Psychology and Aging
2012, Vol. 27, No. 4, 1027–1032

0882-7974/12/$12.00 DOI: 10.1037/a0028379

BRIEF REPORT

Retrieval-Induced Forgetting in Old and Very Old Age

Alp Aslan and Karl-Heinz T. Bäuml
Regensburg University

Selectively retrieving a subset of previously studied information can cause forgetting of related, nonretrieved information. Such retrieval-induced forgetting (RIF) has typically been attributed to inhibitory control processes. Examining participants with a mean age of about 70 years, previous work reported intact RIF in older adults, suggesting efficient inhibition in older adults' episodic memory. We replicated the prior work by finding reliable RIF in young-old participants (60–75 years), but additionally found RIF to decline with increasing age and to be inefficient in old-old participants (above 75 years). The results support the proposal of an inhibitory deficit in (very) old age.

Keywords: cognitive aging, inhibitory processes, inhibition-deficit hypothesis, episodic memory, retrieval-induced forgetting

One leading account to explain cognitive decline in older age is the inhibition-deficit hypothesis (Hasher & Zacks, 1988). According to this hypothesis, older adults experience increasing difficulty in suppressing or down-regulating the activation of distracting thoughts and stimuli. As a result, their minds become cluttered with task-irrelevant information, leaving fewer resources for the processing of task-relevant information and inducing cognitive decline. Many findings from different cognitive areas, like attention, working memory, and language processing, are consistent with the inhibition-deficit hypothesis (for a review, see Lustig, Hasher, & Zacks, 2007). Here, we examine the adequacy of this hypothesis for older adults' episodic memory.

A task that has been suggested to be particularly suited to examine inhibitory control processes in episodic memory is the retrieval-practice task (Anderson, Bjork, & Bjork, 1994). In the standard variant of this task, participants study items from different semantic categories (e.g., *Vegetable–Broccoli, Vegetable–Spinach, Animal–Zebra*) and subsequently perform retrieval practice on half of the items from half of the categories (e.g., *Vegetable–Bro__*). After a retention interval, a category-cued-recall test (*Vegetable–, Animal–*) for all previously studied items is conducted. The typical finding is that recall of the practiced items (*Broccoli*) is improved (retrieval-induced enhancement) and recall of the unpracticed items (*Spinach*) is impaired (retrieval-induced forgetting [RIF]), relative to control items from unpracticed categories (*Zebra*). RIF has generally been attributed to inhibitory control processes. The proposal is that, during retrieval practice, the not-to-be-retrieved items interfere and, to overcome the interference, are actively inhibited (for reviews, see Anderson, 2003, or Bäuml, Pastötter, & Hanslmayr, 2010).

The inhibition account of RIF is supported by a large number of findings. For instance, a defining feature of the account is that it attributes RIF to active suppression of an item's representation itself rather than to changes in the item's associative structure. Therefore, access to an inhibited item should be impaired irrespective of which memory test or retrieval cue is used to probe the item. Consistently, RIF has been found in a wide range of memory tests, including word-stem completion (Anderson et al., 1994; Bäuml & Aslan, 2004), item recognition (Hicks & Starns, 2004; Spitzer & Bäuml, 2007), and tests using so-called independent probes, that is, novel retrieval cues not used until the test phase of the experiment (Anderson & Spellman, 1995; Saunders & MacLeod, 2006). Similarly, in neurocognitive work, neural signals for inhibited items have been found to be reduced at test (Spitzer, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2009; Wimber et al., 2008). Furthermore, inhibitory control is generally believed to be a frontally mediated, resource-demanding process (Conway & Engle, 1994; Kane & Engle, 2002). In line with this view, RIF has been reported to be diminished in individuals with low working memory capacity (WMC) (Aslan & Bäuml, 2011a), and, in neurocognitive work, has been predicted by frontal activations during retrieval practice (Kuhl, Dudukovic, Kahn, & Wagner, 2007; Wimber, Rutschmann, Greenlee, & Bäuml, 2009).

On the basis of the inhibition-deficit hypothesis of cognitive aging and the view that RIF presupposes efficient inhibition, RIF should be reduced or even be absent in older adults. However, the results of previous studies suggest otherwise. Indeed, reliable RIF in older adults has been demonstrated using a variety of study materials, including categorized word lists (Hogge, Adam, & Collette, 2008), sentences (Gómez-Ariza, Pelegrina, Lechuga, Suárez, & Bajo, 2009), photographs (Koutstaal, Schacter, Johnson, & Galluccio, 1999), and personality traits (Lechuga, Gómez-Ariza, Iglesias-Parro, & Pelegrina, in press), and a variety of memory

This article was published Online First May 7, 2012.
Alp Aslan and Karl-Heinz T. Bäuml, Department of Experimental Psychology, Regensburg University, Regensburg, Germany.
Correspondence concerning this article should be addressed to Alp Aslan, Department of Experimental Psychology, Regensburg University, 93040 Regensburg, Germany. E-mail: alp.aslan@psychologie.uni-regensburg.de

tests, including category-cued recall (Moulin et al., 2002), item recognition (Ortega, Gómez-Ariza, Román, & Bajo, 2012, Experiment 1), and independent-probe tests (Aslan, Bäuml, & Pastötter, 2007). In fact, there is only one study to date that reported reduced RIF in older adults. In this study, RIF was found to be eliminated in both young and old adults when an updating task was performed during retrieval practice to divide subjects' attention; however, whereas a relatively demanding task (five-digit updating task) was necessary to eliminate RIF in young adults, a less demanding task (three-digit updating task) was sufficient to eliminate RIF in older adults (Ortega et al., 2012, Experiment 2). Although this finding may point to a partial deficit in older adults' inhibitory function, as a whole, current results support the view of largely intact RIF in older adults, thus challenging the proposal of a general inhibitory deficit in this age group (Hasher & Zacks, 1988).

Previous work investigating age-related changes in RIF mostly examined older adults who, with regard to their age, corresponded roughly to what has been called "young-olds" in the cognitive aging literature, that is, individuals between 60 and 75 years of age (typically resulting in a mean age of about 70 years; e.g., Aslan et al., 2007; Moulin et al., 2002; Ortega et al., 2012). The group of young-olds has often been distinguished from the group of "old-olds," that is, individuals above 75 years of age. This distinction has been motivated by findings from aging studies that, using quite different cognitive tasks, reported only small or nonexistent differences between young-olds and young controls, but larger and significant differences between young-olds and old-olds (Bäckman & Karlsson, 1986; Kliegel & Jäger, 2006; Kvavilashvili, Kornbrot, Mash, Cockburn, & Milne, 2009; Sullivan, 1999; Wahlin, Bäckman, & Winblad, 1995). These findings provide evidence for the existence of cognitive capabilities that remain intact for most of the life span, and become inefficient only at a relatively advanced age.

Evidence for such cognitive capabilities has also arisen in the context of inhibitory tasks, like the Stroop task, or the negative-priming task. On the one hand, Schooler, Neumann, Caplan, and Bruce (1997) found no age-related differences in negative-priming performance between young adults and young-old adults with a mean age of about 70 years and Kieley and Hartley (1997) reported similar results using the Stroop task. On the other hand, Persad, Abeles, Zacks, and Denburg (2002) reported progressive decline in a composite measure of inhibitory function from 60 to 85 years and Schnitzspahn and Kliegel (2009) found related results in a Stroop task, which suggests that inhibitory capabilities may decline primarily *within* old age. If the inhibitory mechanism mediating RIF was also such a "late-declining" capability, remaining intact for most of the life span, and becoming inefficient only at a relatively advanced age, previous RIF work examining mostly young-old participants may have missed an age-related decline in older adults' inhibitory function.

The goal of the present study was to clarify the issue of whether or not older adults show a decline in retrieval-induced inhibition. Drawing on findings that reported major cognitive differences between young-old and old-old participants, we used a more fine-grained design than previous RIF studies and examined RIF performance in both a sample of young-old and a sample of old-old participants. Importantly, to rule out alternative (interference-based) explanations of RIF (e.g., Camp, Pecher, & Schmidt, 2007; see Discussion), and to ensure that any observed forgetting was indeed the result of inhibition, we followed previous RIF work and assessed older adults' memory using an "interference-free" recognition test (e.g., Aslan & Bäuml, 2011a; Román, Soriano, Gómez-Ariza, & Bajo, 2009). We expected to replicate previous work by finding reliable RIF in young-old participants (Aslan et al., 2007; Ortega et al., 2012, Experiment 1). In contrast, on the basis of the young-old/old-old distinction and the inhibition-deficit hypothesis of cognitive aging (Hasher & Zacks, 1988), we expected an age-related decline in RIF efficiency, with largely reduced or even eliminated forgetting in the group of old-old participants. Finally, we also examined the role of WMC in older adults' RIF; we sought to replicate and extend recent work with young adults (Aslan & Bäuml, 2011a) by finding a positive relationship between amount of RIF and WMC in older adults.

Method

Participants

Twenty-four young-old (60–74 years; $M = 69.6$ years) and 24 old-old (75–95 years; $M = 84.0$ years) participants took part in the experiment. They were recruited from the community and tested individually. The two age groups did not differ in the MWT-B (*Mehrfachwahl Wortschatz Intelligenztest* [*Multiple-choice vocabulary intelligence test*]; Lehrl, 2005), a German vocabulary test which measures crystallized intelligence (young-olds: 31.7, old-olds: 30.1, $t(46) = 1.465$, $SE = 1.109$, $p = .150$). The two age groups also did not differ in the MMSE (*Mini Mental State Examination*; Folstein, Folstein, & McHugh, 1975), which screens for cognitive impairment (young-olds: 29.0, old-olds: 28.6, $t(46) = 1.040$, $SE = 0.401$, $p = .304$), and their self-reported health status, as measured on a 6-point Likert scale (from 1 = very good to 6 = very poor; young-olds: 2.4, old-olds: 2.8, $t(46) = 1.453$, $SE = 0.258$, $p = .153$). However, there was an expected difference in the two age groups' WMC (Craik, Anderson, Kerr, & Li, 1995), with old-old participants showing significantly lower operation span (OSPAN) scores (Turner & Engle, 1989; for details, see Aslan & Bäuml, 2011a) than young-old participants (12.0 vs. 20.5, $t(46) = 3.570$, $SE = 2.369$, $p = .001$).

Materials

Twelve exemplars from each of eight semantic categories were drawn from published word norms (Mannhaupt, 1983; Scheithe & Bäuml, 1995). Within a category, each item had a unique word stem.

Design

The experiment had a mixed design with the between-participants factor of *age group* and the within-participants factor of *item type*. All participants went through three main phases: a study phase, in which half of the items from each category were presented, an intermediate retrieval-practice phase, in which half of the studied items from half of the categories were practiced, and a final test phase, in which a recognition test including all previously studied and the remaining nonstudied items was administered. Retrieval practice created three types of studied items (practiced items [*Rp*+], unpracticed items [*Rp*−] from practiced categories, and unpracticed control items [*Nrp*] from unpracticed categories), and two types of nonstudied lure items (lures from practiced categories [*Rp* lures], and lures from unpracticed categories [*Nrp* lures]). Across participants, all items served equally often as (studied) *Rp*+, *Rp*−, and *Nrp* items, and (nonstudied) *Rp* and *Nrp* lures.

Procedure

Study phase. The 48 items of the study list (six items from each of eight categories) were presented successively on index cards, at a rate of 5 s per item. Each item was shown together with its category label (e.g., *Vegetable-Broccoli*). The order of presentation was random with the restriction that no two items from the same category were presented in succession. After the last item of the study list, participants engaged in a 1-min backward-counting task as a recency control.

Retrieval-practice phase. Participants were successively presented the word stems of 12 items (three items from each of four categories) on index cards, each stem together with its category cue (e.g., *Vegetable-Bro__*). For each card, participants were given 5 s to recall the corresponding item from the study list. The verbal responses were noted by the experimenter. The order of the word stems was random, with the restriction that no two items from the same category were practiced in succession. After the first retrieval-practice cycle, a second, identical practice cycle was conducted.

Test phase. After another 1-min backward-counting task, participants engaged in a recognition test. They were provided with 48 previously studied and 48 nonstudied items and were asked to judge whether each presented item was "old" or "new." They had 5 sec per item but were given extra time when needed. The items were presented in random order, with the restriction that no two items from the same category were tested in succession. Again, participants' verbal responses were noted by the experimenter.

Results

Mean success rate in the retrieval-practice phase was high and did not differ between young-old and old-old participants (96.9% vs. 94.3%), $t(46) = 1.601$, $SE = 0.016$, $p = .116$.

Table 1 shows percentage of hits and false alarms as a function of age group and item type. Preliminary analyses revealed that false-alarm rates did not differ reliably between the two age groups, $t(46) = 1.749$, $SE = 0.040$, $p = .087$, although there was a trend for higher false-alarm rates in old-olds than young-olds (17.0% vs. 10.0%). Also, false-alarm rates did not differ between *Rp* and *Nrp* lures (13.5% vs. 13.5%), $t(46) < 1$.

To examine the beneficial and detrimental effects of selective memory retrieval on older adults' recognition performance, we performed ANOVAs using $d' = z$(hit rate) - z(false-alarm rate) as the dependent variable. Figure 1 depicts the calculated d'-values as a function of age group and item type. Addressing the detrimental effect of selective retrieval, a 2 × 2 ANOVA with the between-participants factor of *age group* (young-olds, old-olds), and the within-participants factor of *item type* (*Rp*–, *Nrp*) revealed significant main effects of age group, $F(1, 46) = 5.261$, $MSE = 1.044$, $p = .026$, $\eta_p{}^2 = .103$, and item type, $F(1, 46) = 4.333$, $MSE = .178$, $p = .043$, $\eta_p^2 = .086$. These main effects reflect higher recognition in the young-olds than the old-olds and impaired recognition of unpracticed items compared with control items. Importantly, there was a significant interaction between the two factors, $F(1, 46) = 4.544$, $MSE = .178$, $p = .038$, $\eta_p^2 = .090$, reflecting the fact that reliable RIF was present in the young-olds, $t(23) = 3.068$, $SE = 0.118$, $p = .005$ but not in the old-olds, $t(23) < 1$.

Addressing the beneficial effect of selective retrieval, a 2 × 2 ANOVA with the between-participants factor of *age group* (young-olds, old-olds), and the within-participants factor of *item type* (*Rp*+, *Nrp*) revealed significant main effects of age group, $F(1, 46) = 11.919$, $MSE = .853$, $p = .001$, $\eta_p^2 = .206$, and item type, $F(1, 46) = 63.437$, $MSE = .239$, $p < .001$, $\eta_p^2 = .580$. These main effects reflect higher recognition in the young-olds than the old-olds, and higher recognition of practiced items compared to control items. There was no interaction between the two factors, $F(1, 46) < 1$, reflecting the fact that reliable retrieval-induced enhancement was present in both the young-olds, $t(23) = 6.764$, $SE = 0.118$, $p < .001$ and the old-olds, $t(23) = 4.959$, $SE = 0.163$, $p < .001$.

We also performed complementary correlational analyses based on (all) individuals' age, individuals' RIF ($d'_{\mathrm{Nrp}} - d'_{\mathrm{Rp-}}$), and individuals' retrieval-induced enhancement ($d'_{\mathrm{Rp+}} - d'_{\mathrm{Nrp}}$). Consistent with the group-level analyses, the individual-level analyses revealed a reliable negative relationship between age and RIF (r = −.326), $p = .024$, whereas no such relationship was present between age and retrieval-induced enhancement ($r = .191$), $p = .193$. The difference between the two correlations was reliable, $p = .015$.

Finally, we examined the role of WMC in older adults' RIF by correlating (all) individuals' RIF and retrieval-induced enhancement scores with their OSPAN scores. These analyses revealed a reliable positive relationship between WMC and RIF ($r = .286$), $p = .049$, whereas no such relationship was present between WMC and retrieval-induced enhancement ($r = -.219$), $p = .134$. The difference between the two correlations was reliable, $p = .018$.

Table 1
Percentage of Hits and False Alarms as a Function of Age Group and Item Type

	Young-olds		Old-olds	
	Hits	False alarms	Hits	False alarms
Rp +	90.8 (1.8)	9.7 (1.6)	84.6 (2.5)	17.4 (4.1)
Nrp	72.4 (3.4)	10.3 (1.7)	58.9 (5.0)	16.7 (3.5)
Rp−	60.1 (3.6)	9.7 (1.6)	60.6 (4.9)	17.4 (4.1)

Note. Standard errors are given in parentheses.

Discussion

In this study, we tested the inhibition-deficit hypothesis of cognitive aging by examining young-old (up to 75 years) and old-old participants' (above 75 years) performance in the retrieval-practice task. We found reliable RIF in the group of young-old participants, thus replicating the results of previous work that

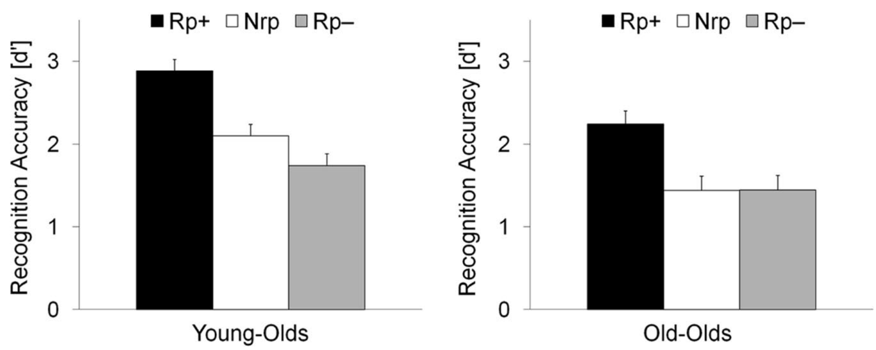

Figure 1. Recognition accuracy (*d'*) in young-old and old-old participants as a function of item type (*Rp*+, *Nrp*, *Rp*−). Error bars represent standard errors.

examined individuals of comparable age (e.g., Aslan et al., 2007; Moulin et al., 2002). Going beyond the previous work, however, we additionally found RIF to decline with individuals' age and to be inefficient in the group of old-old participants. Following the view that RIF is mediated by inhibitory control processes (e.g., Anderson, 2003), the present findings thus support the proposal of an inhibitory deficit in older adults' episodic memory.

Previous individual-differences work suggested a close link between the efficiency of inhibitory processes and WMC (for a review, see Redick, Heitz, & Engle, 2007). Consistent with this previous work and the inhibitory account of RIF, a recent individual-differences study with young adults reported a positive relationship between amount of RIF and WMC (Aslan & Bäuml, 2011a). In the present study, we replicated this positive relationship between RIF and WMC for older adults. In particular, the present finding of high(er) WMC and reliable RIF in young-olds, and low(er) WMC and no RIF in old-olds, suggests that age-related working memory decline (Craik et al., 1995) may contribute to age-related decline in RIF efficiency.

The present findings relate to those of a recent RIF study by Ortega et al. (2012). In this study, RIF was found to be eliminated in both young and young-old adults when an updating task was performed during retrieval practice to divide subjects' attention. However, whereas young adults' RIF was eliminated only with a relatively demanding secondary task, young-old adults' RIF was eliminated even if the secondary task had only moderate demand level. While this finding points to a decrease in inhibitory efficiency already in young-old adults, the decrease appears to be slight enough to allow young-olds to still show reliable RIF when working under full attention. In contrast, the present results demonstrate inefficient RIF in old-old adults even under full-attention conditions. Together, the two lines of findings provide strong evidence for the view that retrieval-induced inhibition declines with age and may be completely absent in very old age.

The present finding of an age-related decrease in older adults' RIF efficiency mirrors recent developmental work with children. Like older adults, young children have been hypothesized to show deficits in inhibitory control (Bjorklund & Harnishfeger, 1990), and accordingly, should exhibit difficulties in the retrieval-practice task. Consistent with this hypothesis, Aslan and Bäuml (2010) recently reported reduced RIF in kindergartners, as compared with second graders and young adults. Conflating the present and the previous findings to an overall life span perspective, it thus appears that the inhibitory mechanism underlying RIF develops around the time of school entry, remains relatively stable for most part of the life span, and becomes inefficient again not until very old age.

The current conclusion of an inhibitory deficit in older age, of course, depends on the validity of the inhibition account of RIF. Although there is broad agreement in the (neuro)cognitive literature that RIF reflects the operation of active inhibitory processes during retrieval practice, it has alternatively been suggested that RIF may arise more passively at test. The proposal is that, because of their increased interference, the (stronger) practiced items may block access to the (relatively weaker) unpracticed items and thus induce RIF (e.g., Camp et al., 2007). However, if RIF was a simple by-product of the strengthening of the practiced items, similar levels of RIF should have been observed for young-old and old-old participants in the present study, given that the two subject groups showed similar levels of retrieval-induced enhancement. In particular, given that individuals' vulnerability to interference effects generally increases with age (e.g., Lustig & Hasher, 2006), on the basis of the interference account, one would even expect old-olds to show more RIF than young-olds. The finding of the presence of RIF in young-olds and the absence of RIF in old-olds clearly challenges the interference view and rather supports the inhibitory account of RIF.[1]

The present finding that RIF shows measurable decline only at a relatively advanced age is consistent with previous aging research reporting "late-declining" capabilities in different cognitive areas, like selective attention, memory, or visuospatial processing (e.g., Bäckman & Karlsson, 1986; Kliegel & Jäger, 2006; Kvavilashvili et al., 2009; Sullivan, 1999; Wahlin et al., 1995). In particular, the finding is in line with the results of a very recent companion study in which we examined older adults' performance in listwise directed forgetting (DF) (Aslan & Bäuml, 2011b). This DF task measures an individual's capability to intentionally forget previously studied information when cued to do so, and, like RIF, has often been attributed to inhibitory control processes (for reviews, see MacLeod, 1998; Bäuml et al., 2010). Although previous

[1] Arguably, old-olds' low recall levels might have reduced competition between items and thus reduced the need for inhibition. However, no relationship emerged between amount of RIF and *Nrp* performance level ($p = .142$), indicating that the absence of RIF in this age group reflects a "real" inhibitory deficit and is not simply the result of their low recall level.

work generally reported intact inhibition in older adults' DF (e.g., Sego, Golding, & Gottlob, 2006; Zellner & Bäuml, 2006), in the companion study, we demonstrated that only young-old, but not old-old participants show reliable DF. This finding parallels that of the present study, suggesting that, like RIF, DF is a cognitive capability that falls off rather late in the life span. Furthermore, both DF and RIF have been found to be inefficient in individuals with low WMC (Aslan & Bäuml, 2011a; Aslan, Zellner, & Bäuml, 2010) and young children (e.g., Aslan & Bäuml, 2010; Harnishfeger & Pope, 1996), indicating that the two forms of episodic forgetting may be mediated by resource-demanding inhibitory mechanisms with similar developmental trajectories.

In conclusion, the present study demonstrates that the inhibitory processes underlying RIF decline with age. Although these processes are still largely present in young-old adults, they seem effectively absent in old-old adults. The finding is consistent with previous work reporting inhibitory deficits in many other areas of older adults' cognition, suggesting that a decline in inhibitory function is a fairly general and perhaps unavoidable feature of the aging process.

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Received December 22, 2011
Revision received March 20, 2012
Accepted March 27, 2012 ■