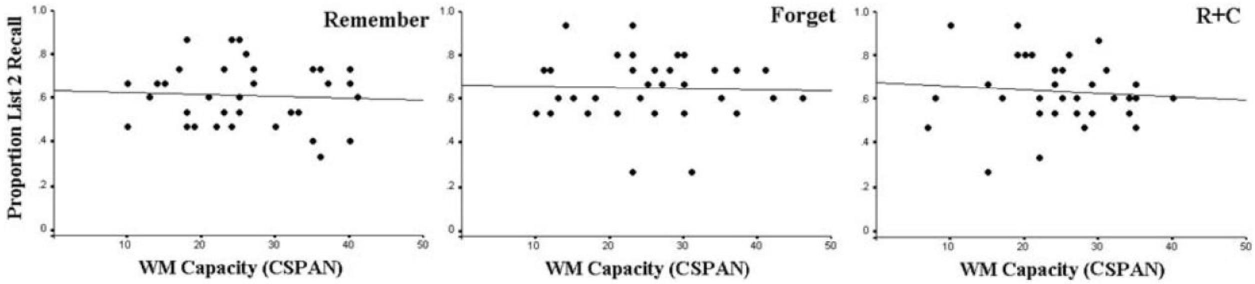

Figure 4. Proportion of List 2 words recalled as a function of working memory capacity (counting span) and instruction (forget, remember, or context change), Experiment 2. Lines show best-fitting linear regressions.

There was neither a significant relationship between WMC and List 2 recall nor an interaction effect (both *F*s < 1). Best-fitting regression lines are shown as Figure 4 and relevant statistics and regression coefficients are in Table 3. Table 4 gives the List 2 recall rates for the high-span and low-span group (based on CSPAN scores) for each cue. Neither List 1 memory in the remember condition nor List 2 memory in any condition were reliably predicted by WMC. Thus, controlling encoding strategy attenuated the positive relationship between working memory capacity and recall seen in Experiment 1. Perhaps WMC enhances free recall performance because high-span people select better study strategies than low- span people do.

Conclusions. We replicated the findings of Experiment 1 by finding that a context change manipulation resulted in greater forgetting among high-span people than among low-span people. We also found that high-span people were better able to intentionally forget items than low-span people following explicit instructions to forget.

The interaction between WMC and instruction (forget, remember, or context-change) remained despite controlling study strategy and replacing OSPAN with CSPAN as the measure of WMC. However, controlling encoding strategy *did* eliminate the advantage of having high WMC on recall in the control remember condition. Thus, encoding strategy differences might mediate the recall advantages of high-span people, but they do not explain the deficits of high-span people following the context-change task or an intentional forgetting instruction.

Table 3
Statistics and Regression Coefficients for Each Instruction Condition: Proportion of Words Recalled Regressed on CSPAN Score, Experiment 2

	df	*F*	R^2	Slope (*B*)	Intercept
List 1					
Remember	34	<1	.02	.00	.48
Context change	34	5.02*	.15	−.01	.68
Forget	34	4.17*	.15	−.01	.61
List 2					
Remember	34	<1	.00	.00	.63
Context change	34	<1	.00	.00	.68
Forget	34	<1	.01	.00	.66

Note—All *F* tests have 1 as the *df* numerator and the number in column 2 as the *df* denominator. * $p < .05$.

GENERAL DISCUSSION

In two experiments, we explored the relationship between WMC and the amount of forgetting following manipulations of context change and directed forgetting. Both experiments involved studying two lists and the instruction was delivered after the first list. In Experiment 1, participants were free to learn the items in any way they pleased. In Experiment 2, we controlled the encoding strategy across all participants. The remember group, which was not exposed to context change or directed forgetting manipulations, produced better List 1 memory among high-span people than among low-span people in Experiment 1, but the high-span advantage was eliminated when strategy was controlled in Experiment 2. In contrast, both the instruction to forget and the disruption of context manipulation produced greater forgetting among high-span people than among low-span people in both experiments. As the context-change group was instructed to keep remembering List 1 items before receiving context-change instructions, they would have no reason to intentionally inhibit List 1 items. These results suggest that high WMC may not always be advantageous when trying to resist forgetting during an interruption.

These findings are relevant both to directed forgetting and to the effects of disruptions as a function of working memory. We first discuss the relationship between WMC and directed forgetting, and then the relationship between WMC and context change.

Directed Forgetting and WMC

Our results indicated that directed forgetting effects were moderated by WMC, with the forgetting effect driven more by high-span people than low-span people, who were apparently unable to comply with a forget instruction. In both experiments, high-span people showed impaired List 1 memory, whereas low-span people did not. We also replicated Sahakyan and Kelley's (2002) finding that a context-change group mimicked the recall pattern of a group instructed to forget (see also Sahakyan & Delaney, 2003). Furthermore, the degree of memory impairment resulting from the context change was inversely related to WMC just like the relationship between the amount of forgetting initiated by directed forgetting instruction and WMC.

A negative relationship between WMC and directed forgetting is consistent with earlier findings. Macrae,

Table 4
Proportion of List 1 Words Recalled, by Span Group and Instruction, Experiment 2

	Remember		Forget		Context Change	
	M	*SD*	*M*	*SD*	*M*	*SD*
List 1						
High-span group	.46	.19	.11	.14	.21	.15
Low-span group	.34	.13	.34	.23	.31	.12
List 2						
High-span group	.57	.14	.62	.14	.62	.10
Low-span group	.60	.13	.64	.13	.64	.22

Bodenhausen, Milne and Ford (1997) and M. Conway, Harries, Noyes, Racsmány and Frankish (2000) found that dividing attention during study resulted in reduced directed forgetting costs. Dividing attention would reduce available WM resources and hence decrease context change. A recent fMRI study on directed forgetting found enhanced activation in the dorsolateral prefrontal cortex near Brodmann's area (BA) 9 in the forget condition as compared to the remember condition—a region often involved in WM tasks as well (Knox, 2002). Impaired attentional control might also explain why patients with frontal lesions show reduced directed forgetting (Conway & Fthenaki, 2003).

Sahakyan and Kelley (2002) originally designed their context-change task to test their context-change account of directed forgetting, according to which the context-change group should behave identically to the forget group. That is because the context-change account of directed forgetting proposes that people attempt to comply with a forget instruction by sampling new contextual elements (for example, by deliberately thinking of something else), with which they encode the second list. The context-change task simulates this process without the intent to forget, and therefore should produce comparable costs. Therefore, the finding that WMC has the same relationship to List 1 recall in the forget and context-change conditions provides yet one more parallel finding for the forget and the context change groups. Although similar behavioral outcomes in the forget and context change groups do not rule out the involvement of other mechanisms in directed forgetting, the lack of dissociations between these two conditions is consistent with the context based hypothesis of directed forgetting.

Context and WMC

The most unexpected finding in our study was that the context-change task led to more forgetting among high-span than among low-span people. To explain the effects of WMC differences on the context change task, we consider three hypotheses. The common theme across all hypotheses is that low-span people are less context-dependent than high-span people during encoding and/or retrieval of memories.

One possibility, called the *deficient contextual binding* hypothesis, is that low-span people do not bind contextual information to studied items as efficiently as high-span people (for evidence that supports deficient contextual binding, see Unsworth & Engle, 2006). According to the deficient contextual binding hypothesis, low-span people would suffer little from context change manipulation compared to a control remember group. High-span people, on the other hand, should suffer considerably from context changes if they were more efficient at binding contextual information to the studied items. (A variant on this hypothesis would propose that low-span people are less efficient at storing context, not at binding contexts to events.) Although this hypothesis can explain why context change hurts high-span people more than low-span people (compared to their respective remember baselines), it is unclear why high-span people do worse than low-span people following a context change. If low-span people were less likely to bind the context to the items than high-span people, then changes of context should hurt high-span more than low-spans compared to no context change (which we found). However, it is hard to understand why the low- span people (who did not bind the items to the context) should ever have any advantage over high-span people (who created more item-to-context associations)—even after context is changed. Thus, it seems that a contextual binding problem in low-span people has trouble explaining the present results.

A second possibility is a *context-susceptible strategies* hypothesis suggesting that low-span and high-span people rely on qualitatively different strategies while learning and retrieving the items. The strategies of low-span people may not be disrupted by contextual changes, perhaps because they pay no attention to context to begin with and instead learned the items in some other way that minimized the involvement of context at the time of retrieval. On the other hand, high-span people use encoding strategies that rely heavily on context. Under ordinary circumstances the strategies of high-span people lead to better memory, but when context is changed, they suffer more than low-spans. For example, low-span people might rely on interitem associations at study and test, while high-span people rely heavily on context-item associations. Experiment 2, in which encoding strategies were equated, provides some evidence against the different encoding hypothesis. High-span participants had no recall advantage over low-span in the Experiment 2 remember group. However, recall rates following the context change manipulation still showed disproportionate forgetting in high-spans over low-spans.

Finally, a third possibility is the *intensified context shift* hypothesis, which suggests that the degree of context change is larger in magnitude in high-span than low-span people. We propose that low-span people may be less able to access the context and change it compared to high-span people. One way through which context change may be intensified in high-span people is that they may put more effort into performing context-change tasks than low- span people. Another way that a richer context might be produced is if WMC is correlated in some way with the strength or type of memories surrounding one's childhood home. Perhaps, for example, emotional associations with childhood are stronger for high-span people than for low-span people, resulting in a greater change of mood and thus more context change during the parents' house task.

Consistent with the intensified context shift hypothesis, high-spans showed more impairment of List 1 recall than the low-spans following both directed forgetting and the context-change manipulations. Furthermore, the intensified context shift hypothesis can explain why low-span people recalled more List 1 items following a context shift than high-span people – it is not that low span people do not encode context well, but rather that they do not shift context well, which protects them from the context-dependent forgetting that is observed in high-span people.

The intensified context change hypothesis also provides an explanation of why high-span people are often able to resist proactive interference more effectively than low- span people are. Kane and Engle (2000) found that low- span people showed higher levels ofproactive interference compared to high-span people when studying word lists drawn from a single semantic category (e.g., animals). While high-span and low-span people recalled about the same number of items on the first list, low-span people recalled fewer items from later lists compared to high-span people. If high-span people are better able to change contexts, perhaps they do so when they are tested repeatedly under conditions with high proactive interference buildup. Because context changes reduce proactive interference (see Smith & Vela, 2001, for a review), high-spans would show reduced proactive interference compared to low- spans. If high-span people change contexts more often, one might expect that high-span people should show reduced access to earlier-studied items relative to low-span participants after studying highly interfering lists. Consistent with this prediction, a paired-associates study by Rosen and Engle (1998) found that high-span participants forgot more earlier-studied items on a cued recall test relative to low-span participants after studying an additional list of interfering items. They suggested that high-span people suppressed the List 1 items to avoid interference. However, this is also the pattern of results one would expect if high-span participants set up a new mental context to help reduce proactive interference: items in an earlier context would be less accessible, while items in the current context would suffer less proactive interference. Notably, the intensified context shift hypothesis does not predict a general ability to resist all types of interference, such as dual-task interference (cf. Oberauer, Lange & Engle, 2004).

Other studies seem consistent with the notion that high WMC is associated with more effective context change. Wegner, Schneider, Carter, and White (1987, p. 7) argued that the most successful participants in thought-suppression tasks ("don't think of a white bear") could dissociate the suppression context from the original context. Many participants reported intentionally trying to think of something else, but unsuccessful participants often found themselves thinking about uninteresting features of the original study context (e.g., light switches) that triggered recall of the to-be-suppressed item. Effective thought-suppressors thought of things outside of the original study context. Effective thought suppression was also positively related to WMC, perhaps reflecting more effective control over context in high-span people (Brewin & Beaton, 2002).

Conclusions

In conclusion, our studies show that certain kinds of interruptions may be more disruptive for high-span people than low-span people. Given that research with mental context change is at its young stages and needs further investigation, it is impossible to know which specific elements of the disruption activity were responsible for context change. For example, one may speculate that thinking about childhood home is likely to create a meaningful and rich internal representation, whereas speeded reading is probably less likely to do so. Hence, thinking about childhood home may lead to greater changes in mental context than engaging in a meaningless speeded reading task. Further research is needed to identify which tasks are likely to create greater (versus smaller) context change and hence, hurt memory of high-span people more than low-span people.

Our studies also showed that WMC mediates the directed forgetting effect as well. It would be interesting to see whether populations that have diminished executive control ability, such as older adults, also show reduced context change effects (like young adults with low WMC). If not, it might point to different underlying causes for low WMC in young adults and WMC decline in older adults.

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Please address correspondence to P. F. Delaney, Department of Psychology, 296 Eberhart Building, P.O. Box 26I70, University of North Carolina at Greensboro, Greensboro, NC 27402-6I70 (e-mail: p_delane@uncg.edu).

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