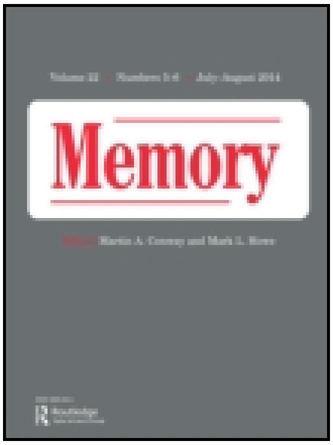

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Working memory capacity predicts the beneficial effect of selective memory retrieval

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Working memory capacity predicts the beneficial effect of selective memory retrieval

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Selective retrieval of some studied items can both impair and improve recall of the other items. This study examined the role of working memory capacity (WMC) for the two effects of memory retrieval. Participants studied an item list consisting of predefined target and nontarget items. After study of the list, half of the participants performed an imagination task supposed to induce a change in mental context, whereas the other half performed a counting task which does not induce such context change. Following presentation of a second list, memory for the original list's target items was tested, either with or without preceding retrieval of the list's nontarget items. Consistent with previous work, preceding nontarget retrieval impaired target recall in the absence of the context change, but improved target recall in its presence. In particular, there was a positive relationship between WMC and the beneficial, but not the detrimental effect of memory retrieval. On the basis of the view that the beneficial effect of memory retrieval reflects context-reactivation processes, the results indicate that individuals with higher WMC are better able to capitalise on retrieval-induced context reactivation than individuals with lower WMC.

Keywords: Retrieval; Working memory capacity; Context reactivation; Inhibition; Blocking.

Numerous studies from the past decades have shown that selective retrieval of some (nontarget) memories can have detrimental effects on recall of other (target) memories. Evidence for such retrieval-induced forgetting has arisen both when target recall followed nontarget recall immediately, as in studies using the classic output-interference task (e.g., Roediger, 1974; Smith, 1971; for a review, see Roediger & Neely, 1982), and when target recall was delayed and separated from nontarget recall by a distractor phase, as in studies using the more recent retrieval-practice task (e.g., Anderson, Bjork, & Bjork, 1994; Anderson & Spellman, 1995; for a review, see Anderson, 2003). However, research from recent years also revealed that selective retrieval is not always detrimental but, under some circumstances, can be beneficial.

Employing the listwise directed-forgetting task (e.g., Bjork, 1970), Bäuml and Samenieh (2010), for instance, let participants study a list of items and, after study, presented a cue to either forget or continue remembering the list. Following presentation of a second list, memory for predefined target items of the original list was tested, either with or without preceding retrieval of the list's remaining (nontarget) items. Whereas preceding nontarget retrieval impaired recall of to-be-remembered target items, it improved recall of to-be-forgotten target items, thus revealing a

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beneficial effect of memory retrieval after the forget instruction. Subsequent work replicated this beneficial effect for to-be-forgotten memories (Bäuml & Samenieh, 2012; Dobler & Bäuml, 2012) and extended it to memories that were subject to context-dependent forgetting (Bäuml & Samenieh, 2012) and memories that were subject to time-dependent forgetting (Bäuml & Dobler, in press; Bäuml & Schlichting, 2014).

Bäuml and Samenieh (2012) suggested a two-factor account to explain the two opposing effects of selective memory retrieval. According to this account, retrieval generally triggers two processes, inhibition or blocking of interfering memories (e.g., Anderson, 2003; Roediger & Neely, 1982) and reactivation of the study context (e.g., Howard & Kahana, 1999, 2002). Inhibition and blocking may primarily be active when access to the to-be-retrieved memories' encoding context is still maintained and interference between items is high, as may be the case after a short retention interval when no forget cue was provided and no context change was induced. In this case, preceding nontarget retrieval may thus reduce subsequent target recall, inducing the detrimental effect of memory retrieval. In contrast, context-reactivation processes may primarily be active when access to the original encoding context is impaired and interference between the single items is low, as may be the case for memories that are subject to directed forgetting, context-dependent forgetting or time-dependent forgetting (e.g., Estes, 1955; Geiselman, Bjork, & Fishman, 1983; Sahakyan & Kelley, 2002). In this case, preceding nontarget retrieval may reactivate the encoding context, which may then serve as a retrieval cue for the recall of the target items and induce the beneficial effect of memory retrieval (see also Bäuml & Dobler, in press).

In the present study, we approached the two opposing effects of retrieval from an individual-differences perspective by examining the possible role of working memory capacity (WMC) in selective memory retrieval. Following the most common definition of working memory as a system for the concurrent maintenance and processing of information (Baddeley, 1986), WMC is typically assessed by means of complex span tasks designed to tap both components of the concept (for a review, see Conway et al., 2005). For instance, in the reading span task (Daneman & Carpenter, 1980), participants are required to read and evaluate sets of sentences (processing) while memorising the last word of each sentence (maintenance). Similarly, in the operation span (OSPAN) task (Turner & Engle, 1989), participants are required to solve sets of arithmetic equations (processing) while keeping in mind unrelated words (maintenance). Previous research has shown that WMC, as measured by such complex span tasks, is an important individual-differences variable that explains a significant portion of variance in a wide range of cognitive tasks (for reviews, see Conway et al., 2005, or Kane & Engle, 2002).

Recent work has indicated that WMC can also play a role in selective memory retrieval. Indeed, using the retrieval-practice task, several studies have found that the detrimental effect of selective retrieval is diminished or even eliminated in groups of individuals known to suffer from reduced WMC. These groups include various clinical populations (e.g., Soriano, Jiménez, Román, & Bajo, 2009; Storm & White, 2010), kindergartners (Aslan & Bäuml, 2010) and older adults (Aslan & Bäuml, 2012; Ortega, Gomez-Ariza, Román, & Bajo, 2012). Consistently, Aslan and Bäuml (2011) recently reported a positive relationship between the size of the detrimental effect and individuals' WMC in a large sample of young adults when using the retrieval-practice task (but see Mall & Morey, 2013). All of these findings are consistent with the proposal that (groups of) individuals with higher WMC show more efficient inhibition than (groups of) individuals with lower WMC (Redick, Heitz, & Engle, 2007).

There is evidence that WMC may also play a role for the beneficial effect of selective retrieval, although the issue has not yet been investigated directly. For instance, Dobler and Bäuml (2012) found a beneficial effect of retrieval when target recall followed nontarget recall immediately (thus mimicking the output-interference task), but not when target recall was delayed by interpolated distractor activity (thus mimicking the retrieval-practice task). The finding is consistent with the view that, for the beneficial effect to arise, the reactivated context information needs to be maintained in working memory during target recall, and disruption of such maintenance reduces the reinstated context's activation level and thus its effectiveness in cuing the target information (e.g., Polyn, Norman, & Kahana, 2009). Because the concurrent maintenance of context information and the recall of target information should place relatively high demands on working memory, the finding suggests that individuals may differ in their capability to capitalise on retrieval-induced context reactivation, and individuals with higher WMC may thus show larger beneficial effects of selective retrieval than individuals with lower WMC (see also Spillers & Unsworth, 2011).

Results from a recent developmental study support the suggestion of a possible role of WMC for the beneficial effect of memory retrieval. In this study, Aslan and Bäuml (2014) examined the effects of selective retrieval in second, fourth and seventh graders using the output-interference task. They found that, although the detrimental effect of selective retrieval was present from second grade on and did not vary in size with age level, the beneficial effect was present in the oldest children group but was absent in the two younger children groups, indicating that the capability to capitalise on retrieval-induced context reactivation emerges relatively late in development. Because WMC continues to develop until adolescence and is still quite low in elementary school children (Case, Kurland, & Goldberg, 1982; Siegel, 1994), this finding is consistent with the view that the beneficial effect of selective retrieval depends on WMC.

The goal of the present study was to examine the role of WMC in the two opposing effects of selective retrieval directly. We employed the output-interference task to examine the influence of preceding nontarget recall on subsequent target recall, and used a diversion task to change subjects' internal context. Participants studied a list of items consisting of predefined targets and nontargets. After study of the list, half of the participants performed an imagination task supposed to induce a change in their mental context (Bäuml & Samenieh, 2012; Sahakyan & Kelley, 2002), whereas the other half performed a simple counting task which does not induce such context change (Klein, Shiffrin, & Criss, 2007). Following presentation of a second list, participants were asked to recall the original list's target items, either with or without preceding recall of the list's nontarget items. We expected to replicate previous work by finding a detrimental effect of preceding nontarget retrieval after the counting task, i.e., in the absence of a context change, but a beneficial effect of preceding nontarget retrieval after the imagination task, i.e., in the presence of a context change (e.g., Bäuml & Samenieh, 2012). More important, following the view that the beneficial effect of retrieval is mediated by context-reactivation processes (Bäuml & Dobler, in press; Bäuml & Samenieh, 2012) and previous work suggesting a positive relationship between WMC and the capability to capitalise on retrieval-induced context reactivation (Aslan & Bäuml, 2014; Dobler & Bäuml, 2012), we further expected high-WMC individuals to show a larger beneficial effect of retrieval than low-WMC individuals. If previous findings obtained with the retrieval-practice task generalised to the present output-interference task, a positive relationship should also arise between WMC and the detrimental effect of selective retrieval.

METHOD

Participants

A total of 144 adults (M = 24.5 years, SD = 5.0 years) participated in the study. They were tested individually.

Materials

Four study lists (A, B, C, D) were constructed, each consisting of 15 unrelated concrete German nouns drawn from the CELEX database (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Lists A and C were designated to be used as List 1, List B and D were designated to be used as List 2. List A was always followed by List B (list pair AB), List C was always followed by List D (list pair CD). Lists A and C consisted of 5 target and 10 nontarget items each. Among all items, each target item had a unique initial letter. The remaining items began with a unique word stem (e.g., Bäuml & Samenieh, 2012).

Design

The experiment had a 2 × 2 mixed factorial design similar to the one used in Bäuml and Samenieh (2012, Experiment 2). However, deviating from Bäuml and Samenieh, we manipulated CONTEXT (context change vs. no context change) between participants, and PRIOR NONTARGET RETRIEVAL (absent vs. present) within participants, which was done to obtain individual measures of the two retrieval effects. After study of List 1, participants in the context-change condition were asked to imagine different scenarios, whereas participants in the no-context-change condition were asked to count backwards. Retrieval conditions differed in whether the target items of List 1 were retrieved first or after prior recall of the list's nontarget items. Order of retrieval conditions, as well as assignment of list pairs to context and retrieval conditions, were counterbalanced.

Procedure

The procedure is shown in Figure 1A. In both context conditions, List-1 items were exposed individually at a 4-s rate in a random order. Subsequently, the inter-list instructions were provided. Participants in the no-context-change condition counted backwards from a three-digit number for 90 s. In contrast, participants in the context-change condition were asked to imagine two different scenarios in succession for 45 s each. In particular, they were instructed to imagine and describe orally (1) what they would do if they were invisible (e.g., Sahakyan & Kelley, 2002) and (2) what their last vacation abroad was like (Delaney, Sahakyan, Kelley, & Zimmerman, 2010). Following the interlist context manipulation, List 2 was presented analogous to List 1. After 60 s of backward counting in either context condition, List 1 was tested. In the condition without prior nontarget retrieval, targets were tested before nontarget items, whereas in the condition with prior nontarget retrieval, nontargets were tested before targets. Testing order was controlled through presentation of the items' unique initial letter (targets) or unique word stem (nontargets); the nontarget items were cued with their word stem to increase recall chances for these items and, thus, boost the possible detrimental or beneficial effects of prior nontarget retrieval on target recall. The item cues for both item types were presented successively on index cards for 6 s each. The participants wrote their answers on a sheet of paper. List-2 items were tested subsequently in a written free-recall test, but the results are not reported. After

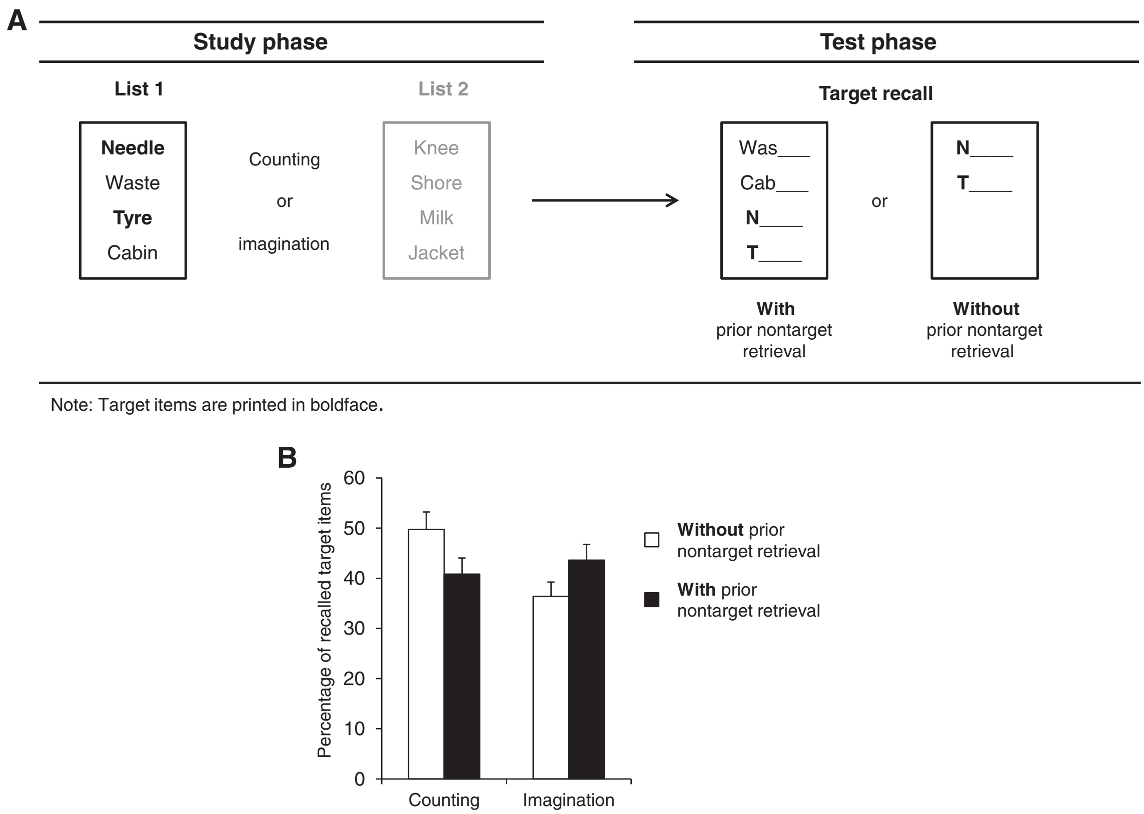

Figure 1. (A) Study and test phase of the experiment: In the study phase, participants studied two lists of items. Between the two lists, participants in the context-change condition engaged in a mental imagination task, whereas participants in the no-context-change condition conducted a counting task. In the test phase, participants were asked to recall predefined target items from List 1 (e.g., Needle, Tyre). The target items were tested with or without prior retrieval of the list's remaining (nontarget) items (e.g., Waste, Cabin). Predefined target items are depicted in bold letters. (B) Mean target recall as a function of context (counting vs. imagination) and prior nontarget retrieval (absent vs. present). The error bars represent standard errors.

a 5-min break, individuals completed the second experimental block in the respective other retrieval condition. The procedure was identical to the first experimental block, except that between study of the two lists, participants in the context-change condition were asked to imagine and describe (1) a mental walk through their childhood home (Sahakyan & Kelley, 2002) and (2) what they would do with a huge lottery win.

Working memory task

Finally, participants' WMC was assessed via a German version of the OSPAN task (Turner & Engle, 1989; see also Aslan & Bäuml, 2011; Aslan, Zellner, & Bäuml, 2010). The OSPAN task requires participants to solve arithmetic equations while trying to remember unrelated words. Each trial consisted of a certain number (varying between 2 and 6) of successively presented equation/word pairs [e.g., (6:3) + 3 = 5? moon]. Participants read each equation aloud, verified whether it was correct by saying "yes" or "no", and read the to-be-remembered word (moon) aloud. Participants were urged to respond quickly. Immediately following the response, the next equation/word pair was presented. After the last equation/word pair, participants were asked to recall the to-be-remembered words in correct order. There were three repetitions of each set size (2–6), leading to a maximum OSPAN score of 60. The span score was defined as the number of recalled words on correct sets. A set was counted as correct if all the presented words of that set were recalled in correct order (see Conway et al., 2005, for a review of scoring methods).

RESULTS

Preliminary analyses revealed that counterbalancing did not affect the overall pattern of results. Indeed, neither list order (lists A and B first vs. lists C and D first) nor order of retrieval conditions (prior nontarget retrieval present first vs. prior nontarget retrieval absent first) revealed a main effect or an interaction effect with any of the other variables (all *p*s > .078).

Figure 1B shows the results for target recall. Memory performance for target items was worse in the context-change condition than in the no-context-change condition when target items were tested first (36.4% vs. 49.7%), $t(142) = 2.95$, $p < .005$, $d = 0.49$, reflecting typical context-dependent forgetting. More important, prior retrieval of nontarget items affected target recall in the two context conditions differently. Whereas prior nontarget retrieval had a detrimental effect on participants' target recall in the no-context-change condition (49.7% vs. 40.8%), $t(71) = 2.27$, $p = .026$, $d = 0.31$, it had a beneficial effect on target recall in the context-change condition (36.4% vs. 43.6%), $t(71) = 2.21$, $p = .030$, $d = 0.28$. Consistently, a 2 × 2 analysis of variance (ANOVA) with the between-participants factor of context (context change vs. no context change) and the within-participants factor of prior nontarget retrieval (absent vs. present) revealed a significant interaction between the two factors, $F(1, 142) = 9.98$, $MSE = 0.047$, $p = .002$, partial $\eta^2 = .07$. There was neither a significant main effect of context, $F(1, 142) = 2.02$, $MSE = 0.099$, $p = .157$, nor a significant main effect of prior nontarget retrieval, $F(1, 142) < 1$. Mean recall performance for nontarget items, when tested first, did not vary with context condition (no context change = 74.4%, context change = 75.0%; $t(142) < 1$).

Participants had a mean OSPAN score of 24.6 (SD = 11.5, range = 2–54), which did not differ between context conditions (no context change = 24.8, context change = 24.4; $t(142) < 1$). We examined the relationship between WMC and the two opposing effects of selective memory retrieval by regressing—separately for the two context conditions—the individual retrieval effect scores on the individual WMC score (detrimental effect = target recall without prior nontarget retrieval – target recall with prior nontarget retrieval; beneficial effect = target recall with prior nontarget retrieval – target recall without prior nontarget retrieval). The resulting scatterplots together with the best-fitting linear regression lines are shown in Figure 2. For the no context-change condition, the regression line was practically horizontal and the slope did not differ significantly from zero, $b = -.039$, $SE = .328$, $p > .90$, indicating that the size of the detrimental effect of selective memory retrieval did not vary with participants' WMC. In contrast, for the context-change condition, the slope of the regression line was positive and differed significantly from zero, $b = .867$, $SE = .284$, $p = .003$, indicating that the size of the beneficial effect of selective memory retrieval increased with increasing WMC. The correlation between the beneficial effect and WMC ($r = .34$) was significantly larger

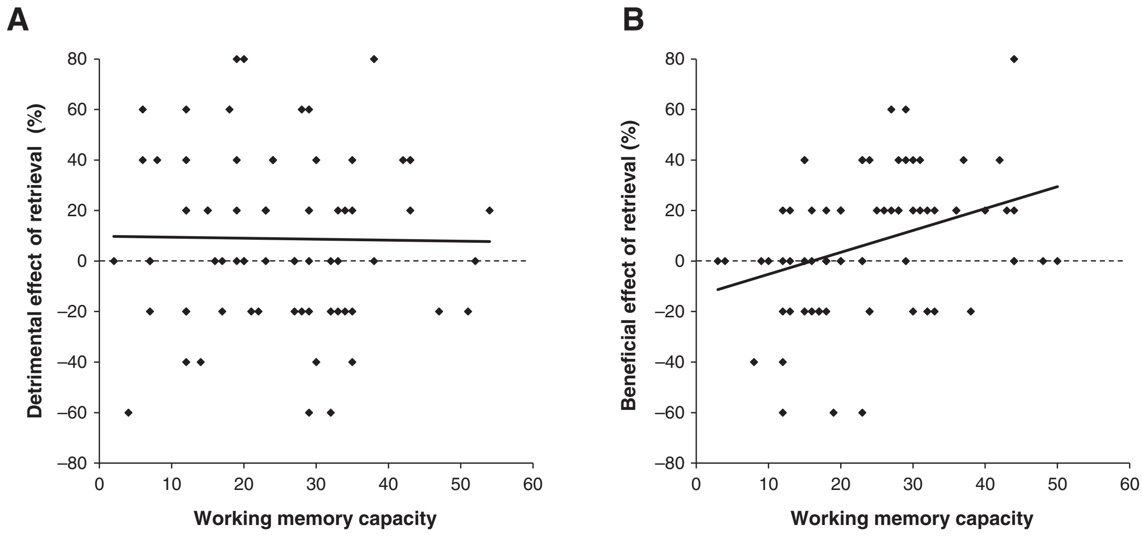

Figure 2. Results of regression analyses. (A) No-context-change (counting) condition. Individual detrimental effect scores (target recall without prior nontarget retrieval – target recall with prior nontarget retrieval) as a function of individual WMC. (B) Context-change (imagination) condition. Individual beneficial effect scores (target recall with prior nontarget retrieval – target recall without prior nontarget retrieval) as a function of individual WMC. The solid lines represent the best-fitting linear regression lines. The dashed lines represent the zero baselines.

than the correlation between the detrimental effect and WMC ($r = -.01$), $p = .015$.

DISCUSSION

We replicated prior work by finding that selective memory retrieval can both impair and improve retrieval of related memories (e.g., Bäuml & Samenieh, 2010, 2012). We found preceding nontarget retrieval to impair target recall after an interpolated counting task, i.e., when access to the study context was largely maintained (e.g., Klein et al., 2007), but to improve target recall after an interpolated imagination task, i.e., when access to the study context was impaired (e.g., Sahakyan & Kelley, 2002). Going beyond the prior work, we additionally found a positive relationship between individuals' WMC and the beneficial effect of memory retrieval, with high-WMC individuals benefiting more from preceding nontarget retrieval than low-WMC individuals. No such relationship arose between WMC and the detrimental effect of memory retrieval.

The beneficial effect of selective retrieval has been attributed to context-reactivation processes, the proposal being that preceding nontarget retrieval triggers the reactivation of the retrieved items' (deactivated) encoding context which then may serve as a retrieval cue for subsequent target recall (Bäuml & Dobler, in press; Bäuml & Samenieh, 2012). Following this view, the present finding of a positive relationship between the beneficial effect of memory retrieval and WMC suggests that individuals with higher WMC are better able to capitalise on retrieval-induced context reactivation than individuals with lower WMC. Due to their superior maintenance capabilities, high-WMC individuals may be more successful than low-WMC individuals in temporarily holding the reinstated context active and using it to guide retrieval of the target items.

The present finding is consistent with the results of two recent studies, which provided first indirect evidence for a role of WMC for the beneficial effect of memory retrieval. The one study (Dobler & Bäuml, 2012) demonstrated that the beneficial effect of memory retrieval is no longer present when preceding nontarget recall and subsequent target recall are separated by an interpolated distractor task. This result indicates that (even high-WMC) individuals' maintenance capabilities may be overstretched if target recall is delayed. In such case, the reactivated context information may no longer be maintained in working memory and the effectiveness of the context cue in searching for the target items be reduced (e.g., Polyn et al., 2009). The other study (Aslan & Bäuml, 2014) demonstrated that the beneficial effect of memory retrieval is present in seventh graders, but is still absent in second and fourth graders, indicating that the capability to capitalise on retrieval-induced context reactivation emerges relatively late in development, which coincides with the finding that WMC continues to develop until adolescence (Case et al., 1982; Siegel, 1994).

The present finding on the role of WMC for the beneficial effect of selective retrieval relates to recent research on the contiguity effect. The contiguity effect refers to the observation that, in free-recall situations, people tend to recall items that were learned in nearby serial positions in succession (Kahana, 1996). For instance, if a participant recalls a word from the fifth serial position of a previously studied list, then the next word recalled has a higher (conditional) probability of being from the fourth or sixth than from the third or seventh serial position. Like the beneficial effect of selective retrieval, the contiguity effect has been associated with context-reactivation processes, assuming that (1) neighbouring items share more contextual information than items from more remote serial positions and (2) the retrieval of a particular item reactivates the contextual information associated with that item (e.g., Howard & Kahana, 1999). Examining the role of WMC in the contiguity effect, Spillers and Unsworth (2011) recently found the effect to be reduced in individuals with low WMC as compared to individuals with high WMC. The finding is consistent with the present results and indicates that the capability to capitalise on retrieval-induced context reactivation depends on WMC.

The present finding of a null correlation between WMC and the detrimental effect of retrieval contrasts with previous studies reporting reduced detrimental effects in individuals (supposedly) suffering from reduced WMC, like low-WMC young adults, older adults or patients with attention deficit hyperactivity disorder (ADHD) (e.g., Aslan & Bäuml, 2011; Ortega et al., 2012; Storm & White, 2010; but see Mall & Morey, 2013).[1] However, these previous studies employed the retrieval-practice task in which target recall was delayed and separated from nontarget recall by a distractor phase, a procedure that may have reduced blocking effects from preceding nontarget recall. Indeed, when target recall is undelayed, as was the case in the present output-interference task, the freshly reactivated nontarget items may come to mind more persistently and thus may (additionally) block access to the target items (Verde, 2009). Because low-WMC individuals typically suffer more from blocking processes than high-WMC individuals (e.g., Aslan & Bäuml, 2010; Kane & Engle, 2000), such negative relationship between WMC and susceptibility to blocking may have cancelled out the typical positive relationship between WMC and inhibitory efficiency (Aslan & Bäuml, 2011; Redick et al., 2007). The present results thus are not necessarily in conflict with the previous work but are consistent with the view of a role of both inhibition and blocking in output interference (e.g., Verde, 2009).

In conclusion, this is the first study to demonstrate a relationship between the beneficial effect of selective memory retrieval and individuals' WMC. The results indicate that high-WMC individuals are better able than low-WMC individuals to capitalise on retrieval-induced context reactivation, making (contextually) inaccessible memories accessible again. On the basis of this finding, the suggestion arises that groups of low-WMC individuals, like certain clinical populations or older adults, may show impaired retrieval-induced context-reactivation processes and thus reduced beneficial effects of selective memory retrieval. It is a high priority for future research to examine the adequacy of this proposal.

[1] Mall and Morey (2013) reported a negative relationship between WMC and the detrimental effect of selective retrieval when using the retrieval-practice task, which contrasts with the results of Aslan and Bäuml (2011). However, the two studies differ in a number of ways from each other, including differences in procedure, item composition, and type of memory test. Given these methodological differences, it is unclear which specific factor (or combination of factors) was responsible for Mall and Morey's failure to replicate the previous results.

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