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On the durability of retrieval-induced forgetting

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On the durability of retrieval-induced forgetting

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Information retrieved from memory becomes more recallable in the future than it would have been otherwise. Competing information associated with the same cues, however, tends to become less recallable, at least for a while. Whether the latter effect—referred to as *retrieval-induced forgetting*—is persistent, or only transient, is the question that motivated the present research. Participants studied category-exemplar pairs, practised retrieving other exemplars of half the categories, and, finally, were tested for their ability to recall initially studied exemplars after a 5-min delay (half the items) and after 1 week (the remaining items). In addition, for half the categories, opportunities to restudy the exemplars were provided between cycles of retrieval practice. The results demonstrate that retrieval-induced forgetting can persist for as long as a week, but that such forgetting is eliminated when participants are intermittently reexposed to unpractised items during retrieval practice.

Keywords: Inhibition; Relearning; Retrieval-induced forgetting.

Remembering, forgetting, and learning are linked in many significant, and mostly symbiotic (see Bjork, 2011), ways. Remembering, for example, is both a learning event and a forgetting event: Information recalled becomes more recallable in the future than it would have been otherwise (see Roediger & Karpicke, 2006), and information in competition with to-be-recalled information can be subjected to *retrieval-induced forgetting* (e.g., Anderson, Bjork, & Bjork, 1994), making it less recallable in the future.

The relevant findings in the literature leave no doubt that the benefits of retrieval as a learning event are long-term benefits—in fact, relative to restudying as a learning event, the benefits of retrieval tend to increase with retention interval—but what about retrieval-induced forgetting? Is it, too, a long-lasting consequence of retrieval? Existing findings (Carroll, Campbell-Ratcliffe, Murnane, & Perfect, 2007; Chan, 2009; MacLeod & Macrae, 2001; Saunders, Fernandes, & Kosnes, 2009; Saunders & MacLeod, 2002) suggest that retrieval-induced forgetting, as opposed to retrieval-induced learning, is transient—gone within 24 hours. One of our goals in the present research was to examine whether that is indeed the case.

THE RETRIEVAL-INDUCED-FORGETTING PARADIGM

Memory researchers have known for some time that retrieval can cause forgetting (e.g., Brown, 1968; Roediger, 1974; Tulving & Arbuckle, 1963). In recent years, however, the paradigm most often used to study retrieval-induced forgetting has been a retrieval-practice procedure developed by Anderson et al. (1994), which involves three phases: study, retrieval practice, and test. In Anderson et al.'s initial instantiation of the paradigm, participants studied a series of category-exemplar pairs (e.g., *fruit-lemon*, *profession-dentist*, *fruit-banana*, *profession-accountant*), presented one at a time in a random interleaved

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order. Then, immediately following this study, the participants were given selective retrieval practice for half of the exemplars from half of the categories (e.g., *fruit-le*_____), which produced three types of items: practised exemplars from practised categories, labelled *Rp + items*; nonpractised exemplars from practised categories, labelled *Rp– items*; and nonpractised exemplars from nonpractised categories, labelled *Nrp items*. Finally, after a brief delay (20 min), the participants were tested on their ability to recall each of the items from the original study list. Anderson et al. found not only retrieval-induced learning, as evidenced by superior recall of Rp + items relative to Rp– and Nrp items, but also—and more surprisingly—retrieval-induced forgetting, as evidenced by inferior recall of Rp– items relative to Nrp items.

Retrieval-induced forgetting has proven to be a highly robust and general phenomenon, emerging in many contexts and with a wide range of materials. According to one theoretical account, which we favour, retrieval-induced forgetting is the consequence of an inhibitory process that acts to resolve competition during retrieval (e.g., Anderson, 2003; Bjork, Bjork, & Anderson, 1998; Storm, 2011). Specifically, we assume that retrieval cues activate both target and nontarget items in memory, creating competition, which requires that the items causing that competition be suppressed or inhibited. More specifically, in the context of the retrieval-practice paradigm, we assume that a given retrieval-practice cue is likely to activate both the target Rp + item and the nontarget Rp– items and that inhibition is elicited to resolve the competition created by the activation of these nontarget Rp– items. The consequences are that subsequent recall of the Rp + item is facilitated and subsequent recall of Rp– items is impaired.

An alternative to the inhibitory account is that retrieval-induced forgetting is simply a consequence of blocking or strength-based associative interference (see, e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). According to the blocking account, retrieval practice strengthens a subset of items associated to a given cue, which causes those items to interfere with the recall of other items associated to that cue on the final test. Such an explanation is appealing in the sense that it invokes well-established mechanisms from research on forgetting, but we think that several types of evidence favour an inhibitory account.

First, retrieval-induced forgetting has been shown to be strength-independent—the extent to which Rp + items are strengthened does not determine the extent to which Rp– items are forgotten (e.g., Anderson, Bjork, & Bjork, 2000; Bäuml, 2002; Storm, Bjork, Bjork, & Nestojko, 2006; but see Verde, 2009). In fact, strengthening Rp + items appears neither sufficient nor necessary for retrieval-induced forgetting to occur. There is even evidence that retrieval-induced forgetting can be cue independent. That is, Rp– items are recalled less well than Nrp items even when new or independent retrieval cues are employed at test, an observation of that is particularly difficult for strength-based interference accounts to explain (e.g., Anderson, Green, & McCulloch, 2000; Anderson & Spellman, 1995; Saunders & MacLeod, 2006; but see, e.g., Camp, Pecher, & Schmidt, 2007; Perfect et al., 2004).

Second, retrieval-induced forgetting appears to be competition dependent—the extent to which Rp– items are forgotten is determined by the extent to which they compete during retrieval practice (e.g., Anderson et al., 1994; Storm, Bjork, & Bjork, 2007; but see Jakab & Raaijmakers, 2009). According to the inhibitory account, only items that compete during retrieval practice should suffer retrieval-induced forgetting because it is only those items that need to be inhibited.

Third, research examining individual and population differences has also supported the inhibitory account (e.g., Aslan & Bäuml, 2010, 2011; Ortega, Gómez-Ariza, Román, & Bajo, 2012; Soriano, Jiménez, Román, & Bajo, 2009; Storm & Angello, 2010; Storm & White, 2010). For instance, Storm and Angello (2010) found that individuals who exhibited more retrieval-induced forgetting were better at overcoming interference in a problem-solving task.

Finally, recent neuroimaging work has provided support for the inhibitory account by examining the neural markers of inhibition during retrieval practice (e.g., Johansson, Aslan, Bäuml, Gäbel, & Mecklinger, 2007; Kuhl, Dudukovic, Kahn, & Wagner, 2007) and final test (e.g., Spitzer, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2009; Wimber et al., 2008). Taken together, these and other findings strongly suggest that an inhibitory process underlies retrieval-induced forgetting (for reviews, see Anderson, 2003; Storm, 2011).

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THE DURABILITY OF RETRIEVAL-INDUCED FORGETTING

Most researchers favouring the inhibitory view have assumed that retrieval-induced forgetting reflects a temporary or transient reduction in the accessibility of an item in memory (MacLeod & Hulbert, 2011). For example, MacLeod and Macrae (2001, p. 149) argued that, ''[i]nhibitory effects need only endure until perceivers have satisfied their current processing objective . . . For this reason, it would be counterproductive if temporary forgetting endured for a considerable period of time. Indeed, if inhibition were to last indefinitely, its effects would be equivalent to the permanent erasure of items from memory.'' Consistent with this conjecture, MacLeod and Macrae observed a significant effect of retrieval-induced forgetting after a 5-min delay, but a complete elimination of the effect after a 24-hour delay, and Carroll et al. (2007), Chan (2009), Saunders and MacLeod (2002), and Saunders et al. (2009) also failed to find evidence of retrieval-induced forgetting after 24 hours. These results seem to suggest that retrieval-induced forgetting is a short-term phenomenon and that inhibition is somehow released across even a modest retention interval.

Some evidence exists, however, that retrieval-induced forgetting can persist beyond a 24-hour delay, even lasting up to a week (Garcia-Bajos, Migueles, & Anderson, 2009; Migueles & Garcia-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006). Unfortunately, most of these studies employed a repeated-test design in which participants were given an initial test shortly after retrieval practice and then tested on the same items 24 hours or 1 week later (Migueles & Garcia-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006). Thus, it is possible that the delayed effects of retrieval-induced forgetting can be attributed to differential retrieval practice on the initial test, rather than to the persisting consequences of inhibition. Owing to the positive consequences of retrieval (see, e.g., Bjork, 1975; Roediger & Karpicke, 2006), the act of recalling items on the initial test may have made those items more recallable on the later test, meaning that it would not be surprising if Nrp items, which were recalled more often than Rp– items on the initial test, are again more recallable than Rp– items after an additional delay.

Thus, to examine the possibility of long-term retrieval-induced forgetting in a rigorous way, the final delayed test must not be confounded with an earlier test for the same items. To date, however, only one study using a close variant of the typical retrieval-induced forgetting paradigm has reported a significant long-term effect of forgetting without using a repeated-test design. That study, reported by Garcia-Bajos et al. (2009), found significant retrieval-induced forgetting following a 1-week retention interval. A possible criticism of their study, however, is that they employed a final test that did not control for the order of recall and participants may have recalled Rp+items first, thus impairing the subsequent recall of Rp– items. As such, the long-term effect of retrieval-induced forgetting may have been the consequence of output interference on the final test, as opposed to the lasting effects of inhibition that arose during retrieval practice. Post hoc analysis provided some evidence against this possibility, but it is impossible to rule out the influence of output interference unless output order is controlled. In fact, recent research has suggested that retrieval-induced forgetting effects observed in studies employing category-cued recall final tests are poor measures of inhibitory-based forgetting (e.g., Soriano et al., 2009; Storm & White, 2010; for a discussion see Anderson & Levy, 2007).

There exist circumstances where the combined effects of retrieval-induced forgetting and output interference are of interest because certain real-world settings, such as witness memory (see, e.g., Shaw, Bjork, & Handal, 1995), may often combine both effects. With respect to long-term retrieval-induced forgetting per se, however, a much stronger case could be made if such effects can be demonstrated using a category-plus-one-letter-stem final test (e.g., fruit-b_____) in which Rp– items and a matched subset of Nrp items are tested before Rp+items. Category-plus-stem cued-recall final tests are commonly employed in studies of retrieval-induced forgetting and, more importantly, have proven to be better indicators of inhibitory-based forgetting than have category-cued final tests.

The majority of research exploring the durability of retrieval-induced forgetting has not controlled for output interference (e.g., Garcia-Bajos et al., 2009; MacLeod & Macrae, 2001; Migueles & Garcia-Bajos, 2007; Saunders & MacLeod, 2002; Saunders et al., 2009), sometimes intentionally, as in witness-memory experiments.

The few studies that have controlled for output interference have either failed to observe long-term forgetting (Chan, 2009; Carroll et al., 2007) or observed long-term forgetting, but were unable to interpret their findings owing to the use of a repeated-test design (Storm et al., 2006). To our knowledge, no published study has shown retrieval-induced forgetting to persist beyond a 24-hour retention interval when using a nonrepeated final test and controlling for output interference.

INTERMITTENT EXPOSURE TO NONPRACTISED ITEMS

A second goal of the present research was to examine the long-term consequences of interleaved episodes of study and retrieval practice. Storm, Bjork, and Bjork (2008) tested, and found support for, an unintuitive prediction derived from assumptions of Bjork and Bjork's (1992) New Theory of Disuse; namely, that reexposing both Rp– and Nrp items following retrieval practice can eliminate—or even reverse—retrieval-induced forgetting (see also Little, Storm, & Bjork, 2011). The theory, resurrecting a distinction that traces back decades (Estes, 1955; Hull, 1943), assumes that items in memory are indexed by two dissociable strengths: *storage strength*, which reflects how well interassociated an item is with everything to which it is related in memory; and *retrieval strength*, which reflects how accessible an item is in response to current cues. The likelihood that an item can be retrieved is assumed to be solely a function of its current retrieval strength; storage strength, on the other hand, which is roughly a measure of learning, acts as a latent variable that retards the loss and enhances the gain of retrieval strength. Once accumulated, storage strength is assumed to be permanent; so with disuse, it is retrieval strength that is lost, not storage strength.

In the context of the retrieval-practice paradigm, therefore, the theory assumes that retrieval-induced forgetting reflects a loss of retrieval strength, not storage strength. Central to the concept of retrieval inhibition (e.g., Bjork, 1989), in fact, is that such inhibition entails a temporary inability to retrieve information from memory, not a permanent loss. The theory assumes further, and somewhat counterintuitively, that increments in retrieval strength and storage strength that result from restudy are a *decreasing* function of the item's current retrieval strength. Thus, to the extent that retrieval-induced forgetting results in Rp– items having lower retrieval strength than corresponding Nrp items, reexposing both types of items will produce larger increments in the storage and retrieval strengths of Rp– items than of Nrp items. Under some circumstances, therefore, reexposure of Rp– items might even result in their becoming more recallable than reexposed Nrp items, especially at a long delay.

In fact, Storm et al. (2008) found that forgetting can be repeatedly induced and eliminated with successive retrieval practice and reexposure trials and that reexposure led to larger increments in the recall of Rp– items than of Nrp items. Arguably, this type of repeated retrieval practice with intermittent reexposure is a pattern that happens quite frequently in real life—but very little is known regarding the consequences of such cycles of retrieval-induced forgetting and relearning. In one condition, Storm et al. provided participants with one block of retrieval practice, one block of reexposure, a second block of retrieval practice, a second block of reexposure, and then a third and final block of retrieval practice. When participants were given a final recall test 5 min later, performance for Rp– items and Nrp items was not significantly different (.44 and .43, respectively). When participants were given the same three blocks of retrieval practice without the intermittent reexposure, however, a robust effect of retrieval-induced forgetting was observed (.22 and .31, respectively).

The finding that intermittent exposure to nonpractised items between rounds of retrieval practice can prevent those items from, in the end, suffering retrieval-induced forgetting should be somewhat of a relief to educators who might worry about the negative consequences of selective retrieval; specifically, the possibility that testing some—but not all—information about a given topic on a practice test could inadvertently lead to students having an impaired ability to recall the untested information about that topic on a later more comprehensive exam. After all, even if nontested information is inhibited by retrieval practice or selective testing, that information can regain its accessibility—and perhaps become even more accessible than it would have been had it not been inhibited in the first place—if given the opportunity to be restudied. To understand fully the impact of repeated forgetting and exposure to items in memory, however, their long-term consequences must be examined.

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THE LOGIC OF THE CURRENT STUDY

The primary goal of the present study was to determine if retrieval-induced forgetting persists across a 1-week delay on a final test that is (1) not susceptible to output interference and (2) not influenced by an earlier test. To address this issue, we administered a modified version of the standard retrieval-practice paradigm in which participants studied category-exemplar pairs and then received extralist retrieval practice for new exemplars from half of the categories. Studied exemplars from practised categories (Rp– items) and studied exemplars from nonpractised categories (Nrp items) were then tested via category-plus-one-letter-stem retrieval cues at one of two retention intervals, 5 min or 1 week, with half the Rp– and Nrp items tested after 5 min and the remaining items tested after 1 week.

In addition, to examine how retrieval-induced forgetting is influenced by intermittent exposure to nonpractised items, participants were reexposed to half of the Rp– and Nrp items between each round of retrieval practice. Two categories received retrieval practice without intermittent reexposure to nonpractised items (No Relearn Rp– items); two categories did not receive retrieval practice or intermittent reexposure (No Relearn Nrp items); two categories received retrieval practice with intermittent reexposure to nonpractised items (Relearn Rp– items); and two categories did not receive retrieval practice, but did receive intermittent reexposure (Relearn Nrp items). We predicted that intermittent reexposure would prevent both short- and long-term retrieval-induced forgetting from being observed.

METHOD

Participants

A total of 64 undergraduate students from the University of California, Los Angeles, and from the University of Illinois at Chicago (13 males, 51 females) averaging 19.9 years of age participated for course credit in an introductory psychology course.

Materials

Eight categories were selected, each consisting of six exemplars of high taxonomic strength that did not begin with the same first letter. The eight categories were first divided into two separate sets of four such that—for any individual participant—half the categories received retrieval practice and the other half did not. The two subsets were further divided into two sets of two such that half of the categories receiving retrieval practice (and half of the categories not receiving retrieval practice) were either relearned or not relearned. Thus, there were (1) two practised categories that were relearned and two practised categories that were not relearned, plus (2) two unpractised categories that were relearned and two unpractised categories that were not relearned. Finally, half of the exemplars from each category were tested after a 5-min retention interval, whereas the other exemplars from each category were tested after a 1-week retention interval.[1] The materials were counterbalanced across conditions such that each exemplar was associated with every experimental condition equally often across participants.

During retrieval practice, participants were shown a series of cues that consisted of a category name plus the first two letters of a relatively low frequency exemplar of the category (e.g., Fruit: ma____ as a cue to recall ''mango''). The targets of this retrieval practice always consisted of items that were not presented during the study phase of the experiment. Although this procedure differs from the typical retrieval-practice paradigm, retrieval-induced forgetting has been reliably observed when participants generate extra-list exemplars during retrieval practice (e.g., Bäuml, 2002; Storm & Angello, 2010; Storm et al., 2006, 2007, 2008). The decision to employ an extralist

[1] Because participants were tested on half of the exemplars from each category on the 5-min test and then the other half of the exemplars from the same categories on the 1-week test, it is possible that taking the 5-min test caused the retrieval-induced forgetting of items to-be-tested on the 1-week test. Without the necessary baseline condition, we do not know whether this type of retrieval-induced forgetting took place. Even if it did occur, however, it is unlikely to account for the long-term retrieval-induced forgetting effect that we observed. Both Rp– and Nrp items would have been susceptible to the consequences of the 5-min test and, moreover, prior work has shown that stronger items are, if anything, more susceptible to retrieval-induced forgetting than are weaker items (Anderson et al., 1994; Storm et al., 2007). That is, because the Nrp items were more accessible at the time of the 5-min test, they would have been expected to be more susceptible to retrieval-induced forgetting than the Rp– items. Thus, if taking the 5-min test did influence the 1-week test, it would have been more likely to decrease the size of the long-term retrieval-induced forgetting effect than to increase it.

semantic generation form of retrieval-practice task was based on a number of considerations. First, Storm et al. (2008) used extralist generation, and we wanted to follow their design as closely as possible. Second, there is good reason to believe that the use of extralist generation makes one less susceptible to interitem integration. Prior work has shown that if participants integrate Rp + and Rp– items during initial study—spontaneously, owing to instruction, or due to the nature of the materials—then retrieval-induced forgetting can be reduced or even eliminated (e.g., Anderson & McCulloch, 1999; Bäuml & Hartinger, 2002; Goodmon & Anderson, 2011). By having participants generate new exemplars during retrieval practice, such interitem integration is prevented. Finally, by employing extralist retrieval practice we were able to make all six exemplars of a given category presented during the study phase serve as either Rp– items or Nrp items, thus increasing the number of critical observations and, hence, statistical power. Importantly, to prevent interference at test, the extralist items used to create retrieval-practice cues were not included on either of the final tests.

Procedure

During the study phase, 48 category-exemplar pairs were presented via computer at a rate of one pair per second (the same presentation rate used by Storm et al., 2008). The presentation order was set randomly with the constraint that no two consecutive pairs were from the same category.

The retrieval-practice/relearning phase immediately followed the study phase. During retrieval-practice/relearning, participants received one block of retrieval practice, followed by one block of relearning, a second block of retrieval practice, a second block of relearning, a third block of retrieval practice, a third block of relearning, a fourth block of retrieval practice, a fourth block of relearning, and, finally, a fifth block of retrieval practice. We gave participants five rounds of retrieval practice, as opposed to the three rounds employed by Storm et al. (2008), in an effort to increase the size of the retrieval-induced forgetting effect and thus the probability of that effect surviving the 1-week delay.

Although the same cues were provided during each block of retrieval practice, and the same items were relearned in each block of relearning, the order of their presentation was different. Each block of retrieval practice consisted of 24 extralist category-plus-two-letter stem cues (six from each of four categories) appearing on the screen for 5 s each (e.g., Category: XX____), with participants instructed to write down an exemplar that completed the two-letter stem. None of the letter-stem cues began with the same letter as a studied item from the same category. Each block of relearning consisted of the re-presentation of all of the category-exemplar pairs from the two practised categories and the two unpractised categories that were to be relearned. Each relearning block contained 24 pairs (six from each of those four categories) presented in random order and for 1 s each.

After completing the retrieval-practice/relearning phase and a subsequent 5-min delay during which they engaged in an unrelated word-search task, participants were given a category-plus-one-letter-stem cued-recall test for 24 of the 48 studied category-exemplar pairs (e.g., Category: X_____). Each cue was presented for 3 s, with the participants responding out loud and the experimenter recording their responses. Upon completion of the test, participants were informed that the first session of the experiment was complete and that they should return in exactly one week to continue the experiment. One week later, participants returned and were immediately given a category-plus-one-letter stem cued-recall test for the remaining 24 studied category-exemplar pairs.

RESULTS AND DISCUSSION

Retrieval-practice performance

Unfortunately, due to the misplacement of several subject packets, retrieval-practice data are not available for 10 of the 64 participants. The remaining 54 participants successfully generated exemplars on 31% ($SD = 13\%$), 35% ($SD = 13\%$), 37% ($SD = 14\%$), 39% ($SD = 15\%$), and 41% ($SD = 15\%$) of the trials during the first, second, third, fourth, and fifth blocks of retrieval practice, respectively. Performance was very similar in the no-relearning and relearning conditions, failing to differ significantly in each round of retrieval practice and failing to differ overall (without relearning: $M = 37\%$, $SD = 16\%$; with relearning: $M = 36\%$, $SD = 15\%$), $t(53) = 0.47$, $p = .64$.

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Final cued-recall performance

Recall performance on the 5-min and 1-week delayed cued-recall tests is shown as a function of retrieval-practice and relearning status in Figure 1 and was analysed using a 2 (delay: 5-min test vs. 1-week test) × 2 (retrieval-practice status: Rp– vs. Nrp) × 2 (reexposure: not relearned vs. relearned) repeated measures analysis of variance (ANOVA). As can be seen in Table 1, all main effects as well as two interactions were statistically significant. First, the retrieval-induced forgetting effect was significantly larger without relearning than it was with relearning. Second, the benefit of relearning was significantly larger after 5 min than it was after 1 week. Of most interest, however, was the fact that retrieval-practice status did not interact significantly with delay. To examine these results further, we analysed recall performance on the 5-min and 1-week tests separately.

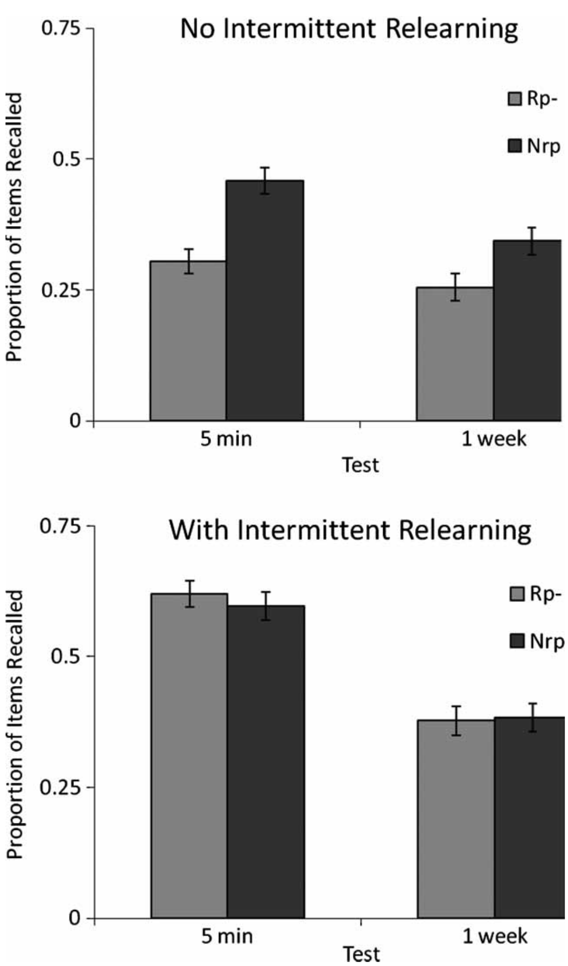

Figure 1. Mean proportion of items correctly recalled on the 5-min and 1-week tests as a function of item type (Rp– and Nrp) and relearning condition (with intermittent relearning or no intermittent relearning). Error bars show mean +/–1.0 SE.

Five-minute delay. Recall performance on the 5-min delayed cued-recall test was analysed using a 2 (retrieval-practice status: Rp– vs. Nrp) × 2 (reexposure: not relearned vs. relearned) repeated measures ANOVA. As expected, a main effect of relearning was observed. Participants recalled more items that had been intermittently relearned between rounds of retrieval practice ($M = 60.1\%$, $SE = 2.0\%$) than they did items that had not been intermittently relearned ($M = 38.2\%$, $SE = 1.8\%$), $F(1, 63) = 82.57$, $MSE = 0.04$, $p < .001$, partial $\eta^2 = 0.57$. A main effect of retrieval-practice status was also observed such that fewer Rp– items ($M = 46.2\%$, $SE = 1.7\%$) were recalled than were Nrp items ($M = 52.7\%$, $SE = 2.0\%$), $F(1, 63) = 8.02$, $MSE = 0.03$, $p = .006$, partial $\eta^2 = 0.11$.

Finally, in replication of the pattern observed by Storm et al. (2008), a significant interaction emerged such that more retrieval-induced forgetting was observed without intermittent relearning than with intermittent relearning, $F(1, 63) = 16.87$, $MSE = 0.03$, $p < .001$, partial $\eta^2 = 0.21$. Moreover, a large and highly reliable effect of retrieval-induced forgetting was observed without intermittent relearning (M forgetting effect = 15.3%), $t(63) = 4.68$, $p < .001$, $d = 0.85$, whereas a nonsignificant effect in the direction of retrieval-induced facilitation was observed with intermittent relearning (M facilitation effect = 2.4%), $t(63) = 0.78$, $p = .44$, $d = 0.08$.

One-week delay. Recall performance on the 1-week delayed cued-recall test was also analysed using a 2 (retrieval-practice status: Rp– vs. Nrp) × 2 (reexposure: not relearned vs. relearned) repeated measures ANOVA. Once again, a

TABLE 1
Analysis of variance for final cued-recall performance

Source	*F*	*MSE*	*p*	*Partial η^2*
Relearning	77.03	0.04	.001	0.55
RP status	10.55	0.04	.002	0.14
Delay	44.65	0.07	.001	0.42
Relearning × RP status	17.40	0.03	.001	0.22
Relearning × Delay	20.93	0.03	.001	0.25
RP status × Delay	0.37	0.03	.544	0.01
Relearning × RP status × Delay	2.04	0.03	.158	0.03

Degrees of freedom for all effects: (1, 63).

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significant main effect of relearning was observed, $F(1, 63) = 13.05$, $MSE = 0.03$, $p = .001$, partial $\eta^2 = 0.17$. A main effect of retrieval-practice status was also observed such that Rp– items ($M = 31.6\%$, $SE = 2.2\%$) were recalled significantly less often than were Nrp items ($M = 36.3\%$, $SE = 2.1\%$), $F(1, 63) = 4.29$, $MSE = 0.03$, $p = .04$, partial $\eta^2 = 0.06$. Although the interaction only approached significance, $F(1, 63) = 3.09$, $MSE = 0.04$, $p = .08$, partial $\eta^2 = 0.05$, a significant retrieval-induced forgetting effect was observed in the condition without intermittent relearning (*M* forgetting effect = 8.9%), $t(63) = 2.70$, $p = .009$, $d = 0.31$, whereas no evidence of retrieval-induced forgetting was observed in the condition with intermittent relearning (*M* forgetting effect = 0.5%), $t(63) = 0.16$, $p = .87$, $d = 0.02$.

Although retrieval-induced forgetting persisted across the 1-week delay, the size of the effect did decrease, at least numerically, across that delay. Interestingly, this decrease appeared to be driven by changes in the Nrp items. Examining the nonrelearned items alone, we see that Nrp items dropped 11.4% across the delay, whereas Rp– items dropped only 5.0%. This pattern appears to suggest that Rp– items were somehow protected from forgetting. There is, however, another plausible explanation: Perhaps Rp– items that were inaccessible on the 5-min test were more likely to become accessible on the 1-week test. In other words, the attenuated forgetting of Rp– items could be due to their recovery or reminiscence. Because different items were tested at different delays, however, separating reminiscence and oblivescence in the present study is impossible.

GENERAL DISCUSSION

The present research suggests that retrieval-induced forgetting can survive a 24-hour delay. In fact, significant retrieval-induced forgetting was observed even after a 1-week delay. Although long-term effects of retrieval-induced forgetting have been observed in some studies (e.g., Garcia-Bajos et al., 2009; Migueles & Garcia-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006), interpreting these studies is complicated by aspects of their respective designs. In many of these experiments, for example, participants were tested on the same items twice: first on a nondelayed test and second on a delayed test (e.g., Migueles & Garcia-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006). Owing to this repeated-test design, the retrieval-induced forgetting observed on the delayed tests may have been caused by the fact that Rp– items were recalled less often than Nrp items on the nondelayed test, which would have amounted to different amounts of retrieval practice for the two types of items (Roediger & Karpicke, 2006). Furthermore, the only study to show significant long-term retrieval-induced forgetting without using a repeated-test design employed a final test that did not control for the order in which participants recalled the exemplars (Garcia-Bajos et al., 2009). Participants in their study may have recalled Rp+ items first, thus causing output interference for Rp– items at final test. To our knowledge, the current study is the first to show significant long-term retrieval-induced forgetting when both output interference is controlled and when performance on the final test is not contaminated by an earlier, nondelayed, test. The fact that we found long-term forgetting under these more controlled conditions suggests that the forgetting observed in prior studies may have also been caused by the persisting consequences of inhibition arising during retrieval practice.

Practical implications

The finding that retrieval-induced forgetting can be a persisting phenomenon has potentially important practical implications. For example, the way in which eyewitnesses are questioned after observing a crime may influence their ability to remember other details about that crime (MacLeod, 2002; Saunders & MacLeod, 2002; Shaw et al., 1995). Similarly, the way in which students are tested—in the classroom or in their own studying—may render related nontested information less recallable on future tests or in future real-world contexts (e.g., Carroll et al., 2007; Chan, McDermott, & Roediger, 2006; Little et al., 2011). The implications of retrieval-induced forgetting in these and other contexts, however, are likely to be determined, in part, by the power of selective retrieval practice to cause forgetting beyond just a few minutes. If retrieval-induced forgetting is a persisting phenomenon, which the current results suggest it can be, then the practical consequences may be more far reaching than previously appreciated.

In that connection, it is important to emphasise that the size of the long-term retrieval-induced

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forgetting effect we observed was no doubt reduced by a critical control feature—namely, avoiding having the effects of an earlier test carry over to the final, criterion test—a control that is, typically, going to be absent in real-life situations. That is, there may be many situations in one's life where what amounts to Rp + items are recalled over and over again, making Rp– items progressively less accessible than corresponding Nrp items, which would then lead to advantages in the recall of Nrp items over Rp– items being propagated—and increased—over time. Such effects could be a consequence of one's moving to a new town and/or job, for example, where old names and numbers might compete with the retrieval of to-be-learned new names and numbers, or perhaps as a consequence of one's simply wanting to recall some events or facts repeatedly versus others, as Bjork et al. (1998) suggested might characterise some victims of abuse.

Generality of the present findings

Although we observed significant long-term retrieval-induced forgetting in the current experiment, it is important to note that the procedure we employed did differ from the typical retrieval-practice procedure. For example, participants typically receive three rounds of retrieval practice, whereas participants in our study received five rounds of retrieval practice. This difference is potentially important because several studies have shown that increasing the number of retrieval-practice trials can increase the magnitude of the retrieval-induced forgetting effect (e.g., Levy, McVeigh, Marful, & Anderson, 2007; Storm et al., 2008; but see Macrae & MacLeod, 1999). Storm and colleagues, for example, found that participants exhibited 1%, 5%, and 9% effects of retrieval-induced forgetting after one, two, and three rounds of retrieval practice, respectively.

In fact, we chose to employ five rounds of retrieval practice precisely because we hoped it would increase the size of the effect (which it did, up to 15% in the 5-min condition) and, thus, increase the likelihood of the effect persisting across the 1-week delay. Owing to this decision, however, we do not know whether long-term retrieval-induced forgetting would have been observed had we employed only three rounds of retrieval practice. To address this issue, we ran a second experiment identical to the one reported here with one exception: Rather than give participants five rounds of retrieval practice, participants were given three rounds of retrieval practice. Although we do not report these data in full, it is important to note that a significant effect of retrieval-induced forgetting was observed for nonrelearned items after the 1-week delay. Specifically, Rp– items ($M = 27.8$, $SE = 2.1\%$) were recalled significantly less often than Nrp items ($M = 33.1\%$, $SE = 2.2\%$), $t(77) = 2.00$, $p < .05$, $d = 0.23$.

The fact that the size of the retrieval-induced forgetting effect was smaller after three rounds of retrieval practice (5.3%) than five rounds of retrieval practice (8.9%) supports our intuition that increasing the amount of retrieval practice makes it easier to observe forgetting after a long delay. Although speculative, one might wonder if increasing the amount of retrieval practice even further might make the consequent forgetting even more long-lasting. To date, no study employing a long retention interval has manipulated the number of retrieval-practice trials.

Different studies *have* employed differing numbers of retrieval-practice trials, but other differences about those studies, such as the nature of the materials used and/or the details of the designs, make it difficult, if not impossible, to know what effect the number of retrieval-practice trials may have had. It is interesting to note, however, that Chan (2009), who failed to observe retrieval-induced forgetting after 24 hours on a nonrepeated final test that controlled for output interference, only employed two rounds of retrieval practice.

Theoretical implications

It is important to remind ourselves that whether an item remains forgotten across some delay is likely to depend less on the length of that delay than on what happens during that delay. As expressed by McGeoch (1932, p. 144), "[i]n time all events occur, but to use time as an explanation would be to explain in terms so general as to be meaningless . . . Time, in of itself, does nothing." Thus, whether retrieval-induced forgetting is observed after 20 min, 24 hours, 1 week, or 20 years, is likely to depend on a number of factors that simply correlate with the duration of the retention interval, such as the degree of contextual change or whether the forgotten items are reencountered.

Given that perspective, and from the standpoint of the inhibitory view of retrieval-induced

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forgetting that we favour, long-lasting retrieval-induced forgetting may be largely restricted to situations in which Rp– items are repeatedly subjected to inhibition and not reexposed. That items will, under normal circumstances, recover from inhibition is intrinsic to the very idea of inhibition—versus, say, erasure—as is captured in Brunton's (1883) classic definition of *inhibition*: ''the arrest of the function of a structure or organ, by the action upon it of another, while the power to execute those functions is still retained, and can be manifested as soon as the restraining power is lifted''. Consistent with that idea, both MacLeod and Macrae (2001) and Saunders et al. (2009) demonstrated the absolute recovery of Rp– items following a 24-hour delay, suggesting that the retrieval-induced forgetting effect was eliminated not because Nrp items dropped to the level of Rp– items, but because Rp– items that were not recallable on the first test became recallable on the second test.

Another way to examine whether Rp– items are more likely than Nrp items to be recovered across a retention interval is to examine relative patterns of reminiscence and oblivescence. Such an analysis is impossible in the current study because participants were only tested on each item once, either after 5 min or 1 week. We can, however, analyse the data from Storm et al. (2006) to check this possibility because participants in that study were tested on the same items after both 5 min and 1 week. If items suffering retrieval-induced forgetting are being recovered, then the extent to which inaccessible items become accessible should differ across Rp– and Nrp items.

Using the data from Storm et al. (2006), we analysed the number of items that participants were able to recall after 1 week that they were not able to recall after 5 min (reminiscence). On average, 6.5% ($SE = 1.1\%$) of the Rp– items were not recalled on the first test but successfully recalled on the second test, whereas 3.3% ($SE = 0.7\%$) of the Nrp items were not recalled on the first test but successfully recalled on the second test, and this difference was statistically significant, $t(63) = 2.67$, $p = .01$, $d = 0.36$. When we analysed the number of items that participants failed to recall after 1 week that were recalled after 5 min (oblivescence), Rp– items ($M = 10.3\%$, $SE = 1.4\%$) and Nrp items ($M = 11.0\%$, $SE = 1.6\%$) failed to differ, $t(63) = 0.46$, $p = .646$, $d = 0.06$. The observation that Rp– items are more likely than Nrp items to be recovered across a retention interval is consistent with an inhibition-plus-recovery view and may explain why retrieval-induced forgetting tends to become attenuated with delay. It is important to note, however, that this interpretation is preliminary and should be treated with some caution. It is possible, for example, that Rp– items exhibited higher levels of reminiscence than Nrp items because of their lower level of initial recall.

Another factor that has been shown to reduce retrieval-induced forgetting is reexposure. Two recent studies have shown that reexposing Rp– and Nrp items following retrieval practice is sufficient to eliminate the effect (Little et al., 2011; Storm et al., 2008). Reexposure, in fact, consistent with the implications of the New Theory of Disuse (Bjork & Bjork, 1992) discussed earlier, may change everything. The theory predicts that under some conditions, including a long retention interval, relearned Rp– items may become more recallable than relearned Nrp items. The design of the present experiment did not create the optimal conditions for observing such an advantage, however, because the learning phase concluded with a retrieval-practice cycle, not a relearning cycle. The present work does suggest, however, that reexposure to Rp– and Nrp items between multiple rounds of retrieval practice can prevent retrieval-induced forgetting. Specifically, whereas five rounds of retrieval practice led to significant forgetting (both after 5 min and 1 week), the same five rounds of retrieval practice interleaved by four rounds of reexposure failed to cause forgetting.

The finding that interleaved reexposure can eliminate retrieval-induced forgetting, although compatible with the inhibitory view of retrieval induced forgetting, is somewhat problematic for the blocking explanation of retrieval-induced forgetting. Retrieval practice—even if interleaved by reexposure to Rp– and Nrp items—should still have caused the practised items to become strengthened. Moreover, research has shown that the benefits of testing tend to increase with retention interval (e.g., Halamish & Bjork, 2011; Kornell, Bjork, & Garcia, 2011; for a review, see Roediger & Karpicke, 2006), suggesting that the practised items may have exerted even more interference on nonpractised items after the delay. Thus, if retrieval-induced forgetting simply reflects blocking or associative interference then one might have expected to observe retrieval-induced forgetting in the relearning condition.

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CONCLUDING COMMENT

Although retrieval-induced forgetting can persist for a week or more, the present findings do not imply that such forgetting is necessarily permanent. After all, retrieval-induced forgetting was somewhat attenuated across the delay. Nevertheless, even if retrieval-induced forgetting is typically a temporary effect—one that only persists if items are both repeatedly subjected to retrieval-induced forgetting and not re-encountered—it may still have a lasting influence on memory by biasing subsequent learning and rehearsal. Items suffering retrieval-induced forgetting are by definition less recallable, which should make them less likely to be recalled and integrated with new learning. Thus, one might expect items that are frequently inhibited and rarely encountered to become progressively weaker in memory over time compared to items that are frequently encountered and rarely inhibited. Such dynamics may underlie updating processes whereby old and irrelevant information is set aside in favour of new and more relevant information. If information remains relevant, or becomes relevant again, there are likely to be intermittent relearning opportunities; if not, such information may become increasingly forgotten via the retrieval of competing information.

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