

Retrieval-induced forgetting in young children

ALP ASLAN AND KARL-HEINZ T. BÄUML
Regensburg University, Regensburg, Germany

A prominent theory of cognitive development attributes the poor performance that children show in many cognitive tasks to a general lack of inhibitory control. We tested this theory by examining children's inhibitory capabilities in retrieval-induced forgetting (RIF), a memory task in which selective retrieval of previously studied material causes forgetting of related, nonretrieved material. Such forgetting is often attributed to inhibitory control processes, which supposedly suppress the nonretrieved items' memory representation. We examined RIF in kindergartners, second graders, and adults, using both recall and recognition testing. Although all three age groups showed significant RIF in recall, only adults and second graders, but not kindergartners, showed RIF in recognition. Because inhibition-based RIF should be present in recall *and* recognition, these findings indicate that in adults and second graders, but not in kindergartners, RIF is mediated by inhibition. The results support the view of inefficient inhibitory processes in young children's cognition.

A prominent theory of cognitive development attributes the poor performance that children show in many cognitive tasks to a general lack of inhibitory control (Bjorklund & Harnishfeger, 1990). The main idea is that young children have particular difficulties in suppressing activated, but irrelevant, information. The irrelevant information consumes limited mental resources that otherwise would be available for the processing of relevant information, and, as a result, task performance decreases. As children grow older, their inhibitory control processes become more and more efficient, leading to increasingly successful performance, especially in situations that require the selective processing of target information in the face of interference.

The inefficient-inhibition hypothesis is consistent with many findings from developmental research. Lechuga, Moreno, Pelegrina, Gómez-Ariza, and Bajo (2006), for instance, reported inefficient inhibition in young children using an updating task that required participants to intentionally suppress irrelevant information from working memory. Similarly, other studies demonstrated that young children are disproportionately poor at inhibiting highly plausible but incorrect endings of sentences in the garden path task (Lorsbach & Reimer, 1997), or at inhibiting the irrelevant meaning of a color word in the negative-priming version of the Stroop task (Tipper, Bourque, Anderson, & Brehaut, 1989).

A task particularly suited to exploring inhibitory processes in episodic memory is the retrieval-practice task (Anderson, R. A. Bjork, & Bjork, 1994). In the standard variant of the task, participants study items from different semantic categories (e.g., FRUIT–*orange*, FRUIT–*banana*, ANIMAL–*tiger*) and subsequently perform retrieval practice on half of the items from half of the categories (e.g.,

FRUIT–*or*___). On the final category cued recall test (e.g., FRUIT–___), recall of the practiced items (e.g., *orange*) is typically improved and recall of the unpracticed items (e.g., *banana*) is impaired, relative to control items from unpracticed categories (e.g., *tiger*). The latter finding is called retrieval-induced forgetting (RIF) and is supposed to arise from inhibitory control processes during retrieval practice. The proposal is that, during retrieval attempts, the not-to-be-retrieved items interfere and, to overcome the interference and guarantee successful retrieval of the sought-after items, are inhibited (for reviews, see Anderson, 2003, or Bäuml, 2008).

The inhibition account attributes RIF to active suppression of an item's representation itself, rather than to changes in the item's associative structure. Consistently, RIF is not restricted to recall tests, but arises in item recognition tests as well (e.g., Hicks & Starns, 2004; Spitzer & Bäuml, 2007; Veling & van Knippenberg, 2004). Also in line with the inhibition account is the finding that RIF is a retrieval-specific effect that occurs when the to-be-practiced material is actively retrieved, but not when it is reexposed for additional study (e.g., Anderson, E. L. Bjork, & Bjork, 2000; Bäuml, 2002). Furthermore, inhibitory control is generally considered a frontally mediated, resource-demanding process. Consistently, recent work reported frontal activations during the practice phase that predicted later forgetting of the unpracticed information (Kuhl, Dudukovic, Kahn, & Wagner, 2007; Wimber, Rutschmann, Greenlee, & Bäuml, 2009) and showed that RIF is eliminated when a secondary task is performed during retrieval practice (Román, Soriano, Gómez-Ariza, & Bajo, 2009). Whereas these findings support the inhibitory-control view of RIF, they are hard to reconcile with noninhibitory accounts of RIF, according to

A. Aslan, alp.aslan@psychologie.uni-regensburg.de

which RIF arises at test as a result of interference from the (strengthened) practiced items (e.g., Camp, Pecher, & Schmidt, 2007; Jakab & Raaijmakers, 2009).

On the basis of the inefficient-inhibition hypothesis and the view that RIF presupposes controlled inhibition, one might expect RIF to be reduced, or even absent, in young children. Intriguingly, however, current evidence suggests otherwise. Indeed, two recent studies investigated children's RIF using the standard retrieval-practice task. Zellner and Bäuml (2005) examined first, second, and fourth graders, using categorized word lists; Lechuga et al. (2006) examined 8- and 12-year-old children, using propositional material. Both studies reported reliable RIF in children that was equivalent in amount to that in adult controls, indicating that RIF is intact already in school-age children. At first glance, it thus seems that inefficient inhibition is not a general feature of young children's cognition, but rather a task-dependent one.

However, there are at least two reasons why such a conclusion might be premature. First, RIF has not yet been investigated in children younger than school age, thus neglecting the possibility that developmental changes in inhibitory function occur prior to school entry. Second, the finding of RIF in children does not by itself implicate the existence of efficient inhibition. Indeed, as emphasized by Anderson and Levy (2007), the same inhibitory process recruited to suppress the unpracticed items in the retrieval practice phase is also required at test to combat interference from (stronger) practiced items during attempts to recall the (weaker) unpracticed items. Following this line of reasoning, individuals with poor inhibitory capabilities should not only be less efficient in suppressing the unpracticed items during retrieval practice, but, at test, should also suffer higher amounts of interference from the practiced items, which might impair retrieval of the unpracticed material, and thus induce RIF. If so, young children may show RIF; the forgetting, however, need not be caused by efficient inhibition during retrieval practice, but may be due to inefficient inhibition and exaggerated interference at test.

One way to solve the confound between inhibitory capability and amount of interference at test is to employ memory tests in which such interference effects are largely eliminated. As indicated above, many studies with adults demonstrated RIF not only in "interference-contaminated" tests such as category-cued recall, but also in largely interference-free tests such as item recognition (e.g., Hicks & Starns, 2004; Spitzer & Bäuml, 2007; Veling & van Knippenberg, 2004). The finding of RIF in such largely interference-free tests indicates that, to examine whether young children show efficient retrieval-induced inhibition, item recognition tests should be employed.

To date, only two studies examined RIF in children using memory tests that supposedly preclude interference effects. Ford, Keating, and Patel (2004) reported reliable forgetting in 7-year-old children's item recognition that was comparable to that of an adult control group, indicating that (retrieval-induced) inhibition is intact in school-age children. However, Ford et al. used item recognition not only at test, but also in the retrieval-practice phase. In

particular, in both the practice phase and the test phase, recognition performance was assessed using exclusively old items, but no new lure material, as memory probes, which may have confounded genuine memory effects with decision processes. Also using a nonstandard variant of the retrieval-practice task, Conroy and Salmon (2005) reported reduced RIF in school-age children in an item-specific cued recall test. However, because performance on the cued recall test was contaminated by prior free recall of the same items, and no adults were included as controls, the results do not allow strong inferences on the development of inhibitory control processes.

To clarify the issue of whether young children show efficient retrieval-induced inhibition, in the present study, we examined retrieval-practice effects in kindergartners, second graders, and young adults. To distinguish inhibition-based RIF from (noninhibitory) interference-based RIF, we assessed memory with both a standard category-cued recall test and an item recognition test. Following Anderson and Levy (2007), interference-based RIF would be indicated if participants showed forgetting only in recall, but not in recognition. In contrast, because the presentation of intact items should circumvent the interference from practiced competitors, inhibition-based RIF would be indicated if participants showed forgetting in recognition as well. On the basis of previous work, we expected significant RIF with both recall and recognition testing in adults. If children showed efficient inhibition, they should show the same pattern of results as adults, with significant forgetting in both types of tests. Alternatively, if children showed inefficient inhibition, they should show (interference-based) RIF in recall, but should not show (inhibition-based) RIF in recognition.

METHOD

Participants

Forty-eight kindergartners ($M = 4.6$ years old, $SD = 0.5$), 48 second-graders ($M = 7.5$ years old, $SD = 0.5$), and 48 young adults ($M = 21.9$ years old, $SD = 2.4$) took part in the experiment. The children were recruited from two kindergartens and an elementary school in Regensburg, Germany; the adults were students at Regensburg University. All participants were tested individually.

Materials

Twelve exemplars from each of eight semantic categories were drawn from a German word norm for children (Hasselhorn, 1990). The 3 exemplars with the highest and the 3 exemplars with the lowest word frequency within each selected category were never studied, but were used as lures in the recognition test. From the remaining 6 items, the 3 exemplars with the higher word frequency were used as *target* items, and the 3 exemplars with the lower word frequency were used as *nontarget* items.¹ Within a category, each item had a unique word stem.

Design

To adjust task difficulty between children and adults, the experiment was carried out in two identical blocks (using half of the categories each) in children, and a single block (using all categories) in adults. In each block, participants went through three phases: (1) a study phase, (2) an intermediate retrieval-practice phase, in which the nontargets from half of the categories were practiced, and (3) a test phase, in which either a recall or a recognition test was administered.

Retrieval practice created four types of items. Practiced categories contained practiced nontarget items (Rp^+) and unpracticed target items (Rp^-); unpracticed categories contained (unpracticed) nontarget items (Nrp^+) serving as controls for Rp^+ items, and (unpracticed) target items (Nrp^-) serving as controls for Rp^- items. Across participants, all nontargets served equally often as Rp^+ and Nrp^+ items, and all targets served equally often as Rp^- and Nrp^- items.

Procedure

Study phase. Throughout the experiment, stimuli were presented orally by the experimenter. The study phase started with the presentation of a category name, followed by the category's six exemplars in random order, at a rate of 3 sec per word. Thereafter, the items of the next category were presented in the same manner. The order of the categories was random.

Retrieval-practice phase. Following a 1-min distractor task, participants performed retrieval practice on three nontargets from half of the categories. The experimenter read out a category name and the word stem of a to-be-practiced item (e.g., FRUIT-or___), and participants were asked to remember a previously studied item that fit the cue within 5 sec. The verbal responses were noted by the experimenter. The order of the word stems was random. Following the first retrieval-practice cycle, a second, identical practice cycle was conducted.

Test phase. Following another 1-min distractor task, half the participants in each age group engaged in a recall test and half in a recognition test. The assignment of participants to the two tests was random. Participants in the recall condition were provided the category names and were asked to recall as many of the categories' studied exemplars as possible. They had 30 sec per category, but were given extra time if needed. The order of the categories was counterbalanced, such that the mean position of practiced and unpracticed categories was equal across participants. Participants in the recognition condition were provided previously studied and 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 if needed. The items were presented in a fixed random sequence to half of the participants; the other half were given the same sequence in reversed order, ensuring that the mean position of practiced, unpracticed, control, and lure items was equal across participants. In both tests, participants' verbal responses were noted by the experimenter.

RESULTS

Because the procedure differed in detail between children and adults (see the Method section), results for the two groups are reported separately. The measure of memory accuracy was percentage correct in the recall test, and $d' = z(\text{hit rate}) - z(\text{false alarm rate})$ in the recognition test.²

Adults

Adults successfully completed 95.9% of the nontarget items' word stems in the retrieval-practice phase. Success rates did not vary with test type (recall vs. recognition; $p > .90$).

Retrieval practice improved memory for the practiced (nontarget) items, in both recall (Rp^+ , 80.9% vs. Nrp^+ , 58.3%) [$t(23) = 5.3$, $SE = 0.04$, $p < .001$] and recognition (d'_{Rp^+} , 3.02 vs. d'_{Nrp^+} , 2.26) [$t(23) = 4.5$, $SE = 0.17$, $p < .001$], and caused forgetting of the unpracticed (target) items, in both recall (Rp^- , 52.8% vs. Nrp^- , 62.5%) [$t(23) = 2.2$, $SE = 0.04$, $p < .05$] and recognition (d'_{Rp^-} , 1.72 vs. d'_{Nrp^-} , 2.00) [$t(23) = 2.2$, $SE = 0.13$, $p < .05$].

Children

Mean success rates in the retrieval-practice phase were high, but were lower in kindergartners (75.8%) than in second graders (89.9%) [$t(94) = 6.0$, $SE = 0.02$, $p < .001$]. In both age groups, success rates did not vary with test type (recall vs. recognition; both $ps > .10$).

Recall test. Regarding the final recall test (upper panel of Figure 1), retrieval practice improved memory for the practiced items in both second graders [$t(23) = 6.3$, $SE = 0.04$, $p < .001$] and kindergartners [$t(23) = 4.6$, $SE = 0.05$, $p < .001$]; the amount of improvement did not differ between the two age groups ($p > .80$). In addition, retrieval practice impaired recall of the unpracticed items in both second graders [$t(23) = 2.2$, $SE = 0.04$, $p < .05$] and kindergartners [$t(23) = 3.3$, $SE = 0.03$, $p < .005$]; the amount of RIF did not differ between the two age groups ($p > .50$).

Recognition test. Table 1 shows percentage of hits and false alarms as a function of age group and item type. As can be seen from the table, second graders made fewer false alarms in the recognition test than did kindergartners [$t(46) = 2.8$, $SE = 0.12$, $p < .01$]. However, there was no difference in false alarm rates between lures from practiced and unpracticed categories in both kindergartners (12.3% vs. 13.4%) and second graders (6.3% vs. 7.1%); both $ps > .50$.

Regarding children's recognition performance (lower panel of Figure 1), retrieval practice improved memory for the practiced items in both second graders [$t(23) = 8.5$, $SE = 0.13$, $p < .001$] and kindergartners [$t(23) = 5.7$, $SE = 0.12$, $p < .001$]. However, whereas retrieval practice impaired memory for the unpracticed items in second graders [$t(23) = 2.5$, $SE = 0.12$, $p < .05$], there was no such impairment in kindergartners [$t(23) < 1$], who showed, if anything, a slight tendency in the opposite direction, with better recognition of Rp^- items than of Nrp^- items.³

DISCUSSION

This study examined RIF in children and adults, using both recall and recognition testing. We found significant RIF in young adults, irrespective of whether memory was assessed with category-cued recall or item recognition, thus replicating results from prior work (e.g., Anderson et al., 1994; Hicks & Starns, 2004). Going beyond the prior work, we additionally found that, whereas kindergartners and second graders showed RIF in recall, only second graders—but not kindergartners—showed RIF in recognition. Because inhibitory effects of retrieval practice should be present in recall *and* recognition testing (e.g., Anderson, 2003; Bäuml, 2008), these findings indicate that in adults and second graders, but not in kindergartners, RIF is mediated by inhibitory control.

The finding that RIF is absent in kindergartners' recognition is consistent with the inefficient-inhibition hypothesis, according to which young children show a general lack of inhibitory control (Bjorklund & Harnishfeger, 1990). In particular, the difference in recognition performance between kindergartners and second graders

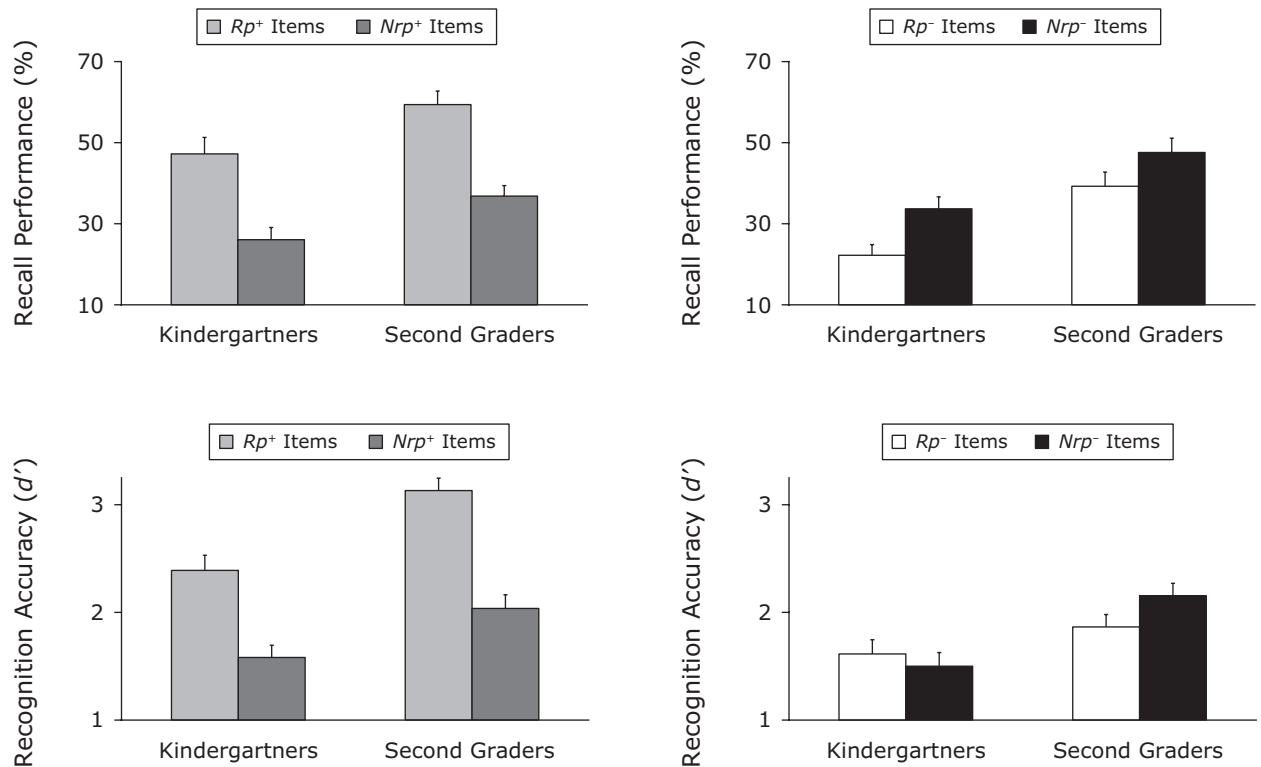


Figure 1. Memory performance in kindergartners and second graders as a function of item type (Rp^+ vs. Nrp^+ , Rp^- vs. Nrp^-). The dependent measure on the final recall test is percentage recall (upper panels). The dependent measure on the final recognition test is $d' = z(\text{hit rate}) - z(\text{false alarm rate})$ (lower panels). The error bars represent standard errors. Rp^+ (light gray) and Nrp^+ (dark gray) denote the practiced (nontarget) items and their controls. Rp^- (white) and Nrp^- (black) denote the unpracticed (target) items and their controls.

Table 1
Mean Percentage, With Standard Errors, of Hits and False Alarms
As a Function of Age Group and Item Type

	Kindergartners				Second Graders				Adults			
	Hits		False Alarms		Hits		False Alarms		Hits		False Alarms	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Rp^+	85.1	2.7	12.3	2.0	95.1	1.4	6.3	1.4	99.3	0.4	11.5	1.8
Rp^-	61.5	3.5	12.3	2.0	59.4	3.5	6.3	1.4	63.9	3.7	11.5	1.8
Nrp^+	63.2	3.1	13.4	2.0	66.7	2.9	7.1	1.5	79.2	3.3	11.1	1.9
Nrp^-	59.7	3.7	13.4	2.0	69.8	3.4	7.1	1.5	72.2	3.0	11.1	1.9

Note—Retrieval practice created four types of studied items (Rp^+ , Rp^- , Nrp^+ , Nrp^-), but only two different types of lure items (lures from practiced categories [Rp lures] vs. lures from unpracticed categories [Nrp lures]; see the Method section). As a consequence, false alarm rates for Rp^+ and Rp^- items were equivalent for each age group, as were false alarm rates for Nrp^+ and Nrp^- items.

suggests that remarkable progress in inhibitory function occurs around the time of school entry. Such progress mimics results from previous work, in which intrusion rates in children's cued recall were examined (e.g., Harnishfeger & Bjorklund, 1993). It might also be related to the pronounced growth spurt in frontal cortex that occurs between the ages of four and seven (Dempster, 1993), because RIF has been shown to reflect a frontally mediated, resource-demanding process (e.g., Kuhl et al., 2007; Román et al., 2009).

The present indication that inhibitory control, as studied in the retrieval-practice paradigm, develops around

the time of school entry contrasts with prior work suggesting that inhibitory control in episodic memory is not present before the end of the elementary school years (Harnishfeger & Pope, 1996; Paz-Alonso, Ghetti, Matlen, Anderson, & Bunge, 2009). This prior work examined intentionally recruited episodic forgetting—that is, directed forgetting and think/no-think impairment—whereas the present work examined RIF—that is, some form of unintentional forgetting (for a recent review of both intentional and unintentional forgetting, see Bäuml, 2008). The two lines of studies, therefore, are not necessarily in conflict, but rather point to a developmental dissociation between

the two types of episodic forgetting, indicating that unintentionally triggered inhibition emerges earlier in development than does intentionally triggered inhibition.

Previous developmental work showed that young children are particularly susceptible to interference effects (Dempster, 1993). Consistent with this work, the present finding of reliable RIF in kindergartners' recall likely reflects (exaggerated) retrieval interference at test, rather than efficient inhibition. Indeed, due to their poorer inhibitory capabilities, kindergartners should not only have been less efficient than second graders in suppressing the unpracticed items during retrieval practice; they should also have been less efficient in combating interference from the practiced items at test (Anderson & Levy, 2007). As a result, RIF should have arisen without inhibition, though only in the "interference-contaminated" recall test.

Kindergartners and second graders differed in success rates during retrieval practice, so that, in principle, the difference in RIF in the two age groups' recognition performance might be due to the difference in success rates. Such a scenario, however, appears unlikely. First, previous work showed that retrieval success in the practice phase does not predict the amount of RIF in the test phase, and that even (unsuccessful) retrieval attempts can be sufficient to cause forgetting (Storm, Bjork, Bjork, & Nestojko, 2006). Consistently, in neither of our three age groups did individuals' RIF in the recognition test vary with the success rate in the retrieval practice task.⁴ Second, despite the fact that success rates differed between kindergartners and second graders, there was no difference in RIF in the two age groups' recall performance. If success rate determined amount of RIF at test, kindergartners and second graders should differ in RIF in recognition *and* recall, a prediction that contrasts with the present results.

In conclusion, the present results add to the list of findings reporting inefficient inhibition in different areas of children's cognition, including children's working memory (Lechuga et al., 2006), children's intentional forgetting (Harnishfeger & Pope, 1996), children's selective attention (Tipper et al., 1989), and children's text comprehension (Lorsbach & Reimer, 1997). Together with previous developmental work, the present results thus support the view that inefficient inhibition is a fairly general feature of young children's cognition.

AUTHOR NOTE

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NOTES

1. This was done to boost the RIF effect for target items. Indeed, previous work found that categories' high-frequency exemplars may be more susceptible to RIF than are categories' low-frequency exemplars (Anderson et al., 1994).

2. The use of d' as a measure of recognition accuracy entails the assumption that the underlying (Gaussian) distributions for old and new items are equal in variance. If the variances are unequal, one may use

accuracy measures that depend on the ratio of variances, s , between the new-item and the old-item distributions—for example, d_a (which equals d' if $s = 1$; see Verde, Macmillan, & Rotello, 2006). The recognition literature suggests that, if variances are unequal, the variance of the old-item distribution often exceeds that of the new-item distribution, with s typically falling into the range between $s = 0.6$ and $s = 1.0$. On the basis of this literature, we varied the value of s parametrically (from 0.5 to 1.1, in steps of 0.1) and calculated the corresponding d_a measures. As it turned out, the same conclusions were reached with the various d_a measures as with d' (i.e., when $s = 1$). We therefore report the recognition analyses for d' only.

3. A comparison between second graders' and kindergartners' recognition performance suggests a significant difference in the magnitude of the detrimental (but not the beneficial) effect of retrieval practice [$t(46) = 2.1$, $SE = 0.19$, $p < .05$]. However, because false alarm rates differed between kindergartners and second graders, amount of RIF cannot be meaningfully compared between the two age groups (Rotello, Masson, & Verde, 2008).

4. Correlational analyses revealed that success rate accounted for only 0.9% (kindergartners), 1.1% (second graders), and 0.8% (adults) of the variance in individuals' RIF scores (all $ps > .60$).

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