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The Two Faces of Selective Memory Retrieval: Earlier Decline of the Beneficial Than the Detrimental Effect With Older Age

Alp Aslan
Martin Luther University Halle-Wittenberg

Andreas Schlichting
Regensburg University

Thomas John
Martin Luther University Halle-Wittenberg

Karl-Heinz T. Bäuml
Regensburg University

Recent work with young adults has shown that, depending on study context access, selective memory retrieval can both impair and improve recall of other memories (Bäuml & Samenieh, 2010). Here, we investigated the 2 opposing effects of selective retrieval in older age. In Experiment 1, we examined 64 younger (20–35 years) and 64 older participants (above 60 years), and manipulated study context access using list-method directed forgetting. Whereas both age groups showed a detrimental effect of selective retrieval on to-be-remembered items, only younger but not older adults showed a beneficial effect on to-be-forgotten items. In Experiment 2, we examined 112 participants from a relatively wide age range (40–85 years), and manipulated study context access by varying the retention interval between study and test. Overall, a detrimental effect of selective retrieval arose when the retention interval was relatively short, but a beneficial effect when the retention interval was prolonged. Critically, the size of the beneficial but not the detrimental effect of retrieval decreased with age and this age-related decline was mediated by individuals' working memory capacity, as measured by the complex operation span task. Together, the results suggest an age-related dissociation in retrieval dynamics, indicating an earlier decline of the beneficial than the detrimental effect of selective retrieval with older age.

Keywords: cognitive aging, episodic memory, retrieval, context reactivation, inhibition

It is a well-established finding in memory research that the very act of retrieving information from episodic memory can impair the retrieval of other information. Evidence for such retrieval-induced forgetting has arisen from two experimental tasks: the output-interference and the retrieval-practice task. Studies using the output-interference task repeatedly found that recall performance declines as a function of the items' serial testing position, suggesting that the preceding retrieval of some items can impede the subsequent retrieval of other items (e.g., Roediger, 1974; Smith, 1971). Similarly, studies using the more recent retrieval-practice task showed that the intervening retrieval of some items of a previously studied list can cause forgetting of the list's remaining items on a later memory test (e.g., Anderson, Bjork, & Bjork, 1994; for reviews, see Anderson, 2003; Bäuml, Pastötter, & Hanslmayr, 2010; Storm & Levy, 2012).

Retrieval-induced forgetting has mostly been attributed to inhibitory control processes. The proposal is that, during selective retrieval of some items, the other, not-(yet)-to-be-retrieved items interfere and get inhibited to resolve the interference (e.g., Anderson, 2003). Although the inhibition account of retrieval-induced forgetting has received considerable empirical support from a variety of findings (e.g., Anderson & Spellman, 1995; Healey, Campbell, Hasher, & Ossher, 2010; Levy, McVeigh, Marful, & Anderson, 2007; Spitzer & Bäuml, 2007), noninhibitory processes may also contribute to the effect. For instance, selective retrieval also strengthens the retrieved items' memory representation, which may lead these strengthened items to come to mind persistently and, in this way, block access to the other items (e.g., Raaijmakers & Jakab, 2012; Verde, 2009).

Previous aging research has employed retrieval-induced forgetting primarily to examine older adults' inhibitory capabilities in episodic memory. Although initial work suggested intact inhibition in older adults (e.g., Aslan, Bäuml, & Pastötter, 2007; Gómez-Ariza, Pelegrina, Lechuga, Suárez, & Bajo, 2009; Koutstaal, Schacter, Johnson, & Galluccio, 1999), more recent studies have reported age-related differences in retrieval-induced forgetting. Ortega, Gómez-Ariza, Román, and Bajo (2012), for instance, found that retrieval-induced forgetting was eliminated in younger and older adults when a secondary task was performed during selective retrieval to divide participants' attention. However,

Alp Aslan, Department of Psychology, Martin Luther University Halle-Wittenberg; Andreas Schlichting, Department of Experimental Psychology, Regensburg University; Thomas John, Department of Psychology, Martin Luther University Halle-Wittenberg; Karl-Heinz T. Bäuml, Department of Experimental Psychology, Regensburg University.

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Correspondence concerning this article should be addressed to Alp Aslan, Department of Psychology, Martin Luther University Halle-Wittenberg, Emil-Abderhalden-Strasse 26-27, 06108 Halle (Saale), Germany. E-mail: alp.aslan@psych.uni-halle.de

whereas a relatively demanding secondary task was necessary to eliminate the forgetting in the younger adults, a less demanding task was already sufficient to eliminate the effect in the older adults, suggesting that inhibition becomes more fragile with age. In another retrieval-induced forgetting study, Aslan and Bäuml (2012) distinguished between so-called young-old adults aged 60 to 74 years, and old-old adults aged 75 years and above, thus employing a more fine-grained design than did previous work. Whereas the group of young-old adults showed typical retrieval-induced forgetting, no forgetting arose in the group of old-old adults. Extant evidence thus converges on the view that inhibitory efficiency in episodic memory declines with age (Hasher & Zacks, 1988), but the decline seems to be late-emerging and subtle enough to allow many older adults to show efficient retrieval-induced forgetting, at least when working under full attention.

However, retrieval is not always detrimental for recall of other memories but, under certain conditions, can also be beneficial. Bäuml and Samenieh (2010), for instance, examined the effects of selective retrieval in list-method directed forgetting (Bjork, 1970). Participants studied a list of items (e.g., *book, tiger, wool, apple*) and, after study, were provided a cue to either forget or continue remembering the list. Following study of a second list, participants were tested on predefined target items of the original list (e.g., *book, wool*), either with or without preceding retrieval of the list's remaining (nontarget) items (e.g., *apple, tiger*). In the remember condition, typical retrieval-induced forgetting arose and preceding nontarget retrieval impaired target recall. In contrast, in the forget condition, preceding nontarget retrieval improved target recall, suggesting that memories that are subject to directed forgetting can benefit from selective retrieval (see also Bäuml & Samenieh, 2012). Directed forgetting has often been attributed to some form of contextual forgetting, assuming that the forget cue triggers processes that inhibit access to the List-1 study context (e.g., Geiselman, Bjork, & Fishman, 1983; Pastötter & Bäuml, 2010) or induces an abrupt change in participants' internal context and thus increases the contextual mismatch between study and test (Sahakyan, Delaney, & Goodmon, 2008; Sahakyan & Kelley, 2002).[1] On the basis of this assumption, the beneficial effect of selective retrieval was explained by context-reactivation processes. Preceding nontarget retrieval may trigger reactivation of the study context and the reactivated context information may then serve as a retrieval cue for recall of the target items (Bäuml & Dobler, 2015; Bäuml & Samenieh, 2012).

That retrieval is not always detrimental for recall of other memories has also been shown in time-dependent forgetting. Bäuml and Schlichting (2014), for instance, let participants study a single list of items consisting of predefined target and nontarget items. After a retention interval of either 4 min or 48 hr, memory for the target items was tested, either in the presence or the absence of preceding nontarget retrieval. Preceding nontarget retrieval was found to impair target recall after the short retention interval, but to improve target recall after the prolonged retention interval, thus extending the previous results on the effects of selective retrieval in list-method directed forgetting to time-dependent forgetting (see also Bäuml & Dobler, 2015). Like directed forgetting, time-dependent forgetting has often been attributed to impaired context access, assuming that context fluctuates over time and such fluctuation induces an increasing contextual mismatch between study and test as the retention interval is increased (e.g., Estes, 1955; Mensink & Raaijmakers, 1988).[2] Following this view, the beneficial effect of selective retrieval was again explained by context-reactivation processes, proposing that preceding nontarget retrieval reactivates the study context and the reactivated context information then serves as a retrieval cue for target recall.

Whereas in the meantime the beneficial effect of selective retrieval has been repeatedly demonstrated in young adults, it has not been investigated in older adults. Indeed, previous work examining selective retrieval effects in older adults exclusively employed situations in which access to the study context at test was largely maintained and thus focused on the detrimental effect of selective memory retrieval (e.g., Aslan et al., 2007; Gómez-Ariza et al., 2009). In contrast, no study has yet examined selective retrieval effects in older adults when access to the study context was impaired, leaving it open as to whether older adults also show the beneficial effect of selective retrieval. Corresponding knowledge would be important, because it would provide information on whether older adults' recall includes retrieval-induced context-reactivation processes. Such context-reactivation processes can make initially inaccessible memories accessible again, thus partly compensating for the forgetting that arises initially when access to the study context gets impaired. If retrieval-induced context-reactivation processes were reduced in older adults, such reduction could therefore play a critical role in older adults' poor episodic recall.

Although the issue has not yet been investigated directly, there is evidence that the beneficial effect of selective retrieval may be reduced in older adults. One (indirect) line of evidence comes from research on the contiguity effect. The contiguity effect refers to the observation that, in free recall situations, participants tend to recall in succession items that were studied in nearby serial positions (Kahana, 1996), an observation that has been associated with context-reactivation processes (e.g., Howard & Kahana, 1999). Kahana, Howard, Zaromb, and Wingfield (2002) examined age-related changes in the contiguity effect and found the effect to be reduced in older adults, as compared to young controls, suggesting that the capability to capitalize on context-reactivation processes declines with adults' age.

A second (indirect) line of evidence indicating that the beneficial effect of selective retrieval may be reduced in older

[1] Although the inhibition and context change accounts differ in detail, they both emphasize impaired context access as the source of the forgetting (e.g., Bäuml & Samenieh, 2012; Bjork & Bjork, 1996; Geiselman, Bjork, & Fishman, 1983; Kimball & Bjork, 2002; Sahakyan & Kelley, 2002). Regarding the controversy on whether inhibition or context change mediate the forgetting, there is recent evidence that inhibition may be the underlying mechanism, at least in older adults and when using a variant of the task called selective list-method directed forgetting (Aguirre, Gómez-Ariza, Bajo, Andrés, & Mazzoni, 2014). The present study was not designed to distinguish between the single accounts and employed the "standard" nonselective task (see Method section of Experiments 1 and 2).

[2] Although forgetting after prolonged retention intervals has often been attributed to context change, other factors like, for example, increased interference, can also contribute to time-dependent forgetting. Using short retention intervals, Bäuml and Samenieh (2012) recently found that whereas inducing a context change between study and test induces beneficial effects of selective retrieval, increased interference at test causes detrimental effects. The finding supports the view that the beneficial effect of selective retrieval after prolonged retention intervals arises from context reactivation rather than a reduction in interference level.

adults comes from a recent individual-differences study that examined the role of working memory capacity (WMC) for the two effects of selective retrieval. Using the operation span task (Turner & Engle, 1989) as a measure of subjects' WMC, Schlichting, Aslan, Holterman, and Bäuml (2015) found a positive relationship between the beneficial effect of retrieval and individuals' WMC, with high-WMC individuals' recall, but not low-WMC individuals' recall, benefiting from preceding nontarget retrieval. Because older adults are known to suffer from reduced WMC (e.g., Craik & Salthouse, 2008), they might therefore show reduced beneficial effects of selective memory retrieval. In fact, although simple maintenance abilities are relatively spared in older age, age-related deficits become particularly apparent when task demands are increased and simultaneous processing—either of the maintained or other information—is required for successful task accomplishment (e.g., Cabeza & Dennis, 2013). Given that the concurrent maintenance of context information and recall of target information should place relatively high demands on older adults' limited WMC, older adults might have difficulty capitalizing on retrieval-induced context reactivation and thus might be less able than younger adults to benefit from the preceding retrieval of other information.

The goal of the present study was to examine more directly whether the beneficial effect of selective retrieval is reduced in older adults. To address the issue, two experiments were conducted to examine whether older adults, who show the detrimental effect of selective memory retrieval, also show the beneficial effect. In both experiments, we employed the output-interference task to examine the effects of preceding retrieval of nontarget items on recall of target items (e.g., Bäuml & Samenieh, 2010). To manipulate study context access, we used list-method directed forgetting in Experiment 1 (e.g., Bäuml & Samenieh, 2010) and time-dependent forgetting in Experiment 2 (e.g., Bäuml & Schlichting, 2014). Finally, we also examined the possible role of WMC for age-related changes in the two effects of selective retrieval. To this end, we additionally assessed individuals' WMC, using the simple digit-span backward task in Experiment 1 and the complex operation span task in Experiment 2.

Experiment 1

Employing list-method directed forgetting, younger and older adults studied a list of items and, after study, were asked to either forget or continue remembering the list. After presentation of a second list, participants were tested on predefined target items from the original list, either with or without preceding retrieval of the list's remaining items. In addition, individuals' WMC was assessed using the digit-span backward task. In the remember condition, we expected to replicate previous work by finding comparable detrimental effects of selective memory retrieval in the two age groups (e.g., Aslan et al., 2007; Gómez-Ariza et al., 2009). In contrast, we expected differences between the two age groups in the forget condition. Following the view that the beneficial effect of retrieval is mediated by context-reactivation processes, and recent (indirect) evidence that older adults may have difficulty capitalizing on such processes (Kahana et al., 2002), we expected a beneficial effect of selective retrieval in younger adults, but a reduced or even eliminated effect in older adults. Finally, on the basis of the recent results on the role of WMC for the beneficial effect of retrieval (Schlichting et al., 2015), we expected the age-related decline in the beneficial effect to be related to the age-related decline in WMC.

Method

Participants. Sixty-four younger (range: 18–35, M = 22.7, SD = 3.8 years) and 64 older adults (range: 60–86, M = 70.4, SD = 7.8 years) took part in the experiment. They were all recruited from the community and tested individually. The two age groups did not differ in their years of formal education (younger adults: 14.7, older adults: 13.8, $t(126) = 1.417$, $SE = 0.673$, $p = .159$), and performed comparably in the MWT-B (Mehrfachwahl-Wortschatz-Intelligenztest [Multiple-choice vocabulary intelligence test]; Lehrl, 2005), a German vocabulary test which estimates crystallized intelligence (younger adults: 27.7, older adults: 29.1, $t(126) = 1.651$, $SE = 0.861$, $p = .101$).

Materials. Four study lists (A, B, C, D) were constructed, each consisting of 12 unrelated concrete German nouns drawn from the CELEX database (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Lists A and C were used as List 1, Lists B and D were used as List 2. List A was always followed by List B, List C was always followed by List D. For both List A and List C, four items were randomly chosen as target items, and eight items as nontarget items. Like in the prior work (e.g., Bäuml & Samenieh, 2010), this distinction remained unknown to the participants. Among all items, each target item had a unique initial letter. The remaining items began with a unique word stem.

Design and procedure. The experiment had a 2 × 2 × 2 mixed-factorial design with the between-participants factors of age group (younger adults vs. older adults) and preceding nontarget retrieval (with vs. without), and the within-participants factor of cue condition (remember vs. forget). An overview of the experimental procedure is depicted in Figure 1A. In both cue conditions, the 12 List 1 items were presented successively on index cards, one every 5 s, in random order. Two study cycles were conducted to avoid potential floor effects in the older age group. Thereafter, the interlist cue (remember or forget) was provided. In the remember condition, participants were told that List 1 should be remembered for an upcoming memory test. In the forget condition, participants were told that List 1 had been presented erroneously and thus should be forgotten (e.g., Bjork, 1970, 1989). After a 60-s backward-counting task, the target items of List 1 were tested, either with or without preceding testing of the list's nontarget items. 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 stems to increase recall chances for these items, and thus to boost possible detrimental or beneficial effects of preceding nontarget retrieval on subsequent target recall. For both item types, the item cues (i.e., initial letters or word stems) were presented successively and in random order for 6 s each, and participants were asked to recall and say aloud the appropriate items from the previously studied List 1. Participants' verbal responses were noted by the experimenter. List 2 items were tested subsequently, but the results are

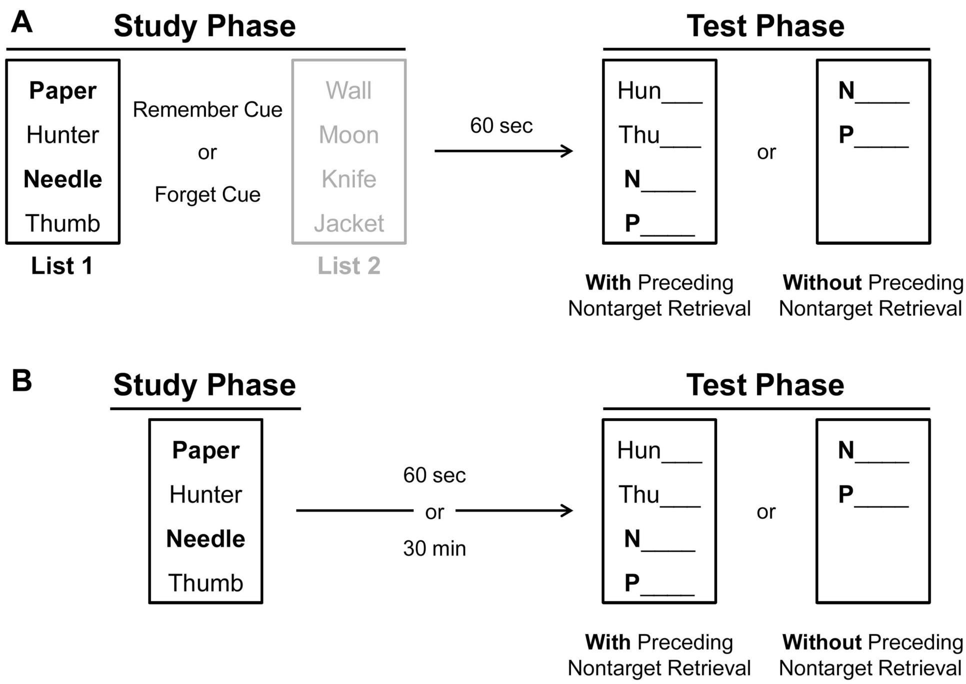

Figure 1. (A) Overview of the procedure in Experiment 1: In the study phase, participants studied two word lists. After study of List 1, they received a cue to either forget or continue remembering that list before studying List 2. After a retention interval of 60 s, participants were tested on predefined target words (boldface type) from List 1, either with or without preceding retrieval of the list's remaining (nontarget) words. (B) Overview of the procedure in Experiment 2: In the study phase, participants studied a single word list. After a retention interval of either 60 s or 30 min, participants were tested on predefined target words (boldface type) from the list, either with or without preceding retrieval of the list's remaining (nontarget) words.

not reported.[3] After a short break, the remaining cue condition (remember or forget) started. The order of the remember and forget conditions was counterbalanced across participants, as was the assignment of the four lists to the two conditions (for similar procedure, see Bäuml & Samenieh, 2010, 2012).

Working memory task. Participants' WMC was assessed using the digit-span (backward) task from the German version of the WAIS–R (Tewes, 1991). Each trial consisted of a certain number (varying between 2 and 8) of successively presented digits, read out by the experimenter at a rate of 1 s per digit (e.g., 5–2–7–9). Following presentation of the last digit of a sequence, participants were asked to reproduce the sequence in reverse order (i.e., 9–7–2–5). Following the participant's response, the next sequence was presented. There were two repetitions of each set size (2–8), leading to a maximum digit-span score of 14. The digit-span score was defined as the total number of correctly recalled sequences. A sequence was counted as correct if all the presented digits from that set were recalled in correct (i.e., reverse) order.

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 cue conditions (remember condition first vs. forget condition first) revealed a main effect or an interaction effect with any of the other variables (all $ps \geq .085$).

Mean target recall is shown in Figure 2. A 2 × 2 × 2 analysis of variance (ANOVA) with the between-participants factors of age group (younger adults vs. older adults) and preceding nontarget retrieval (with vs. without), and the within-participants factor of cue condition (remember vs. forget) revealed significant main effects of age group, $F(1, 124) = 40.284$, $MSE = 0.080$, $p < .001$, $\eta_p^2 = .245$, and cue condition, $F(1, 124) = 7.314$, $MSE = 0.056$, $p = .008$, $\eta_p^2 = .056$. These main effects reflect higher overall recall in younger compared with older adults, and reduced overall recall in the forget compared with the remember condition. In addition, there was a significant two-way interaction between preceding nontarget retrieval and cue condition, $F(1, 124) = 13.161$, $MSE = 0.056$, $p < .001$, $\eta_p^2 = .096$, which was further qualified by a significant three-way interaction, $F(1, 124) = 4.181$, $MSE = 0.056$, $p = .043$, $\eta_p^2 = .033$. Planned comparisons revealed that the three-way interaction was due to an age-related dissocia-

[3] Typically, presenting a forget cue after the first list does not only cause List 1 forgetting but also List 2 enhancement (e.g., Geiselman et al., 1983). The focus of the present experiment was on the List 1 forgetting effect, so that we always asked participants to recall List 1 items first and List 2 items second. However, because prior List 1 recall typically influences List 2 enhancement (Golding & Gottlob, 2005; Pastötter, Kliegl, & Bäuml, 2012), we ignored List 2 recall data in this experiment.

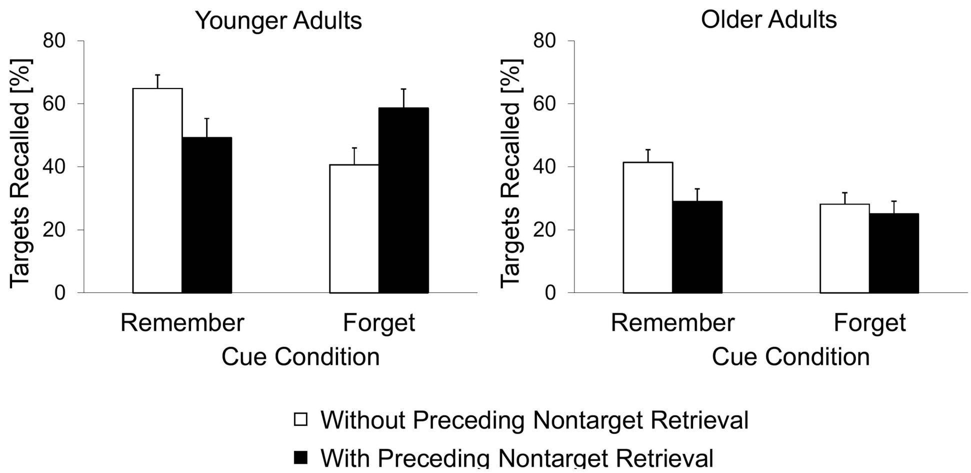

Figure 2. Results of Experiment 1: Mean target recall as a function of age group (younger adults, older adults), cue condition (remember, forget), and retrieval condition (with preceding nontarget retrieval, without preceding nontarget retrieval). Error bars represent standard errors.

tion between the two opposing effects of retrieval. Indeed, whereas the detrimental effect on recall of to-be-remembered target items was present in both age groups (younger adults: 15.6%, $p = .041$, $d = 0.522$; older adults: 12.5%, $p = .032$, $d = 0.549$), the beneficial effect on recall of to-be-forgotten items was present in the younger adults (18.0%, $p = .016$, $d = 0.622$), but was absent in the older adults (−3.1%, $p = .570$).[4]

When additionally including participants' digit-span score as a covariate into the analysis, results revealed neither a main effect of digit span, nor an interaction effect between digit span and cue condition, both $ps \geq .728$. In particular, inclusion of the scores did not alter any of the significant effects found in the analysis reported above, suggesting that performance in the digit span task did not significantly influence the observed pattern of results. This held while there was a significant difference in digit-span scores between younger (mean: 8.1, range: 4–14) and older adults (mean: 5.9, range: 2–10), $t(126) = 5.963$, $SE = 0.388$, $p < .001$.

Additional analyses revealed that, when preceding nontarget retrieval was absent, target recall was lower in the forget condition than in the remember condition, $F(1, 62) = 19.763$, $MSE = 0.055$, $p < .001$, $\eta_p^2 = .242$, which reflects the standard directed-forgetting effect. The size of the directed-forgetting effect did not differ between the two age groups, $F(1, 62) = 1.681$, $MSE = 0.055$, $p = .200$, which is consistent with prior work (e.g., Aslan & Bäuml, 2013; Sego, Golding, & Gottlob, 2006; Zellner & Bäuml, 2006).

Finally, mean recall performance for nontarget items, when tested first, was very high and did not differ between the two age groups (younger adults: 96.9%; older adults: 94.5%) and the two cue conditions (remember: 95.7%; forget: 95.7%). Consistently, a 2 × 2 ANOVA with the factors of age group (younger adults, older adults) and cue condition (remember, forget) revealed neither main effects nor an interaction effect between the two factors (all $ps \geq .156$).[5]

Discussion

We replicated previous work in our group of young adults by finding preceding nontarget retrieval to impair target recall in the remember condition, but to improve target recall in the forget condition (e.g., Bäuml & Samenieh, 2010). More important, we found that whereas preceding nontarget retrieval impaired also older adults' target recall in the remember condition, it did not affect older adults' target recall in the forget condition. These findings indicate that older adults, who show the detrimental effect of selective retrieval, may not show the beneficial effect. The detrimental effect of selective retrieval has often been attributed to inhibition (e.g., Anderson, 2003), whereas the beneficial effect of selective retrieval has been explained in terms of context reactivation (e.g., Bäuml & Samenieh, 2012). On the basis of these views, the present findings indicate that older adults can show intact retrieval-induced inhibition, but have difficulty capitalizing on retrieval-induced context reactivation.

In this experiment, the beneficial effect of selective retrieval was reduced in older adults, but we found no evidence for a role of WMC for this age-related reduction. At first glance, this finding seems to be at odds with prior work (Schlichting et al., 2015) and to suggest that age-related working memory decline cannot account for the present age-related decline in the beneficial effect. However, in the prior work, the complex operation span task was employed to measure participants' WMC, a task that may be a more sensitive measure of WMC than the simple span task used in this experiment (e.g., Conway et al., 2005). Before drawing firm conclusions on the possible role of WMC for the age-related reduction in the beneficial effect, we therefore revisited the issue

[4] We performed complementary analyses in which we examined only the first cue condition of each participant, skipping the second cue condition. As it turned out, the pattern of results remained unaffected, indicating that the present within-participants manipulation of cue condition did not influence the main findings (see also Zellner & Bäuml, 2006).

[5] Nontarget recall was higher than target recall because the items' unique initial letters were used as retrieval cues for targets and the items' word stems were used as retrieval cues for the nontargets, which was done to ensure high recall success for the nontarget items (see typical studies on retrieval-induced forgetting, e.g., Anderson, Bjork, & Bjork, 1994, and Method above). The presence of these powerful retrieval cues was also the reason why nontarget recall was not much affected by cue condition and age level.

in Experiment 2, then using a more sensitive measure of participants' WMC.

Experiment 2

There were three main goals in Experiment 2. The first goal was to conceptually replicate and generalize the results of Experiment 1 using a different manipulation of study context access. To achieve this, we varied the retention interval between study and test and contrasted a short-retention-interval condition with a long-retention-interval condition, assuming that context access becomes more difficult with the passage of time (e.g., Estes, 1955). The second goal was to examine the developmental course of the beneficial effect of retrieval in a more fine-grained manner than in Experiment 1. Rather than comparing a group of young adults (around 20 years) with a group of older adults (above 60 years), and "merely" demonstrating that the beneficial effect is present in the former group but is absent in the latter group, in Experiment 2, we examined participants from a relatively wide age range (40–85 years) and investigated how the beneficial effect develops across the selected age range. Finally, the third goal was to examine the role of WMC for age-related changes in the beneficial effect of selective retrieval using a putatively more sensitive working memory task than in Experiment 1. Specifically, we assessed each participant's WMC by means of the complex operation span task (Turner & Engle, 1989). Doing so, we manipulated preceding nontarget retrieval within rather than between participants, which enabled us to measure the two effects of selective retrieval on an individual level and relate these measures to individuals' age and WMC.

Participants studied an item list and were later tested on the list's predefined target items, either with or without preceding retrieval of the list's remaining (nontarget) items. Half of the participants were tested after a short retention interval of 60 s, whereas the other half was tested after a prolonged retention interval of 30 min. We expected to conceptually replicate the results of Experiment 1. In particular, in the short-retention-interval condition, we expected to find an overall detrimental effect of selective retrieval that is largely independent of individuals' age. In contrast, in the prolonged-retention-interval condition, we expected to find an overall beneficial effect of selective retrieval that is age-dependent and declines with individuals' age. Finally, we expected the age-related decline in the beneficial effect to be (partly) mediated by the age-related decline in WMC.

Method

Participants. A total of 112 participants (range: 40–85, M = 60.6, SD = 11.4 years) took part in the experiment. They were all recruited from the community and tested individually. On average, participants had 14.6 years of formal education, and an MWT-B score of 30.6, that is, values well comparable to those of Experiment 1. Regarding WMC, participants' operation span scores varied widely (from 4–42), with a mean of 16.5.

Materials. Two study lists (A, B) were constructed, each consisting of 18 unrelated concrete German nouns drawn from the same CELEX database as in Experiment 1. For each of the two lists, six items were randomly chosen as target items and 12 items as nontarget items. Again, the distinction between target and nontarget items remained unknown to the participants. Items were chosen such that, within a list, each item had a unique initial letter.

Design and procedure. The experiment had a 2 × 2 mixed-factorial design with the within-participants factor of preceding nontarget retrieval (with vs. without) and the between-participants factor of retention interval (short vs. long). An overview of the experimental procedure is depicted in Figure 1B. In both retrieval conditions, the 18 items of a list were presented successively on index cards, one every 5 s, in random order. Two study cycles were conducted to avoid potential floor effects in older participants. Following study of the list, participants in the short-retention-interval condition engaged in a 60-s backward-counting distractor task, whereas participants in the long-retention-interval condition engaged in several distractor tasks for a total duration of 30 min. These tasks consisted of 60 s of backward counting followed by rating tasks in which participants rated the size of geometrical objects, and the attractiveness of unknown faces for another 28 min. In the final minute, participants engaged in an imagination task in which they were asked to report what they would do if they were invisible, or what they would do with a huge lottery win (Sahakyan & Kelley, 2002; Schlichting et al., 2015). Following the (short or long) retention interval, memory for the six target items was tested, either with or without preceding retrieval of the list's 12 nontarget items. Testing order was controlled through presentation of the items' unique initial letter (targets) or unique word stem (nontargets). For both item types, the item cues (i.e., initial letters or word stems) were presented successively and in random order for 6 s each, and participants were asked to recall and say aloud the appropriate items from the previously studied list. Again, participants' verbal responses were noted by the experimenter. After a short break, the remaining retrieval condition (with or without) started. The order of the two retrieval conditions was counterbalanced across participants, as was the assignment of the two lists to the two retrieval conditions.

Working memory task. Participants' WMC was assessed using a German version of the operation span task (Turner & Engle, 1989). In this task, participants had to solve arithmetic equations while trying to memorize unrelated words. Each trial consisted of a certain number (varying between two and five) of successively presented equation/word pairs—for example, $(6 : 3) + 1 = 4$? *table*. Participants read each equation aloud, determined whether it was correct by saying "yes" or "no", and read the to-be-memorized word (*table*) aloud. Participants were urged to respond quickly and, immediately following the response, the next equation/word pair was presented. Following 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 (2–5), leading to a maximum operation span score of 42. 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 from that set were recalled in correct order (see Conway et al., 2005, for a review of scoring methods).

Results

As in Experiment 1, counterbalancing did not affect the overall pattern of results. Indeed, neither list order (list A first vs. list B) nor order of retrieval condition (with preceding nontarget first vs.

without preceding nontarget first) revealed a main effect or an interaction effect with any of the other variables (all $ps \geq .225$).

Mean target recall is shown in Figure 3. A 2 × 2 ANOVA with the within-participants factor of preceding nontarget retrieval (with vs. without) and the between-participants factor of retention interval (short vs. long) revealed a significant main effect of retention interval, $F(1, 110) = 28.373$, $MSE = 0.076$, $p < .001$, $\eta_p^2 = .205$, reflecting lower target recall after the long than after the short retention interval, and a significant interaction between the two factors, $F(1, 110) = 32.952$, $MSE = 0.033$, $p < .001$, $\eta_p^2 = .231$. Planned comparisons confirmed that this interaction effect was due to preceding nontarget retrieval impairing target recall in the short-retention-interval condition (with: 56.9%, without: 72.9%, $p < .001$, $d = 0.687$), but improving target recall in the long-retention-interval condition (with: 51.2%, without: 39.3%, $p = .003$, $d = 0.504$).

In the next step, we performed linear regression analyses to examine whether the two retrieval effects varied with individuals' age. The resulting scatterplots together with the best-fitting regression lines are shown in Figure 4. Results revealed a significant negative relationship between age and the beneficial effect of retrieval (target recall with preceding nontarget retrieval minus target recall without preceding nontarget retrieval for participants in the long-retention-interval condition), $r = -.297$, $b = -.007$, $p = .026$, whereas no such relationship arose between age and the detrimental effect of retrieval (target recall without preceding nontarget retrieval minus target recall with preceding nontarget retrieval for participants in the short-retention-interval condition), $r = +.067$, $b = +0.001$, $p = .625$.[6] Regressing the two retrieval effects on individuals' WMC, results further revealed a positive relationship between WMC and the beneficial effect of retrieval, $r = +.397$, $b = +0.013$, $p = .002$, but no such relationship between WMC and the detrimental effect of retrieval, $r = -.038$, $b = -0.001$, $p = .784$.[7]

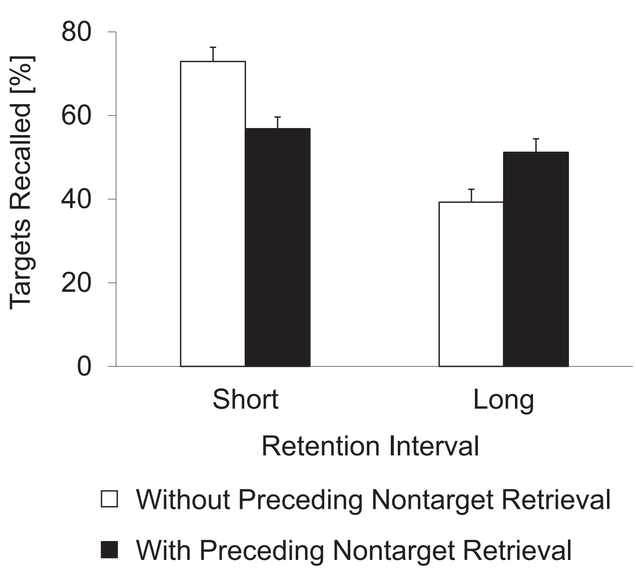

Figure 3. Results of Experiment 2: Mean target recall as a function of retention interval (short, long) and retrieval condition (with preceding nontarget retrieval, without preceding nontarget retrieval). Error bars represent standard errors.

To examine whether the above-reported relationship between age and the beneficial effect of retrieval was mediated by individuals' WMC, we performed a mediation analysis following the procedure suggested by Baron and Kenny (1986). The results of this mediation analysis revealed that (a) age predicted the potential mediator WMC, $b = -0.434$, $p < .001$, (b) the potential mediator WMC predicted the beneficial effect of retrieval when the effect of age was controlled, $b = +0.011$, $p = .032$, and (c) the relationship between age and the beneficial effect was significantly reduced, as indicated by the Sobel test (Sobel, 1982), $p = .042$, and did not differ from zero when controlling for the potential mediator WMC, $b = -0.002$, $p = .505$, suggesting that WMC completely mediated the effect of age on the beneficial effect of retrieval. A corresponding mediation analysis using WMC as a potential mediator between age and the detrimental effect of retrieval was not performed, given that no relationship between the two latter variables was found in the first place (see above).

Additional analyses revealed that, when preceding nontarget retrieval was absent, target recall was lower in the long-retention-interval condition than in the short-retention-interval condition, $t(110) = 7.353$, $SE = 0.046$, $p < .001$, $d = 1.390$, which reflects standard time-dependent forgetting. Furthermore, mean recall performance for nontarget items, when tested first, was very high and did not differ between the two retention-interval conditions (short: 95.4%; long: 93.5%), $t(110) = 1.429$, $SE = 0.014$, $p = .156$.

Discussion

The results of Experiment 2 replicate and extend the findings of Experiment 1 using a different age range, a different way to manipulate study context access, and a different measure of WMC. In particular, we found that when the retention interval between study and test was relatively short, preceding nontarget retrieval impaired target recall independent of age. In contrast, with the prolonged retention interval, we found preceding nontarget retrieval to improve target recall and this beneficial effect to decrease over the age range examined. In addition, by assessing participants' performance on the operation span task, we showed

[6] We also conducted complementary categorial analyses, performing a median split on individuals' age and comparing the youngest half with the oldest half of participants. The results of these categorial analyses paralleled those of Experiment 1 and the regression analyses above. Whereas in the short-retention-interval condition, the detrimental effect of selective retrieval was present in both the younger and the older subgroup, in the long-retention-interval condition, the beneficial effect of selective retrieval was present in the younger, but absent in the older subgroup. This held while the younger subgroup showed higher overall recall rates than the older subgroup, and the two subgroups did not differ in amount of time-dependent forgetting when preceding nontarget retrieval was absent.

[7] We also performed complementary robust regression analyses using the M-Estimation procedure introduced by Huber (1964) to examine whether outliers affected the present pattern of results. As it turned out, this was not the case. Indeed, the robust regression analyses confirmed both the negative relationship between the beneficial effect of retrieval and age ($b = -0.007$, $p = .039$), and the positive relationship between the beneficial effect and WMC ($b = +0.012$, $p = .004$); the analyses also confirmed the nonsignificant correlations between the detrimental effect of retrieval and age ($b = +0.002$, $p = .447$), and between the detrimental effect and WMC ($b = -0.001$, $p = .860$).

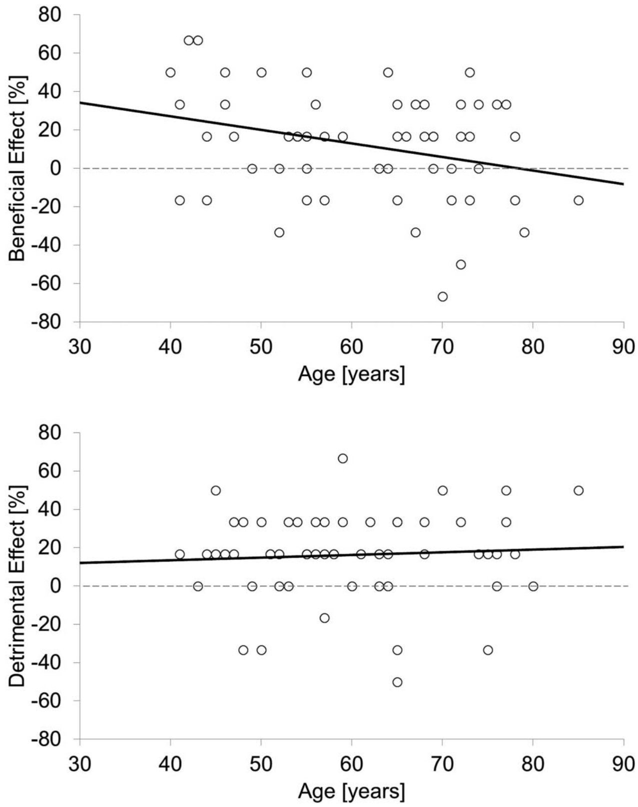

Figure 4. The two effects of selective retrieval as a function of individuals' age. The beneficial effect (upper panel) is derived from participants in the long-retention-interval condition by subtracting target recall in the without-preceding-nontarget-retrieval condition from target recall in the with-preceding-nontarget-retrieval condition. The detrimental effect (lower panel) is derived from participants in the short-retention-interval condition by subtracting target recall in the with-preceding-nontarget-retrieval condition from target recall in the without-preceding-nontarget-retrieval condition. The solid lines represent the best-fitting linear regression lines. The dashed lines represent the zero baselines.

that the age-related decline in the beneficial effect was mediated by an age-related decline in individuals' WMC.

General Discussion

Previous work has shown that selective memory retrieval can both impair and improve recall of other memories (e.g., Bäuml & Samenieh, 2012; Bäuml & Schlichting, 2014). In Experiment 1, we replicated these two faces of memory retrieval in young adults, finding the selective retrieval of nontargets to impair recall of to-be-remembered targets, but to improve recall of to-be-forgotten targets. In contrast, older adults showed the detrimental effect of selective retrieval for to-be-remembered targets, but did not reveal any evidence of the beneficial effect for to-be-forgotten targets. Examining participants from a relatively wide age range (40–85 years), we also replicated the two faces of selective retrieval in Experiment 2, finding preceding retrieval of nontargets to impair target recall after the short retention interval, but to improve target recall after the prolonged retention interval. Importantly, whereas the detrimental effect of selective retrieval was found regardless of participants' age, the beneficial effect was age-dependent and decreased with increasing age. Together, the results of the two experiments suggest an age-related dissociation in retrieval dynamics, indicating an earlier decline of the beneficial than the detrimental effect of selective retrieval with older age.

Bäuml and Samenieh (2012) suggested a two-factor account to explain the two faces of selective memory retrieval. According to this account, selective retrieval triggers different processes, depending on whether access to the study context at test is impaired or not. When the study context is (largely) maintained at test and interference between items is high, as should have been the case in the present remember condition and the short-retention-interval condition (e.g., Klein, Shiffrin, & Criss, 2007; Sahakyan & Kelley, 2002), selective retrieval is supposed to trigger primarily inhibitory processes (e.g., Anderson, 2003), inducing a detrimental effect of selective memory retrieval. In contrast, when access to the study context is impaired at test and interference between items is relatively low, as should have been the case in the present forget condition and the long-retention-interval condition (e.g., Estes, 1955; Geiselman et al., 1983), selective retrieval is supposed to trigger primarily context-reactivation processes (e.g., Howard & Kahana, 2002; Raaijmakers & Shiffrin, 1981), inducing a beneficial effect of selective memory retrieval.[8] The present finding of an age-related dissociation between the two opposing effects of selective retrieval is consistent with this two-factor account, indicating that the two effects are mediated by separable mechanisms with different developmental trajectories. In particular, the findings suggest that older adults can have difficulty capitalizing on retrieval-induced context reactivation, and this difficulty may already arise at an age level at which retrieval-induced inhibition is still intact. The suggestion is in line with previous work that reported intact retrieval-induced forgetting (e.g., Aslan et al., 2007; Gómez-Ariza et al., 2009) but a reduced contiguity effect (e.g., Kahana et al., 2002) in older age.

An alternative view on the present results could be that the lack of the beneficial effect of selective retrieval in older adults does not reflect impaired context reactivation but exaggerated retrieval-induced forgetting in situations in which context access is impaired. However, such explanation has to assume that (a) older adults show more inhibition of to-be-forgotten items than younger adults, while showing equal amounts of inhibition of to-be-remembered items (Experiment 1), and (b) older adults show more inhibition after prolonged retention intervals than younger adults, while showing equal amounts of inhibition after short retention intervals (Experiment 2). To date, there is no empirical evidence for such a proposal. Rather, there is reason to expect that, if the activation level of items is reduced—as it may occur after the presentation of a forget cue or after a prolonged retention interval—interference between the items is lowered and not much room is left for inhibition (e.g., Anderson et al., 1994; Bäuml, 1998; Storm, Bjork, & Bjork, 2007). If so, not only younger adults but

[8] The present results are consistent with the most simple form of the two-factor account, which assumes that one type of processes is active when context access is maintained, and the other type of processes is active when context access is impaired. In general, a more realistic view will be that both types of processes are active in both context conditions, and that the one type of processes dominates the effects in the one condition, and the other type of processes in the other (see Bäuml & Samenieh, 2012).

also older adults should show reduced, if any, inhibition when context access is impaired. Older adults' failure to show a beneficial effect of selective retrieval should therefore not be due to exaggerated retrieval-induced forgetting.

Recent work provided evidence for a critical role of WMC for the beneficial effect of selective retrieval in young adults (Schlichting et al., 2015). In this study, a positive relationship between the beneficial effect and WMC was found, suggesting that low-WMC individuals are less able than high-WMC individuals to benefit from retrieval-induced context reactivation. We replicated the finding in Experiment 2, and extended it to a sample of older participants. Moreover, by showing that the (negative) relationship between the beneficial effect and age largely disappears when individuals' WMC is controlled, the results of Experiment 2 provide direct evidence that decline in WMC is the driving force of the age-related decline in the beneficial effect of selective retrieval. The finding is consistent with the view that, due to their limited WMC (e.g., Cabeza & Dennis, 2013; Craik & Salthouse, 2008), older adults may be overchallenged by the (dual) task of holding the reinstated context information active and simultaneously searching memory for target information. From a broader perspective, the finding also fits with other aging research suggesting a general executive-control deficit in older adults' episodic memory (e.g., Aguirre, Gómez-Ariza, Bajo, Andrés, & Mazzoni, 2014; Aslan & Bäuml, 2012, 2013; Ortega et al., 2012).[9] The fact that we did not find a relationship between the beneficial effect of retrieval and WMC in Experiment 1 when we used the simple digit span task, but found such relationship in Experiment 2 when we used the more complex operation span task, supports the view that the complex operation span task is a more sensitive measure of WMC than the simple digit span task (Conway et al., 2005).

Although we found WMC to be positively related to the beneficial effect of retrieval, no such relationship arose between WMC and the detrimental effect. The finding of a null correlation between WMC and the detrimental effect is consistent with the results of the recent study by Schlichting et al. (2015), but contrasts with those of a previous study by Aslan and Bäuml (2011), who found a positive relationship between the two factors. However, whereas Aslan and Bäuml examined the issue using the retrieval-practice task in which target recall was delayed and separated from nontarget recall by a distractor phase, here and in the Schlichting et al. (2015) study, the issue was examined using the output-interference task in which target recall followed nontarget recall immediately. Delay between nontarget and target recall may affect the extent to which blocking contributes to the recall impairment of the target items. Indeed, when target recall is undelayed, the freshly reactivated nontarget items may come to mind persistently and thus may not only induce inhibition but also blocking of the target items (see Verde, 2009). Because low-WMC individuals are often more vulnerable to blocking effects than high-WMC individuals (e.g., Aslan & Bäuml, 2010; Kane & Engle, 2000), the typically positive relationship between WMC and inhibitory efficiency (Aslan & Bäuml, 2011; Redick, Heitz, & Engle, 2007) may be masked by the induced blocking. Such reasoning can explain why a positive relationship between WMC and retrieval-induced forgetting was present in studies in which target recall was delayed (e.g., Aslan & Bäuml, 2011) but was absent in studies in which no such delay occurred (e.g., Schlichting et al., 2015, present Experiment 2).

The present results are in line with a recently proposed general theory of cognitive aging that is based on context processing and utilization (Braver et al., 2001). According to this theory, cognitive aging involves a specific working memory deficit in the ability to represent, maintain, and update context information, broadly defined as any internally represented information (e.g., previous stimuli, task instructions) that can influence the processing of target information. Although the context-processing-deficit theory has been conceptualized to cover age-related declines across various cognitive domains, to date empirical support for it has mostly arisen from the attentional and/or the working-memory domain (e.g., using the so-called AX Continuous Performance Task; Braver et al., 2001; Braver & Barch, 2002; Haarmann, Ashling, Davelaar, & Usher, 2005). The current study was not specifically designed to test this theory, but the present indication that older adults have difficulty maintaining reactivated context information in working memory and using it as a retrieval cue for recall of target information is consistent with the theory and thus may extend its range of validity to the episodic memory domain.

The present findings relate to those of a recent developmental study examining the effects of selective memory retrieval in second, fourth, and seventh grade children. In this study, Aslan and Bäuml (2014) found that although the detrimental effect of selective retrieval was present from second grade on, the beneficial effect was present in the oldest age group, but was still absent in the two younger age groups. This developmental dissociation in children mirrors the present age-related dissociation at the other end of the life span. When integrating the findings of the two studies to an overall life span perspective, it thus appears that the processes mediating the two faces of selective memory retrieval follow a last-in first-out (or Jacksonian) principle (Rovee-Collier, Hayne, & Colombo, 2000), with the processes underlying the beneficial effect maturing later and declining earlier in life than the processes underlying the detrimental effect.

To conclude, we found that older adults can show the typical detrimental effect of selective retrieval without showing the beneficial effect, which suggests that older adults who exhibit intact retrieval-induced inhibition or blocking may not be able to rely on retrieval-induced context reactivation. Retrieval-induced context reactivation reduces contextual forgetting in the course of the recall process, thus compensating against the initial effect of an impaired access to the study context. The present indication that older adults may not be able to trigger such reactivation processes suggests that impaired retrieval-induced context reactivation can play a critical role in older adults' poor episodic recall.

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[9] There is some debate in the literature on whether complex span tasks truly measure individuals' working memory capacity or, alternatively, individuals' interference susceptibility (Lustig, May, & Hasher, 2001). The present results on the detrimental effect of selective memory retrieval seem compatible with both interpretations, whereas the present results on the beneficial effects of selective memory retrieval may be more easily explained by the capacity view. However, the present study was not designed to address or even solve this theoretical controversy.

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