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Successful inhibition, unsuccessful retrieval: Manipulating time and success during retrieval practice

Benjamin C. Storm
University of Illinois at Chicago, IL, USA

John F. Nestojko
University of California, Los Angeles, CA, USA

Retrieving an item or set of items from memory can cause the forgetting of other related items in memory; a phenomenon known as retrieval-induced forgetting. According to the inhibitory account of retrieval-induced forgetting, in searching for a particular item, other items that are related but incorrect can vie for access. Inhibition functions to decrease the accessibility of such interfering items, thereby facilitating access to the target item. Experiments 1 and 2 replicated recent work suggesting that retrieval success is not a necessary condition for retrieval-induced forgetting to occur. Interfering items were forgotten even when retrieval practice was designed to be impossible. Experiments 3 and 4 employed the impossible retrieval practice procedure to examine the time-course of forgetting across a single retrieval practice trial. Results support the inhibitory account of retrieval-induced forgetting and offer insight into the dynamics of how and when inhibition plays a role in retrieval.

Keywords: Retrieval-induced forgetting; Inhibition; Interference.

Silence pervades every moment of our social and mental lives. Whether having a conversation with a friend, planning a weekend getaway, or reminiscing in one's own memories, we are continuously generating some ideas while remaining silent to other ideas. These silences can be intentional or unintentional. We may, for example, remain intentionally silent to withhold secret or taboo information from discussion. Often, however, silences are unintentional and result from the selective and competitive nature of human memory. Only a subset of the information that is stored in memory can and should be retrieved at a given point in time. Although associated with the same retrieval cues, irrelevant and inappropriate information must remain non-retrieved. So what happens to information that is not retrieved? One might think that such information remains unaffected in memory, silently waiting for its turn to be recalled. Research suggests otherwise. Whereas retrieval may facilitate the future accessibility of information that is retrieved, it appears to impair the future accessibility of information that is not retrieved. In this sense, information that is not selected for retrieval—that remains silent—is even more likely to remain silent in the future.

The immediate consequences of retrieval are obvious—items retrieved from memory become accessible to consciousness. Less obvious are the consequences of retrieval on the future accessibility of those and other items. Retrieving an item

Address correspondence to: Benjamin C. Storm, Department of Psychology, University of Illinois at Chicago, 1007 W Harrison St (MC 285), Chicago, IL 60607, USA. E-mail: bstorm@uic.edu

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from memory does not only make that item temporarily accessible, it permanently modifies the representation of that item in memory (Bjork, 1975). Consequently, information retrieved from memory becomes more recallable in the future than it would have been otherwise, and to an extent beyond that which would have occurred given extra study (see e.g., Roediger & Karpicke, 2006). Perhaps most surprising is the effect retrieval has on the accessibility of other items. Whereas many models of memory predict that non-retrieved information should become more accessible following the retrieval of related information (see e.g., Anderson, 1983; Loftus, 1973), a burgeoning body of work on retrieval-induced forgetting suggests that non-retrieved information may actually become less recallable (Anderson, Bjork, & Bjork, 1994).

The majority of research on retrieval-induced forgetting has employed the retrieval practice paradigm, which involves three main phases: study, retrieval practice, and a final test (see Anderson et al., 1994). In the study phase participants study a list of items, often category/exemplar pairs (e.g., *fruit: lemon*, *profession: dentist*, *fruit: plum*, *profession: accountant*), presented one at a time and in an interspersed order. Participants then retrieve half of the exemplars from half of the categories via guided retrieval practice (e.g., *fruit: le_____*). Practised exemplars are referred to as Rp+ items (e.g., *lemon*), non-practised exemplars from practised categories are referred to as Rp– items (e.g., *plum*), and exemplars from non-practised categories are referred to as Nrp items (e.g., *dentist*, *accountant*). After a brief delay (5–20 minutes), a memory test is administered. Not surprisingly, Rp+ items are better recalled than are both Rp– and Nrp items. The more surprising finding is that Rp– items are recalled less well than Nrp items. It is this difference between Rp– and Nrp items that is referred to as retrieval-induced forgetting.

Retrieval-induced forgetting has been shown to be a robust and general phenomenon. Not only is it found using semantically associated categorical information, but for visual scenes and event narratives in eye-witness memory (e.g., MacLeod, 2002; Shaw, Bjork, & Handal, 1995), visuo-spatial materials (e.g., Ciranni & Shimamura, 1999), fact learning (e.g., Anderson & Bell, 2001; Carroll, Campbell-Ratcliffe, Murnane, & Perfect, 2007), mathematic computations (e.g., Phenix & Campbell, 2004), autobiographical memories (e.g., Barnier, Hung, & Conway, 2004), and social information (e.g., Storm, Bjork, & Bjork, 2005). Whereas the empirical phenomenon of retrieval-induced forgetting is well accepted, the mechanism thought to underlie retrieval-induced forgetting remains much more controversial.

The idea that retrieval acts as a self-limiting process is not new to memory research (Roediger, 1978). Retrieval strengthens the items that are retrieved, and such strengthening may block the retrieval of other items associated with the same retrieval cue. However, recent evidence suggests that retrieval-induced forgetting may in some instances result from active inhibitory processes that function to resolve interference. In order to operate adaptively, a memory system must have some means of selecting target items in the face of interference from competing items. For example, there may be strong yet contextually inappropriate items that are activated by a given retrieval cue, and it is essential that there be some means of bypassing or attenuating the interference caused by those competing items. Anderson and colleagues have argued that one way in which this type of competition can be resolved is through inhibition (Anderson, 2003, 2005; Anderson, Bjork, & Bjork, 1994; Bjork, Bjork, & Anderson, 1998). In the retrieval practice paradigm the retrieval cues presented during retrieval practice may activate non-target items (Rp– items) in addition to target items (Rp+ items), creating competition, and requiring that the non-target items be selected against, or inhibited. As a consequence of this inhibition, non-practised items become less accessible in the future than they would have been otherwise.

Researchers who doubt the role of inhibition in retrieval-induced forgetting often argue that it can be explained more parsimoniously by processes of associative interference. Retrieval practice strengthens the association between the practised item and its associated retrieval cue, and by strengthening a subset of items associated with a common retrieval cue, non-practised items will suffer from response competition at the time of test, therefore becoming less accessible given that same retrieval cue. One problem with this explanation is that retrieval-induced forgetting is also observed when independent cues are employed (Anderson & Spellman, 1995). That is, not only is the recall of Rp– items impaired when participants are tested using the same category cues, but also when they are tested using novel, independent, category cues. Cue-independent retrieval-induced forgetting has been replicated

many times (e.g., Anderson & Bell, 2001; Aslan, Bäuml, & Pastotter, 2007; Levy, McVeigh, Marful, & Anderson, 2007; MacLeod & Saunders, 2005; Shivde & Anderson, 2001), providing strong evidence against interference-based accounts of retrieval-induced forgetting. Recently, however, some researchers have questioned the validity of the cue-independent procedure and have failed to find evidence of cue-independence (see, e.g., Camp, Pecher, & Schmidt, 2005, 2007; Camp, Pecher, Schmidt, & Zeelenberg, in press; Perfect et al., 2004; Williams & Zacks, 2001), making it increasingly important to develop other means of testing the competing accounts of retrieval-induced forgetting. Two other observations that appear to support the inhibitory account are strength-independence and competition-dependence.

Strength-independence refers to the observation that the extent to which Rp– items are forgotten is independent of the extent to which Rp+ items are strengthened. According to interference-based accounts, recall for Rp– items is impaired because the strengthened Rp+ items interfere at the time of test. Thus forgetting occurs because other items are strengthened. Research has shown, however, that strengthening other items is not sufficient to cause retrieval-induced forgetting (e.g., Anderson, Bjork, & Bjork, 2000; Bäuml, 2002). For example, when participants re-study Rp+ items rather than retrieve them during what would typically be the retrieval practice phase, the later recall of Rp– items is not impaired, even though the Rp+ items are strengthened to an equivalent extent. If retrieval-induced forgetting is purely the consequence of strengthening the Rp+ items, strengthening those items should cause forgetting even if the strengthening occurs as a result of additional study.

Competition-dependence refers to the observation that the extent to which an item causes competition during retrieval practice determines the extent to which that item suffers from retrieval-induced forgetting (e.g., Anderson, et al., 1994; Shivde & Anderson, 2001; Storm, Bjork, & Bjork, 2007). Anderson et al. (1994; Exp. 3), for example, found that exemplars of high taxonomic strength (e.g., *orange* and *banana*) suffer from retrieval-induced forgetting to a greater extent than exemplars of low taxonomic strength (e.g., *mango* and *guava*). Items weakly associated with the retrieval practice cues are less likely to create competition, and are therefore less likely to be targeted by inhibitory control. Neither strength-independence nor competition-dependence can be easily accounted for by non-inhibitory accounts of retrieval-induced forgetting.

RETRIEVAL SUCCESS AND RETRIEVAL-INDUCED FORGETTING

Researchers have typically assumed that retrieval must be successful for retrieval-induced forgetting to occur, and they have been very careful to design retrieval-induced forgetting experiments in such a way so as to ensure high levels of retrieval practice success. In fact, Anderson et al.'s (1994) original study utilised an expanding schedule of trials in part to ensure participants were successful during retrieval practice (see Landauer & Bjork, 1978). However, according to the inhibitory account, high levels of success may not be necessary. First, because inhibitory-based effects of retrieval-induced forgetting are presumably strength-independent, failing to retrieve—and therefore failing to strengthen items during retrieval practice—should not diminish the amount of forgetting that occurs. Second, and more importantly, the crux of the inhibitory account is that inhibition serves to resolve competition. The term retrieval-induced forgetting is a bit misfortunate in this sense, because it seems to imply that the retrieval itself is causing forgetting. Instead, it is the competition that arises during retrieval that creates the need for inhibition. And if inhibitory processes are elicited to resolve competition during a retrieval attempt, the consequences of those inhibitory processes should occur regardless of whether the retrieval eventually succeeds. Importantly, the interference account makes a very different prediction. The rate of success during retrieval practice should determine the extent to which practised items are strengthened—which, in turn, should determine the extent to which non-practised items suffer from interference on the final test. Thus, the interference account predicts that the magnitude of the retrieval-induced forgetting effect should increase with retrieval practice success.

To date only one study has demonstrated that retrieval success is not a necessary condition for retrieval-induced forgetting (Storm, Bjork, Bjork, & Nestojko, 2006). Storm and colleagues had participants study a list of category/exemplar pairs and then engage in retrieval practice

consisting of category-plus-two-letter stem cues that either did or did not represent the initial letters of any exemplar associated with that category. For half of the cues, retrieval practice was possible (e.g., *Fruit: or___; orange*); for the other half of the cues, retrieval practice was impossible (e.g., *Weapons: wo___; no such weapon*). This manipulation effectively dictated whether retrieval practice could or could not be successful. Retrieval-induced forgetting was observed in both cases and, importantly, the size of the effect did not differ for exemplars associated with categories receiving possible retrieval practice versus exemplars associated with categories receiving impossible retrieval practice. These results suggest that retrieval-induced forgetting can be more accurately characterised as retrieval-*attempt*-induced forgetting.

The primary goal of the current study was to provide additional evidence that retrieval success is not a necessary condition for retrieval-induced forgetting. Memory researchers have cited and interpreted this finding to be compelling evidence favouring the inhibitory account. Furthermore, replicating the effect is especially important due to methodological concerns regarding the final test employed by Storm et al. (2006). Rather than test categories or items independently on the final test, participants were shown all of the category-plus-letter-stem cues simultaneously on a single piece of paper. It is conceivable that this procedure gave participants too much discretion over which items to attempt to recall. Because participants experienced difficulty in retrieving items from the impossible categories during retrieval practice, they may have been biased against attempting to retrieve items from those same categories on the final test. Experiments 1 and 2 attempted to replicate the retrieval-induced forgetting effect with impossible retrieval practice employing final tests less susceptible to this bias.

RETRIEVAL PRACTICE TIME AND RETRIEVAL-INDUCED FORGETTING

There is reason to believe that impossible retrieval practice has the potential, under certain circumstances, to lead to even more retrieval-induced forgetting than possible retrieval practice. When retrieval succeeds, the retrieval attempt is functionally complete, and the person no longer needs to engage in processes of retrieval. However, when retrieval fails, the retrieval attempt continues, thereby forcing the person to continue to engage in processes of retrieval. And if the retrieval attempt is extended so should the probability of an item in memory causing competition, thereby increasing the probability that such an item will be targeted by inhibition and suffer from retrieval-induced forgetting.

In typical studies of retrieval-induced forgetting it is impossible to examine the relationship between retrieval practice time and retrieval-induced forgetting because the time participants take to retrieve an item during retrieval practice is determined by whether or not participants are able to retrieve that item. Given this methodological impasse, it is not surprising that the temporal dynamics of inhibition during retrieval practice have yet to be explored. However, by employing the impossible retrieval practice procedure it is possible to manipulate the amount of time in which participants engage in retrieval. Impossible retrieval practice guarantees that participants will fail to recall a viable item associated with the presented retrieval cue, thereby ensuring that participants will attempt to recall an item until the trial is complete.

In Experiments 3 and 4 participants were presented two exemplars associated with a given category and then shown a retrieval practice cue associated with that category. One-third of the retrieval cues consisted of cues associated with actual category exemplars (possible retrieval practice); the other two-thirds of the retrieval cues consisted of cues not associated with any category exemplar (impossible retrieval practice). We then manipulated the amount of time participants were given to respond to each retrieval practice cue—4, 8, or 12 seconds. On other trials participants were not given any retrieval practice cue, thus providing a baseline (Nrp items). After a brief delay participants were given a surprise test on all of the earlier studied items.

It is not immediately obvious what pattern of results to expect. A straightforward prediction might be that retrieval-induced forgetting will increase linearly as a function of the amount of time participants spend during retrieval practice. That is, 4 seconds should result in a certain amount of forgetting, 8 seconds should result in more, and 12 seconds in still more. Another possibility is that there will be a non-monotonic increase in the amount of forgetting during a retrieval attempt. For example, there is evidence that initial retrieval practice trials lead to facilitation and that impairment is only observed after

repeated trials (e.g., Shivde & Anderson, 2001; Levy et al., 2007). Likewise, it is possible that recall will be facilitated after 4 seconds, and then, as inhibition continues to exert its influence, become increasingly impaired after 8 and 12 seconds. Finally, it is also possible that most of the forgetting will take place as a consequence of the first 4 seconds of retrieval practice, and that little, if any, forgetting will take place thereafter. Regardless of the pattern of results that emerges, exploring the temporal dynamics of forgetting during retrieval will have important implications for both future investigations and theoretical accounts of retrieval-induced forgetting.

EXPERIMENT 1

The first experiment replicated Storm et al.'s (2006) impossible retrieval practice paradigm with one important difference—rather than simultaneously presenting all of the cues during the final test, we displayed each cue individually on the computer screen. In doing so we sought to ensure that participants spent an equivalent amount of time attempting to recall each item on the final test. A second goal of the study was to explore whether participants who demonstrate high levels of retrieval-induced forgetting owing to impossible retrieval practice also demonstrate high levels of retrieval-induced forgetting owing to possible retrieval practice. A significant correlation should be observed if common mechanisms underlie the forgetting caused by both forms of retrieval practice.

Method

Participants

A total of 56 undergraduate students (25 men and 31 women, mean age = 20.6 years, all fluent English speakers) from the University of California, Los Angeles received credit towards an introductory psychology course for their participation.

Materials

Study lists. The study lists consisted of the same 48 category/exemplar pairs (six members of eight categories) used by Storm et al. (2006). For counterbalancing purposes, each category was divided into two subsets (A and B) of three exemplars. During study, participants were exposed to three exemplars from each of the eight categories via semi-random interleaved presentation. Half of the participants studied set A, and half of the participants studied set B.

Retrieval practice. Four of the eight categories received retrieval practice, with the particular categories receiving practice counterbalanced across participants. For two of the practised categories, participants were guided to retrieve three exemplars that had not been presented during their original study phase via category-plus-two-letter-stem retrieval cues (possible retrieval practice). For the other two categories, participants were shown a category name as well as a realistic two-letter stem, but the two letters did not begin an actual exemplar associated with that category (impossible retrieval practice). None of the category/exemplar pairs appeared in both the studied list and the retrieval practice task.

A total of 12 category-plus-stem cues (6 possible and 6 impossible) were presented to an individual participant for practice three times each in a semi-random interleaved order. The particular categories that were associated with possible and impossible retrieval practice were counterbalanced across participants, and the materials were controlled such that no two exemplars shared the same initial two letters and such that no two exemplars in the same category shared the same initial letter.

Procedure

The experiment consisted of three phases: study, retrieval practice, and final test. During the study phase, 24 category/exemplar word pairs were presented one at a time on the computer for 5 seconds each. The order of presentation was random with the constraint that no two consecutive pairs were from the same category. Immediately following study, the retrieval practice phase began with category-plus-stem cues appearing on the screen for 5 seconds each. Participants were instructed to write down the particular exemplar that completed each two-letter stem in their response packet. They were told that there would be repetitions and that the pairs might or might not come from the list they had just studied.

The final test was administered after an unrelated 10-minute distractor task. Recall of the same 24 category/exemplar pairs that had been presented during the study phase was tested using a category-plus-one-letter-stem cued recall

test (e.g., *fruit*: *l*_____ for *fruit*: *lemon*). Because none of the pairs had appeared during retrieval practice, there were no Rp+ items on the final test. The category-plus-stem cues were presented one at a time on the computer screen for 5 seconds each. The cues were presented in a semi-random interleaved order with the average position controlled across all experimental conditions.

Results

Retrieval practice responses

Participants generated responses on 50% ($SD = 29\%$) of the possible retrieval practice trials and 16% ($SD = 20\%$) of the impossible retrieval practice trials. As was observed by Storm et al. (2006), responses during impossible retrieval practice often reflected incorrect responses, and other times, accurate and highly creative responses.

Final recall performance

The mean recall proportions for exemplars as a function of their being Rp– or Nrp items and from categories that had received possible or impossible retrieval practice are presented in Table 1. When these data were analysed in a 2 (Rp– vs Nrp) × 2 (possible vs impossible) repeated measures Analysis of Variance (ANOVA), a significant effect of retrieval-induced forgetting emerged, with Rp– items being recalled significantly less often ($M = .67$, $SE = .02$) than their Nrp counterparts ($M = .73$, $SE = .02$), $F(1, 55) = 4.00$, $MSE = .19$, $p = .05$. The effect did not interact with retrieval practice condition, $F(1, 55) < 1$. Numerically, however, slightly more retrieval-induced forgetting was found following impossible retrieval practice (M for Rp– = .67, $SE = .03$; M for Nrp = .74, $SE = .03$) than possible retrieval practice (M for Rp– = .66, $SE = .03$; M for Nrp = .71, $SE = .03$).

TABLE 1
Mean recall rates

	Item type	
Experiment: Type of final test *Retrieval practice*	*Rp–*	*Nrp*
Experiment 1: Category-plus-stem cued recall		
Possible	.66 (.03)	.71 (.03)
Impossible	.67 (.03)	.74 (.03)
Experiment 2: Category cued recall		
Possible	.50 (.02)	.58 (.02)
Impossible	.50 (.02)	.57 (.02)

Mean recall rates for Rp– versus Nrp items from categories receiving possible versus impossible retrieval practice in Experiments 1 and 2 (*SE* in parentheses).

A significant correlation was observed between the retrieval-induced forgetting effects owing to possible and impossible retrieval practice ($r = .37$, $p < .01$). This relationship was also explored via a median split analysis. Participants were ranked in each counterbalancing condition according to the amount of retrieval-induced forgetting observed in the impossible condition and then assigned to high and low impossible retrieval-induced forgetting groups. Participants in the high impossible group demonstrated an average retrieval-induced forgetting effect of .21 ($SD = .22$), whereas participants in the low impossible group demonstrated an average retrieval-induced facilitation effect of .08 ($SD = .22$). When final recall performance in the possible condition was analysed, a 2 (high vs low impossible retrieval-induced forgetting) × 2 (Rp– vs Nrp) mixed design ANOVA revealed a significant interaction, $F(1, 54) = 11.64$, $p < .001$. Participants in the high impossible group recalled .60 ($SE = .04$) and .76 ($SE = .04$) of the Rp– and Nrp items in the possible condition, respectively, whereas participants in the low impossible group recalled .73 ($SE = .04$) and .67 ($SE = .04$) of the Rp– and Nrp items in the possible condition, respectively. Thus, individuals who demonstrated a larger effect of retrieval-induced forgetting owing to impossible retrieval practice also demonstrated a larger effect of retrieval-induced forgetting owing to possible retrieval practice.

EXPERIMENT 2

The results of Experiment 1 replicate those of Storm et al. (2006), demonstrating that retrieval success is not a necessary condition for retrieval-induced forgetting. Impossible retrieval practice led to just as much forgetting as possible retrieval practice. In Experiment 2 we sought to replicate this finding using another final test commonly employed in studies of retrieval-induced forgetting: category cued recall. Rather than test each exemplar independently, participants were provided a category cue and asked to recall the studied exemplars associated with that category.

Method

Participants

A total of 119 undergraduate students (38 men and 81 women, mean age = 20.2 years) from the University of California, Los Angeles received credit towards an introductory psychology course for their participation.

Materials and procedure

The only change made from Experiment 1 was the final test. Participants were given a category cued recall test for each of the studied categories. The test involved presenting each of the eight category cues for 10 seconds and having the participants attempt to recall the three studied exemplars associated with each category. Participants were warned that they were to only recall the exemplars that they had learned during the initial study phase.

Results

Retrieval practice responses

Generation rates during retrieval practice were very similar to those observed in Experiment 1. Participants generated a response on 48% (SD = 31%) and 13% (SD = 19%) of the possible and impossible retrieval practice trials, respectively.

Final recall performance

The mean correct recall proportions for exemplars as a function of their being Rp– or Nrp items and from categories that received possible or impossible retrieval practice are presented in Table 1. The data were analysed in a 2 (Rp– vs Nrp) × 2 (possible vs impossible) repeated measures ANOVA, and once again a significant effect of retrieval-induced forgetting was observed, with Rp– items being recalled significantly less often ($M = .50$, $SE = .02$) than Nrp items ($M = .58$, $SE = .02$), $F(1, 118) = 13.56$, $MSE = .66$, $p < .001$. And, once again, the effect did not interact with whether retrieval practice was possible or impossible, $F(1, 118) < 1$.

Although somewhat weaker than that observed Experiment 1, a significant correlation was found between the effects of retrieval-induced forgetting owing to possible and impossible retrieval practice ($r = .25$, $p < .01$). As in Experiment 1, we analysed these data via median split within each counterbalancing condition. Participants in the high impossible retrieval-induced forgetting group, who demonstrated an average retrieval-induced forgetting effect of .24 ($SD = .16$) in the impossible condition, recalled .48 ($SE = .03$) and .59 ($SE = .03$) of the Rp– and Nrp items in the possible condition, respectively. Participants in the low impossible retrieval-induced forgetting group, who demonstrated an average retrieval-induced facilitation effect of .12 ($SD = .21$), recalled .52 ($SE = .03$) and .58 ($SE = .03$) of the Rp– and Nrp items in the possible condition, respectively. A 2 (high vs low impossible retrieval-induced forgetting) × 2 (Rp– vs Nrp) mixed design ANOVA confirmed that the interaction was not significant, $F(1, 117) < 1$.

EXPERIMENT 3

The results of Experiments 1 and 2 provide further evidence that retrieval success is not a necessary condition for retrieval-induced forgetting. The attempt to retrieve an item from memory, even if unsuccessful, can cause the forgetting of other items in memory. This finding falls naturally out of the inhibitory account of retrieval-induced forgetting and is problematic for other accounts, such as interference or blocking. The purpose of Experiment 3 was to explore the relationship between the amount of time participants spend attempting to retrieve an item during retrieval practice and the amount of retrieval-induced forgetting that results. Under normal conditions it is impossible to manipulate the time in which participants take to retrieve an item from memory. Experimenters can provide a specific amount of time for participants to respond to a cue, but there is no way to manipulate the time in which it will take participants to retrieve a given response. In fact, because the level of performance during retrieval practice is typically very high, participants are undoubtedly retrieving answers well before the allotted time has expired. However, by employing impossible retrieval practice we are able to effectively manipulate the amount of time that participants attempt to retrieve an item on a given trial.

In Experiment 3 participants were first shown two exemplars from a given category and then,

immediately afterwards, a category-plus-two-letter-stem retrieval cue from the same category. This retrieval cue remained on the screen for 4, 8, or 12 seconds. Critically, two-thirds of the retrieval cues were impossible, and on such trials participants spent the entire allotted time attempting to retrieve an appropriate exemplar. The other third of the retrieval cues were possible. The possible cues were selected to be very easy in order to guarantee that the participants would be able to succeed on at least a few of the retrieval practice trials. Because possible retrieval practice was designed to be extremely easy, and thus, non-competitive, we did not expect much, if any, retrieval-induced forgetting to occur. As such, our analysis will focus exclusively on the impossible trials and, specifically, on how manipulating retrieval practice time influences the extent to which studied items suffer retrieval-induced forgetting.

It is worth pointing out how the paradigm in Experiment 3 differs from that which is typically used in studies of retrieval-induced forgetting. In most experiments participants undergo an entire retrieval practice phase during which they retrieve several members from several categories, several times each. Rarely do experimenters measure retrieval-induced forgetting after a single retrieval practice trial. In consideration of this difference, it is unclear whether forgetting will be observed at all, let alone whether the amount of forgetting will differ depending on the length of the retrieval practice trial. However, by having participants engage in retrieval practice immediately after studying related items we hoped to ensure that the studied items would interfere with retrieval practice, and therefore be targeted by inhibition.

Method

Participants

A total of 104 undergraduate students (17 men and 87 women, mean age = 18.8 years) from the University of Illinois at Chicago participated for course credit in an introductory psychology course.

Materials

Studied lists. A total of 24 lists of two exemplars were presented for participants to study. Each list consisted of two high-frequency exemplars from the same category, presented vertically on the centre of the computer screen. Eight of the categories were designated to the possible condition and were always associated with possible retrieval practice. The other 16 categories were designated to the impossible condition, and were always associated with impossible retrieval practice. The possible and impossible categories were divided into four sets of two and four categories, respectively. Each set consisted of categories for which participants would receive 0, 4, 8, or 12 seconds of retrieval practice following study. The particular set associated with each retrieval practice condition was counterbalanced across participants. Exemplars from categories associated with 0 seconds of retrieval practice will be referred to as Nrp items, and exemplars from categories associated with 4, 8, or 12 seconds of retrieval practice will be referred to as Rp– items.

Retrieval practice. A single category-plus-two-letter-stem cue was created for each of the eight categories in the possible condition. Because we wanted to ensure that participants were able to succeed during possible trials, each cue was associated with a high-frequency exemplar from its respective category. For the 16 categories in the impossible condition, a single category-plus-two-letter-stem cue was created that was not associated with any exemplar from that category. None of the stems in the possible or impossible condition began with the same letter as an exemplar that was studied from the same category.

Procedure

The experiment consisted of two phases: study/retrieval practice and test. The study/retrieval practice phase consisted of 24 trials, during which lists of two category/exemplar pairs were presented for 8 seconds. On 18 of the trials (12 impossible and 6 possible), participants were shown a category-plus-two-letter-stem cue immediately after study and asked to generate an associated exemplar. Participants were warned that none of the answers during retrieval practice would consist of exemplars previously studied. Participants were also warned that they would be tested on the studied exemplars later in the experiment.

The amount of time participants were given on each retrieval practice trial was manipulated within-participants. On six trials participants were given 4 seconds, on another six trials participants were given 8 seconds, and on another

six trials participants were given 12 seconds. The other 6 of the 24 trials served as baseline, during which no retrieval practice cue was shown. On these trials participants immediately proceeded to the next trial. The order of the trials was determined via blocked randomisation, and participants had no way to predict the amount of retrieval practice time—or if there would be retrieval practice—on a given trial. Once participants generated an exemplar in the possible condition, the experimenter pressed a button to begin the next trial. In the impossible condition participants were always given the entire allotted time for each retrieval practice trial. If a participant generated a response they were told that it was not the correct response, and to continue trying.

After completing all 24 study/retrieval practice trials, participants engaged in an unrelated 5-minute distractor task, followed by a final test. Half of the participants were given a category cued recall test in which each of the 24 categories were presented for 8 seconds, and participants were asked to recall the two studied exemplars associated with each category. The other half of the participants were given a category-plus-one-letter-stem cued recall test in which 48 cues were presented for 4 seconds each and asked to recall the studied exemplar associated with each cue. The category cues and category-plus-one-letter-stem cues were presented in a semi-random interleaved order with the average position controlled across all experimental conditions.

Results

Retrieval practice responses

Participants generated correct exemplars on 90% ($SD = 11\%$) of the possible retrieval practice trials. During impossible retrieval practice participants generated a response (regardless of whether it fit the appropriate cues) on 6% ($SD = 8\%$) of the trials. It should be noted that 40% of the participants failed to give a single response during impossible retrieval practice, and that only 11% of the participants gave more than two responses.

Final recall performance

Mean recall performance for exemplars in the impossible condition as a function of retrieval practice time and type of final test are shown in Figure 1. These data were analysed in a 4 (0 vs 4 vs 8 vs 12 seconds) $\times$ 2 (category cued recall vs category-plus-stem cued recall) mixed design ANOVA, with type of test serving as a between-participants variable. A significant main effect of retrieval practice time was observed, $F(1, 102) = 4.05$, $MSE = .13$, $p < .01$, with a mean proportion of .48 ($SE = .02$), .42 ($SE = .02$), .40 ($SE = .02$), and .40 ($SE = .02$), exemplars being recalled in the 0, 4, 8, and 12 second conditions, respectively. A planned *t*-test comparing the Nrp items with the average of the Rp– items (4, 8, and 12 s) confirmed that significant retrieval-induced forgetting had occurred, $t(103) = 3.12$, $p < .01$. Additional *t*-tests confirmed that significant

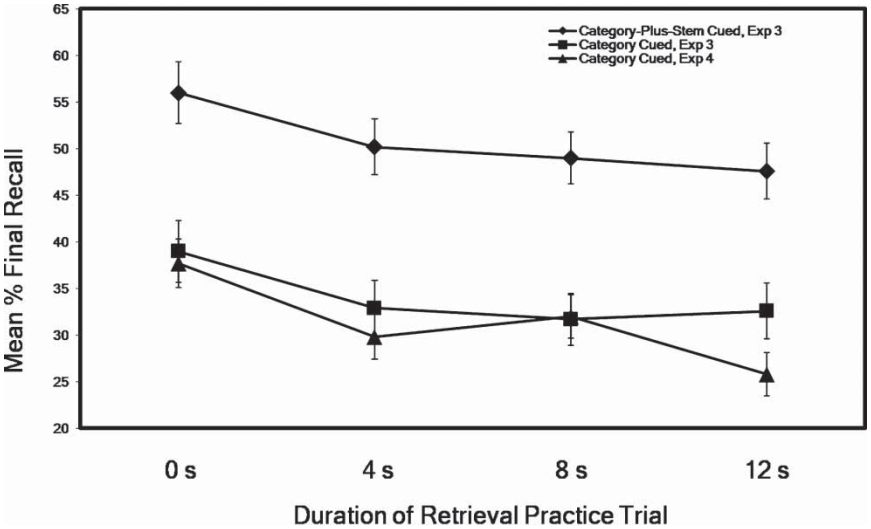

Figure 1. Mean final recall performance for non-practised exemplars in Experiments 3 and 4 as a function of type of final test and duration of retrieval practice trial.

retrieval-induced forgetting occurred in each retrieval practice time condition as well. However, recall performance did not differ between Rp– items associated with different amounts of retrieval practice time, $F(1, 102) < 1$. Also, as can be seen in Figure 1, although the level of recall was different overall, the pattern of results was nearly identical for participants in the two types of testing conditions. More specifically, the effect of retrieval practice time did not interact with type of test, $F(3, 375) < 1$.

EXPERIMENT 4

The results of Experiment 3 suggest that even 4 seconds of a single impossible retrieval practice trial is sufficient to cause retrieval-induced forgetting. However, neither 8 seconds nor 12 seconds of retrieval practice increased the magnitude of the effect. In Experiment 4 we attempted to replicate this finding under slightly different conditions. Participants in the previous experiment were pre-warned that none of the answers during retrieval practice consisted of items that they had previously studied—and, in fact, none of the retrieval practice cues was associated with studied items. The procedure was designed in that way to ensure that participants would not try to actively remember the studied items during retrieval practice. Had participants believed that a retrieval practice cue could, on occasion, be completed with a previously studied item, a very different pattern of results might have emerged.

Warning participants that retrieval practice cues may be associated with earlier studied items might be expected to increase the likelihood that studied items are explicitly rehearsed or implicitly activated during retrieval practice. Consequently, it is possible that final recall performance for the studied items would be facilitated. It is unclear, however, when such facilitation would occur, should it occur. One possibility is that participants will actively think about the studied exemplars during the initial seconds of retrieval practice, and then, only after realising that neither of the studied items fit the cue, target retrieval efforts elsewhere—thereby leading to inhibition, and consequently, retrieval-induced forgetting. Another possibility is that the studied items will be targeted by inhibition initially, but that as participants continue to fail in their retrieval attempts, they will increasingly revisit those items as the trial progresses. To test these possibilities, participants in Experiment 4 were warned that some of the answers during retrieval practice would come from exemplars studied immediately prior, and half of the possible retrieval practice trials were altered so as to conform to these instructions.

Method

Participants

A total of 75 undergraduate students (16 men and 69 women, mean age = 18.5 years) from the University of Illinois at Chicago participated for course credit in an introductory psychology course.

Materials and procedure

Experiment 4 was identical to Experiment 3 with two important exceptions. First, all of the participants were given a category cued recall final test at the conclusion of the experiment. Second, participants were warned that some of the retrieval cues during retrieval practice would be associated with items that had been studied immediately prior. And, in fact, on three of the six possible study/retrieval practice trials, the cues were altered as such. All aspects of the impossible trials were the same as in Experiment 3.

Results

Retrieval practice responses

Participants generated correct exemplars on 89% ($SD = 15\%$) of the possible retrieval practice trials. During impossible retrieval practice, participants generated a response on 11% ($SD = 14\%$) of the trials.

Final recall performance

The mean correct recall proportions for exemplars in the impossible condition, as a function of retrieval practice time (0 vs 4 vs 8 vs 12 s), was analysed using a repeated measures ANOVA. As can be seen in Figure 1, a significant main effect of retrieval practice time was observed, $F(1, 74) = 5.87$, $MSE = .18$, $p < .001$. A mean proportion of .38 ($SE = .03$), .30 ($SE = .02$), .32 ($SE = .02$), and .26 ($SE = .02$), exemplars were recalled in the 0-, 4-, 8-, and 12-second conditions, respectively. A planned *t*-test comparing the Nrp items with the average of the Rp– items (4, 8, and

12 s) confirmed that the retrieval-induced forgetting effect was significant, $t(74) = 3.26$, $p < .01$, and additional *t*-tests confirmed that significant retrieval-induced forgetting occurred in each retrieval practice condition as well. Although the pattern of results was similar to that which was observed in Experiment 3, there were some important differences. Specifically, recall initially dropped after 4 seconds of retrieval practice, increased slightly after 8 seconds of retrieval practice, and then dropped again after 12 seconds of retrieval practice. Paired samples *t*-tests indicated significant forgetting effects after the initial 4 seconds, $t(74) = 2.53$, $p < .05$, and after the final 4 seconds, $t(74) = 2.20$, $p < .05$. The facilitation effect observed between 4 and 8 seconds of retrieval practice was not significant, $t(74) < 1$, $p > .05$. Within-participants contrasts confirmed that both linear, $F(1, 74) = 11.16$, $MSE = .42$, $p < .05$, and cubic, $F(1, 74) = 4.28$, $MSE = .13$, $p < .05$, trends were statistically significant.

GENERAL DISCUSSION

The dynamics underlying human memory retrieval are not as straightforward as they might seem. In order to retrieve a target item from memory, one must have the capacity to suppress, or silence, non-target items in memory. Researchers have suggested that one way in which this is accomplished is through retrieval inhibition (Bjork et al., 1998; Bjork, 1989) or the executive control processes of inhibition (Anderson, 2003, 2005). Inappropriate or unwanted items in memory become activated by a retrieval cue, but are inhibited in order to facilitate the retrieval of a target item. In this sense, retrieval-induced forgetting reflects inhibitory processes that act as a means of facilitating retrieval, not as a consequence of retrieval. Consistent with this idea, the current investigation (across four experiments and 354 participants) clearly and convincingly demonstrates that even unsuccessful retrieval attempts can cause retrieval-induced forgetting.

Experiment 1 sought to replicate Storm et al.'s (2006) impossible retrieval practice paradigm using an item-by-item final cued recall test. We felt it was important to replicate the original effect using a different final test in order to rule out a methodological concern. The final test employed by Storm et al. involved presenting all of the test cues on a single sheet of paper, and giving participants 3 minutes to recall studied exemplars associated with those cues. Owing to the prior difficulty associated with the impossible categories during retrieval practice, it is possible that participants were biased to avoid such categories in favour of categories that did not receive impossible retrieval practice. Thus, it is possible that the impaired recall observed in the impossible condition was not due to inhibition, but merely biased retrieval at the time of test. In Experiment 1 we employed an item-by-item final recall test that ensured that participants spent an equivalent amount of time attempting to recall an exemplar associated with each cue. The pattern of results was nearly identical to that which was observed by Storm et al. (2006). Significant retrieval-induced forgetting was found, and critically, the effect did not differ depending on whether retrieval practice was possible or impossible. The same results emerged when we employed a category cued recall test in Experiment 2.

Both possible and impossible retrieval practice are believed to cause forgetting through processes of inhibition. If this is the case, and if there exist differences in inhibitory capacity between individuals, then individuals who demonstrate larger effects of retrieval-induced forgetting from impossible retrieval practice should also demonstrate larger effects of retrieval-induced forgetting from possible retrieval practice. The results of Experiment 1 demonstrate just such a relationship. Participants demonstrating larger retrieval-induced forgetting effects in the impossible condition also demonstrated larger effects of retrieval-induced forgetting in the possible condition. These results suggest that there are individual differences in inhibition, and that the same mechanisms underlying forgetting owing to possible retrieval practice may underlie forgetting owing to impossible retrieval practice. Although also significant, a somewhat weaker relationship was observed in Experiment 2. It is possible that individual differences in inhibition are most readily observed when the effects of interference are reduced during the final test (i.e., using a category-plus-stem-cued recall test instead of a category-cued recall test). Such a possibility would be consistent with arguments made by Anderson and Levy (2007) regarding the correlated costs and benefits of inhibition. If interference is more tightly controlled on the final test, individual differences in retrieval-induced forgetting may be more likely to result from individual differences in the executive control processes of inhibition.

Experiments 3 and 4 explored the time-course of forgetting during a single retrieval practice trial. In most studies of retrieval-induced forgetting participants are given between 4 and 10 seconds to retrieve Rp+ items during retrieval practice. This time is often sufficient for participants to retrieve the correct exemplar and respond in writing, or vocally to the experimenter. To date, no studies have manipulated the amount of time in which participants engage in retrieval during a single trial. The reason for this is relatively straightforward: it is impossible to manipulate the amount of time participants take to retrieve an item on a given trial. Although experimenters may be able to manipulate the amount of time allotted for each trial, there is no way to dictate when and whether participants will complete a retrieval attempt. However, by employing the impossible paradigm, we were able to effectively manipulate the amount of time participants attempted to retrieve an item during retrieval practice. Because participants could not succeed during retrieval practice, the amount of time participants spent searching for an item associated with each impossible retrieval cue could be pre-determined.

The pattern of results that emerged from Experiment 3 was quite intriguing—4 seconds of retrieval practice led to significant retrieval-induced forgetting, but providing additional retrieval practice time did not increase the magnitude of the effect. In other words, spending 8 or 12 seconds attempting to retrieve an item from memory did not lead to more retrieval-induced forgetting than did spending 4 seconds attempting to retrieve an item from memory. This observation is somewhat surprising given that there are reasons to expect inhibitory control to be necessary during the entire duration of a retrieval practice trial. As such, one might have expected the amount of retrieval-induced forgetting to increase with retrieval practice time. The fact that it does not suggests that inhibition may act primarily during the initial seconds of a retrieval attempt in order to resolve interference, and that once interference is resolved, additional inhibition is either not elicited, or not effective at reducing later recall.

A somewhat different pattern of results was observed in Experiment 4. As in Experiment 3, the majority of the retrieval-induced forgetting effect occurred by 4 seconds. Unlike Experiment 3, however, final recall performance varied between the 4-, 8-, and 12-second retrieval practice conditions—increasing slightly between 4 and 8 seconds of retrieval practice, and then dropping significantly between 8 and 12 seconds of retrieval practice. This trend suggests that forgetting occurred at two points during the 12-second retrieval practice trials: first, during the initial 4 seconds; and second, during the final 4 seconds. One possible interpretation is that after failing to retrieve an exemplar during the initial seconds of a trial, participants attempt to revisit the studied exemplars, and that this re-activation led to an additional round of inhibition on those items. Such a dynamic would be more likely to occur in Experiment 4 than Experiment 3, as participants were warned that the answers to some of the retrieval practice trials would consist of previously studied items.

Another difference between the results of Experiment 3 and Experiment 4 is that the total amount of retrieval-induced forgetting observed after 12 seconds of retrieval practice in Experiment 4 (12%) was nearly twice that which was observed in Experiment 3 (6%). That more forgetting was observed in Experiment 4 might seem counterintuitive. After all, it was in Experiment 4 that participants were warned that a studied item would be the correct answer on a subset of the retrieval practice trials. It seems reasonable to assume that participants given such a warning would explicitly or implicitly activate the previously studied exemplars, thereby facilitating, not inhibiting, their later recall. However, the finding that previously studied exemplars are more impaired under this condition is consistent with the competition-dependence assumption of the inhibitory account of retrieval-induced forgetting (e.g., Anderson et al., 1994; Shivde & Anderson, 2001; Storm et al., 2007). Utilising the list-method directed forgetting paradigm, Storm et al. (2007) found that to-be-remembered items suffered from significantly more retrieval-induced forgetting than to-be-forgotten items. Warning participants that studied items will never be answers during retrieval practice may prevent those items from competing during retrieval practice (making them akin to to-be-forgotten items), and therefore protecting those items from inhibition. Likewise, warning participants that studied items may sometimes serve as answers during retrieval practice may exacerbate the extent to which those items compete during retrieval practice, and therefore increase the extent to which they are targeted by inhibition.

Finally, it is worth noting that retrieval-induced forgetting was observed after only a single retrieval practice trial. In contrast to our current results, three studies have employed a single retrieval practice trial condition as part of their design (Johnson & Anderson, 2004; Levy et al., 2007; Shivde & Anderson, 2001), and each of those studies observed facilitation after a single retrieval practice trial, followed by an increasingly large effect of forgetting following additional retrieval practice trials. Shivde and Anderson (2001) argued that an activation/inhibition balance determines when items will and will not demonstrate forgetting. Essentially, the retrieval practice cue first activates information related to the target, and inhibition initiates to counteract the activation of related, non-target information. It is possible that in some cases inhibition does not immediately outweigh initial activation and, as a consequence, the competing responses remain strengthened after only a single retrieval practice trial. It is not clear why we observed a different pattern of results here. In both Experiments 3 and 4, strong and reliable effects of retrieval-induced forgetting were observed after only a single retrieval practice trial. Clearly multiple retrieval practice trials are not necessary to cause retrieval-induced forgetting.

Implications for theoretical accounts of retrieval-induced forgetting

The inhibitory account of retrieval-induced forgetting contends that non-practised items are forgotten because they interfere during retrieval practice, and are therefore targeted by inhibition. Interference-based accounts contend that non-practised items are forgotten because retrieval practice strengthens practised items, thereby causing them to interfere with the recall of non-practised items at the time of the final test. The finding that unsuccessful retrieval practice leads to the same amount of forgetting as successful retrieval practice fits nicely with the inhibitory account, and poses serious problems for the interference account. After all, if nothing is retrieved during retrieval practice, nothing is strengthened, and therefore nothing should interfere with the recall of non-practised items. According to the inhibitory account, inhibition occurs during retrieval practice so as to facilitate the retrieval of practised items, and thus the forgetting that occurs as a consequence of that inhibition should occur regardless of whether retrieval practice eventually succeeds or fails. In this sense the current findings clearly support the strength-independent assumption of the inhibitory account of retrieval-induced forgetting (e.g., Anderson et al., 2000; Bäuml, 2002).

One might argue that although retrieval may fail during impossible retrieval practice, surely something is strengthened. For example, perhaps participants are failing to come up with correct responses, but they are still coming up with some type of responses, and those responses might be blocking recall at test. Two arguments can be made against this possibility. First, participants who provide more responses during impossible retrieval practice—regardless of the appropriateness of their responses—do not show larger effects of retrieval-induced forgetting than participants who provide fewer responses during impossible retrieval practice. Such a relationship was not observed by Storm et al. (2006), and such a relationship was not observed in any of the four experiments reported here. Second, there is every reason to believe that if participants were to explicitly retrieve or implicitly activate any responses during impossible retrieval practice, it would be the items that they had just previously studied, not items that had not been studied. As such, the later recall of non-practised items would seem more likely to benefit from impossible retrieval practice than be impaired by it.

Proponents of the inhibitory account have often assumed that retrieval-induced forgetting is retrieval-specific—that studying Rp+ items during what is normally retrieval practice, or strengthening Rp+ items in some other way, is not sufficient to cause retrieval-induced forgetting (see e.g., Anderson, 2003, 2005; Bjork et al., 1998; Levy & Anderson, 2002). Rather than contradict this assumption, the current results suggest a slight amendment. It is not the retrieval per se that causes inhibition, it is the retrieval attempt that sets the stage for inhibition to occur. Inhibitory processes function to resolve interference, and such processes appear to be just as active during unsuccessful retrieval as they are during successful retrieval.

Recent research examining theoretical accounts of retrieval-induced forgetting has focused predominately on evidence for and against cue-independence. And although there have been many successful demonstrations of cue-independence (e.g., Anderson & Bell, 2001; Anderson & Spellman, 1995; Aslan et al., 2007;

Levy et al., 2007; MacLeod & Saunders, 2005; Shivde & Anderson, 2001), there have also been failures (Camp et al., 2005, 2007; Perfect, Stark, Tree, Ahmed, & Hutter, 2004; Williams & Zacks, 2001). Some have questioned whether independent cues are even truly independent (see e.g., Camp, Pecher, Schmidt, & Zeelenberg, in press). However, we feel that evidence supporting the inhibitory account of retrieval-induced forgetting does not start and end with cue independence. In fact, the results of the current study—and the results of other studies demonstrating strength-independence and competition-dependence—provide unique and compelling evidence in favour of the inhibitory account as well. Many researchers remain sceptical of inhibition's role in human memory (see e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003), making it all the more important to develop multiple and complementary lines of evidence supporting that role.

Finally, the current findings have important implications for understanding the time-course of forgetting during a single retrieval attempt. Until now, researchers have been unable to manipulate the amount of time in which participants attempt to retrieve an item during retrieval practice. The results of Experiment 3 suggest a negatively accelerated function such that inhibition may have a substantial impact during the initial seconds of a retrieval practice trial, and then increasingly less of an impact as the trial continues. Several possibilities may account for this function. One possibility is that participants engage in a less and less effortful retrieval search as a given trial goes on. In other words, they start to give up. Another possibility is that the inhibition that takes place during the initial seconds of a trial effectively inhibits the items that are going to interfere, thereby eliminating the need for inhibition during subsequent seconds of that trial. Either way, clearly most of the forgetting that was to take place on a given retrieval practice trial took place during the initial seconds of that trial.

However, as suggested by the results of Experiment 4, there may be conditions in which the magnitude of a retrieval-induced forgetting effect does increase with retrieval practice time. In Experiment 4 participants were warned that the accurate response to some of the retrieval practice cues would consist of a previously studied exemplar. It is possible that this warning exacerbated the extent to which the studied exemplars competed with retrieval efforts, thereby causing the studied exemplars to continue to interfere with retrieval practice beyond the initial 4 seconds of a given trial. Thus, whether the magnitude of a retrieval-induced forgetting effect continues to increase with retrieval practice time may depend on the amount of competition provided by non-practised items. It should be noted, however, that the opportunity for additional inhibition—and thus additional forgetting—is only available when retrieval practice fails to initially succeed. Presumably, once retrieval is successful, retrieval efforts cease, and inhibition is no longer necessary. In this sense, it is possible that retrieval failure—and, more generally, retrieval difficulty—has the power to augment effects of retrieval-induced forgetting.

Concluding comment

In memory research, that which is not retrieved is just as important as that which is retrieved. When we retrieve a particular item or set of items from memory, we are effectively neglecting, or remaining silent, to other items in memory. And as work on retrieval-induced forgetting has shown, this silence can have important implications for long-term memory. The current study adds an additional dimension of silence to the discussion—demonstrating that neglecting items not only leads to forgetting when retrieval succeeds, but when retrieval fails. That retrieval success is not a necessary condition to cause forgetting provides strong support for the inhibitory account of retrieval-induced forgetting. Moreover, it provides researchers with a new and powerful tool for studying the role of inhibitory processes in retrieval. By making retrieval practice impossible, researchers have the ability to explore dynamics (such as retrieval practice time) that would otherwise be impossible.

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