Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale

Retrieval-Induced Forgetting: Testing the Competition Assumption of Inhibition Theory

Tanya R. Jonker and Colin M. MacLeod

Online First Publication, April 16, 2012. doi: 10.1037/a0027277

Canadian Journal of Experimental Psychology / Revue canadienne de psychologie expérimentale

1196-1961/12/$12.00 DOI: 10.1037/a0027277

Retrieval-Induced Forgetting: Testing the Competition Assumption of Inhibition Theory

Tanya R. Jonker and Colin M. MacLeod
University of Waterloo

Practicing the retrieval of some information can lead to poorer retrieval of other related information, a phenomenon called retrieval-induced forgetting (RIF). This pattern has been explained as the result of inhibition of the related information during practice (Anderson, 2003). A core assumption of this inhibition account is that, to be suppressed, the related information must compete with the target information at the time of retrieval practice. Three experiments are reported that test this competition assumption. One experiment showed that RIF did not occur without specific retrieval practice of the target items when semantic generation of subordinates was performed. However, in 2 further experiments, RIF did occur when the semantic generation task was paired with category retrieval. Although there was no need for competition between target information and related information in these experiments, RIF was observed. These experiments undermine the competition assumption and hence the inhibition account.

Keywords: retrieval-induced forgetting, memory, inhibition, competition assumption, interference dependence

Forgetting can be a distressing event. When trying to recall the name of an acquaintance, one might find that the names of other acquaintances come to mind, without successful recall of the name being sought. However frustrating these lapses of memory may be, our processing system functions to reduce the influence of irrelevant information so as to facilitate the processing and remembering of relevant information. Indeed, constantly remembering previous experiences that are not relevant to our present situation would be quite distracting, even disturbing. Our ability to forget is an adaptive function (see Bjork, 1989; James, 1890).

One form of forgetting has been of particular interest recently because it seems rather paradoxical. Not surprisingly, the act of retrieval improves later memory for the retrieved material (e.g., Darley & Murdock, 1971; McDaniel & Masson, 1985; McDaniel, Roediger, & McDermott, 2007; Roediger & Karpicke, 2006). However, this act of retrieval also influences memory for related but not retrieved material. Such retrieval may actually result in a cost for related items, a phenomenon called retrieval-induced forgetting (RIF; Anderson, Bjork, & Bjork, 1994; see Anderson, 2003, and Verde, 2012, for comprehensive reviews of the RIF literature).

Tanya R. Jonker and Colin M. MacLeod, Department of Psychology, University of Waterloo, Ontario, Canada.

This research was supported by Discovery Grant A7459 and by an Alexander Graham Bell Canada Graduate Scholarship, both from the Natural Sciences and Engineering Research Council of Canada.

Correspondence concerning this article should be addressed to Tanya R. Jonker, Department of Psychology, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1. E-mail: trjonker@uwaterloo.ca

Investigating RIF

The paradigm typically used to investigate RIF was developed by Anderson et al. (1994). It involves studying several sets of category-exemplar pairs taken from different categories. Thus, participants might study *FRUIT–apple*, *FRUIT–orange*, *DRINK–wine*, and *DRINK–rum* at random points throughout a list. Participants are later tested on these items, but a critical intervening task occurs first: retrieval practice of half of the items from half of the categories. During this intervening retrieval-practice task, participants might practice retrieving *apple* from the *FRUIT* category by completing a word stem (e.g., *FRUIT–ap__*); this task would not be performed on *orange* or on any of the items from the *DRINK* category.

This retrieval practice phase creates three distinct groups of items. By convention, the items that are practiced during the retrieval practice phase are given the shorthand Rp+ (e.g., *apple*). Unpracticed items from practiced categories are given the shorthand Rp− (e.g., *orange*). Finally, items from the categories with no practiced items are given the shorthand Nrp (e.g., *rum* and *wine*) and serve as a comparison group.

This experiment by Anderson et al. (1994) and other variations on this paradigm (see Anderson, 2003, for a review) have produced two basic findings. The first finding is entirely intuitive—enhanced recall for Rp+ items relative to Nrp items. Practice helps the practiced items. The second finding is surprising—impaired recall for Rp− items relative to Nrp items. Practice hurts the related unpracticed items. For example, practicing the item *FRUIT–apple* during a retrieval practice phase will impair the later recall of the unpracticed item *FRUIT–orange* relative to the recall of *DRINK–rum* (i.e., Rp+ > Nrp > Rp−).

The first, and still dominant, explanatory framework for RIF is the theory of memory inhibition (for reviews, see Anderson, 2003; Anderson et al., 1994; Anderson, Bjork, & Bjork, 2000; Anderson & Spellman, 1995; Bäuml, Pastötter, & Hanslmayr, 2010). According to inhibition theory, the cue given during the retrieval

practice phase activates not only the target exemplar but also other studied exemplars from the same category, which then compete for retrieval. For example, upon seeing *FRUIT*, the exemplars *apple*, *orange*, *plum*, and so forth might become activated and compete for retrieval. To restrict retrieval to the target exemplar, the memory representations of competing exemplars are inhibited. This reduces the interference that they cause and allows for successful retrieval of the target. Moreover, this inhibition is enduring such that later recall of Rp− items is impaired; the inhibited competitors have become less accessible in memory.

The strongest empirical support for inhibition theory comes from demonstrations involving exemplar strength, similarity, and independent cuing. Anderson et al. (1994) found RIF among Rp− exemplars with high taxonomic frequency (e.g., *orange* from the category *FRUIT*) but not among Rp− exemplars with lower taxonomic frequency (e.g., *guava*); this was the case even when output interference was controlled. Forgetting differences did not occur, however, when the taxonomic frequency of the Rp+ items differed. Anderson et al. explained their discrepant Rp− strength findings by suggesting that competition mediates the impairment of Rp− items. That is, if Rp− items are strongly associated exemplars from the category, they will compete intensely for retrieval and will therefore be inhibited. On the other hand, weakly associated exemplars will not compete as strongly, if at all, so they do not need to be inhibited. This notion of "reactive inhibition" goes back to Wundt (1902).

Manipulations of item similarity, whether semantic or episodic, also support the competition component of inhibition theory. On the semantic side, Bäuml and Hartinger (2002) demonstrated that RIF did not occur when Rp+ and Rp− exemplars were highly similar, and Goodmon and Anderson (2011) showed that RIF occurred when there were few associations between the Rp− and Rp+ items but not when there were many associations between them. Likewise, on the episodic side, Anderson and McCulloch (1999) and Anderson, Green, and McCulloch (2000) demonstrated that RIF does not occur when exemplars are strongly interrelated. According to inhibition theory, in these situations of item interrelatedness, the memory representations of the competitors and the target items overlap, and the unpracticed competitors therefore benefit from the strengthened features of the practiced targets (see Anderson & Spellman, 1995, for a theoretical explanation of feature overlap).

The third—and most compelling—vein of support for inhibition theory is the demonstration of independent cuing. Independent cues are test cues given at final test that were not presented during the study phase (for the origin of this manipulation, see Anderson & Spellman, 1995). Using this method, Johnson and Anderson (2004) presented unstudied category cues in conjunction with one-letter word stems during the final test phase. For example, the target word *salt* was studied with the category *SEASONING*, but during the final test phase, the recall cue *POPCORN–s____* was given. Even though the original study cue was not used at test, forgetting of *salt* occurred (see also Anderson & Bell, 2001; Saunders & MacLeod, 2006). Under an interference account, forgetting occurs because the test cues favour the practiced items, causing them to obstruct the recall of the unpracticed items (cf. response competition theory; McGeoch, 1942). However, when independent cues are used on the final recall test, these novel cues should not favour the practiced items yet the Rp- items are forgotten—a difficult finding for an interference account to explain. Therefore, RIF with independent cues has, thus far, been the strongest evidence that inhibition—not just interference—plays a central role in RIF (see Anderson, 2003; Anderson & Levy, 2007, for more on this argument), although it should be noted that independent cue data are, in fact, only rarely reported in the RIF literature.

It is important to highlight that the findings regarding exemplar strength and independent cuing have not always replicated (see Williams & Zacks, 2001). Furthermore, some researchers have challenged the idea of independent cuing, suggesting that the cues used are not in fact "independent" but instead can be related through covert cuing (Camp, Pecher, & Schmidt, 2007; Camp, Pecher, Schmidt, & Zeelenberg, 2009), with some providing experimental demonstrations of the cue *dependence* of RIF (Jonker, Seli, & MacLeod, 2011). Others have found that when two studied cues are used, RIF is dependent on the retrieval practice cues presented (Perfect et al., 2004), suggesting reliance on context (see also Verde & Perfect, 2011). Moreover, others have provided manipulations of strength by varying the number of presentations during study and examining primacy and recency strengthening, and have concluded that an experimentally controlled manipulation of strength—as opposed to taxonomic strength—does not support the inhibition account (Jakab & Raaijmakers, 2009).

These findings challenge inhibition theory, but it is, of course, difficult to evaluate a theory when the conflicting evidence is based primarily on null findings. In the present study, we take the complementary approach by seeking to demonstrate RIF under conditions where inhibition would predict none.

Our series of experiments tests the competition assumption of inhibition theory, central to the theory since its beginning (Anderson et al., 1994). In his theoretical article, Anderson (2003) describes competition as a necessary condition for inhibition: "Inhibition is driven by the need to override interference from competing memories during the selective retrieval of target items" (p. 420). To explain this process during retrieval practice, Anderson et al. (1994, p. 1079) postulate that "presenting a cue should activate all associated responses in parallel; this initial spread of activation may then need to be focused to isolate the target response from interfering competitors," the mechanism of focus being inhibition. Thus, when a category cue is presented, strongly associated exemplars will become activated and compete for retrieval, causing interference. To facilitate retrieval, the competitors must be suppressed. This inhibition is, however, reactive, so a memory representation that does not compete will not require suppression and therefore should not be forgotten (i.e., no RIF). Indeed, the aforementioned experiments manipulating exemplar strength and item similarity are interpreted based on the assumption of competition during retrieval.

In the present article, we developed a new manipulation to test the competition assumption; the new task involves generation of a subordinate item from a studied exemplar. Critically, this manipulation was performed for the exemplars in the place of retrieval practice. Generation has been used in RIF before; Bäuml (2002) had participants generate additional exemplars when given the original category label. Thus, following the study of *PET–dog*, participants in Bäuml's (2002) study might be given the category word *PET* and asked to come up with additional—yet unstudied—exemplars, like "fish" or "snake." This type of generation should recruit both studied and unstudied exemplars in response to the category cue; these exemplars should then need to be suppressed, so RIF would be expected—and, indeed, was observed.

Our generation task differed from that of Bäuml (2002). Specifically, participants saw an exemplar (instead of its category word) and were to generate a subordinate. So a participant might have seen the studied exemplar *dog* (instead of its category word *PET*) and been asked to generate a type of dog, like "beagle." During this task, there is no clear need for other studied *PET* exemplars to be activated and to compete for retrieval. Yet a retrieval process is still involved in that an instance of that exemplar—a subordinate such as beagle—must be retrieved from semantic memory. This manipulation is used to create a situation where retrieval occurs without competition.

In the absence of competition among the studied exemplars, inhibition theory predicts no RIF. Indeed, Anderson (2003) states that "any type of retrieval practice that minimizes the need to resolve interference between competing items is unlikely to produce inhibition" (p. 428). Our experiments provide a direct test of this claim.

Experiment 1

In our generation task, which replaced the usual retrieval practice phase, participants were shown half of the studied exemplars from half of the studied categories, and were to generate a subordinate for each exemplar on each practice trial. The rationale was that generation of subordinates involves retrieval without invoking competition from the other studied exemplars. According to inhibition theory, there should be no need to inhibit the other exemplars in a category when subordinate generation occurs and, therefore, there should be no RIF.

Method

Participants. Participants were 5 males and 25 females, with ages ranging from 18 to 39 years (M = 19.7 years). They were recruited from the University of Waterloo's Research Experience Group and offered bonus course credit for their participation. All had normal or corrected-to-normal vision and English was their first and most fluent language.

Materials. The same stimulus set was used for this and all subsequent experiments. Stimuli consisted of six categories of words (e.g., *FOOD* and *PET*), each with six exemplars (e.g., for *PET*: *dog*, *horse*), quite analogous to previous RIF studies. Two filler categories were also selected, each with three exemplars. Thus, there were 42 category-exemplar word pairs (36 experimental, 6 filler). No exemplars within any category began with the same letter. Stimuli for all tasks were presented on a 17-in CRT monitor using E-Prime programming software. They were presented against a black background in white 24-point Times New Roman font at the centre of the screen.

Procedure. During the initial study phase, participants saw category-exemplar word pairs individually on the computer screen and were asked to study the pairs for a later memory test. Each pair was presented for 5 s, with an interstimulus interval of 250 ms between successive word pairs. Stimuli were presented in a constrained random order such that category-exemplar pairs from the same category were never presented in succession. Three of the filler word pairs were presented before the experimental stimuli, and three after, to limit primacy and recency effects (Murdock, 1962).

Following the study phase, participants performed the subordinate generation task (in place of the standard retrieval practice task). They were shown a studied exemplar on the screen and asked to produce a subordinate item. So if they had studied the category-exemplar pair *PET–dog* during the generation task, they might see the exemplar *dog* and then would generate a type of dog, like "beagle." Participants were shown an example using a filler category exemplar during instructions to ensure that they understood the task. They were given 10 s for each generation and were asked to produce a unique generation each time that they saw the same exemplar (e.g., on the second presentation of *dog*, they should generate "poodle" and not repeat "beagle"). In this task, participants were retrieving, but it was semantic retrieval of subordinates of exemplars instead of retrieval of the studied exemplars themselves. Generation was performed for half of the exemplars from half of the categories, and each exemplar was presented 3 times during the generation task (totaling 27 trials), following the standard procedure for the retrieval practice phase. The selection of exemplars was random for each participant, with the order of presentation constrained such that exemplars from the same category were never presented in succession. The presented exemplars were given the typical notation Rp+, the unpracticed exemplars from the same category as the presented exemplars were labelled Rp−, and the exemplars from categories with no category retrieval were labelled Nrp.

A distractor task followed the category-retrieval phase. All experiments reported in this article used a distractor task borrowed from Macrae and Roseveare (2002), in which participants were given 5 min to make a list of as many countries as possible.

The final memory test was a category-cued-recall test—one commonly used in RIF studies (e.g., Anderson et al., 1994; Anderson & McCulloch, 1999; Anderson & Spellman, 1995; M. D. MacLeod & Macrae, 2001). Each category label (e.g., *PET*) from the studied category-exemplar pairs were presented on the computer screen one at a time, and participants were to write down as many of the studied exemplars (e.g., *dog, horse*) from that category as they could. Each category cue was presented for 30 s; a tone alerted participants when the time was up and then the next category appeared on the screen.

Results and Discussion

The alpha level for statistical significance for all experiments was set at .05. Recall data were analysed using a one-way repeated-measures analysis of variance (ANOVA) contrasting the three conditions. This omnibus ANOVA was followed by two orthogonal planned comparisons to assess the potential benefit [Rp+ > (Nrp and Rp−)] and cost [Rp− < Nrp] of retrieval practice (+2, −1, −1, and 0, +1, −1, for Rp+, Rp−, and Nrp, respectively).[1]

Participants generated a unique subordinate of a studied exemplar on 92.1% of the trials.

Overall, recall for Rp+, Rp−, and Nrp items differed, $F(2, 58) = 15.58$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .35$. As is clear in Figure 1, participants recalled more Rp+ items than nonpracticed items, $t(29) = 5.31$, $SE = .03$, $p < .001$, $\eta_p^2 = .49$, but the recall proportions of the Rp− and Nrp items did not differ, $t(29) = 1.12$, $SE = .03$, $p = .27$.

[1] Using a t test to compare Rp+ to Nrp, and Rp− to Nrp, yielded the same pattern of results as the planned comparisons in all reported experiments.

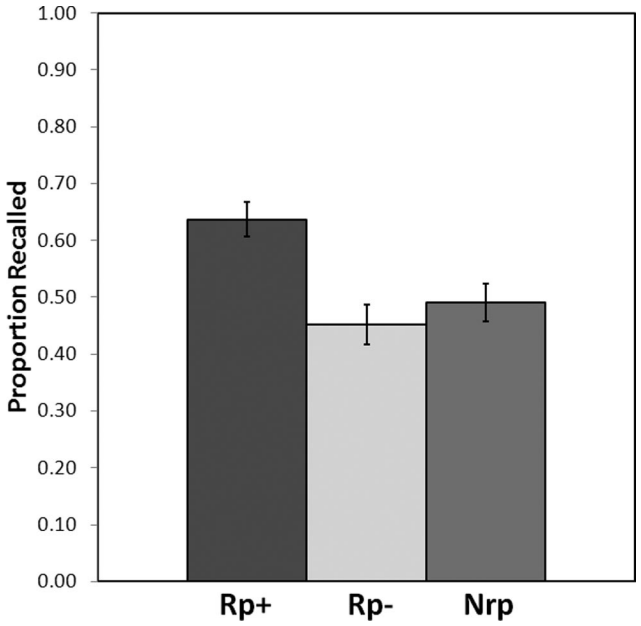

Figure 1. The mean proportions of exemplars correctly recalled on the final cued-recall test in Experiment 1. The error bars represent one standard error of their respective means. Nrp exemplars are those from categories where no semantic generation occurred; these represent the baseline condition. For categories where semantic generation did occur, Rp+ refers to those exemplars involved in subordinate generation and Rp− refers to those exemplars not involved in subordinate generation.

As predicted by inhibition theory, no RIF was observed in this experiment. When we replaced the standard retrieval practice task with a semantic generation task that should not cause competition between related exemplars, no RIF was observed.

Although our focus in this article is on the validity of inhibition theory, it is informative to view the results of Experiment 1 through the scope of other theoretical approaches. An item-based interference or strengthening account argues that the impairment occurs at test because the test cues favour the practiced items, causing them to obstruct the recall of the unpracticed items (e.g., Raaijmakers & Jakab, 2012; see Anderson, 2003, for a review; cf. response competition theory, McGeoch, 1942). Thus, RIF will occur when the test cues favour the practiced items. In the case of Experiment 1, the category cue, which is later used on the test, is not incorporated into the semantic generation task. This absence of category cues in the semantic generation task reduced or prevented the strengthening of the association between the category cue and the exemplar. This would limit the interference caused by the Rp+ exemplars on the final test because the association between the category cue and the Rp+ items was not strengthened. Thus, to provide a more complete exploration of the competition assumption, we incorporated the category cues into the semantic generation task in Experiments 2 and 3 by adding a manipulation that should not cause competition between related studied exemplars.

Experiments 2 and 3

To test the hypothesis that the category must appear during generation for RIF to occur, we paired the semantic generation task from Experiment 1 with a category-retrieval task borrowed from Anderson, Bjork, et al. (2000), who showed that when participants were prompted to retrieve the category (e.g., *Fr___–apple*) instead of the exemplar (e.g., *Fruit___–ap___*), there was no cost for Rp− items, although there was a benefit for the items serving as retrieval cues (*apple*). Retrieval of the category should not necessitate exemplar activation and competition. Thus, we incorporated this noncompetitive manipulation into our generation task to induce category association without competition (see the Appendix for a slightly modified replication of the category retrieval condition from Anderson, Bjork, et al., 2000). In Experiments 2 and 3, as in Experiment 1, participants first generated an instance of the provided exemplar and then subsequently retrieved the studied category for that exemplar. Critically, neither of these manipulations should result in competition at the level of the exemplars, so inhibition theory would still predict no RIF, consistent with our findings in Experiment 1, with those of Anderson, Bjork, et al. (2000), and with our replication in the Appendix.

Method

Participants. In Experiment 2, there were 9 males and 17 females, with ages ranging from 18 to 22 (M = 18.8). In Experiment 3, there were 4 males and 22 females, with ages ranging from 18 to 24 (M = 19.9; 6 participants were not included in Experiment 3 due to misunderstanding the instructions). All participants were recruited from the same pool and with the same constraints as in Experiment 1.

Materials. Stimuli and testing equipment were identical to those in Experiment 1.

Procedure. Following the study phase (identical to that of Experiment 1), the semantic generation task used in Experiment 1 was performed along with the category-retrieval task (Appendix; these two tasks replacing the standard retrieval practice task). Thus, participants first generated a subordinate item for the exemplar shown to them. The exemplar then remained on the screen and participants were to name the studied category to which that exemplar belonged. For example, having studied *PET–dog* earlier, a participant might see *dog*, which served as a cue for two responses. The participant was first to generate a subordinate, like "beagle," and then to follow with the studied category of *dog*, "pet." An example using a filler study item was provided during the instructions to ensure that participants understood the task. They performed generation and category retrieval on half of the exemplars from half of the categories, following the standard procedure for the retrieval practice phase. The distractor phase followed immediately.

The memory test for Experiment 2 was a category cued-recall test, identical to that of Experiment 1. That is, each category label (e.g., *PET*) from the studied pairs was presented on the computer screen one at a time and participants were to write down as many of the studied exemplars (e.g., *dog, horse*) from that category as they could.

Experiments 2 and 3 differed only in that Experiment 3 employed a control for output interference (see Roediger, 1974) in the final test. Output interference controls have been used in RIF studies to rule out the possibility that the effect occurred because participants output Rp+ items before Rp− items on a category-cued free recall test (Anderson et al., 1994). To control for output

interference, category cues along with one-letter word stems (*PET–d___*) were presented during the final recall test. This allowed us to force the output of Rp− items before Rp+ items, presumably eliminating output interference on the crucial Rp− items. All Rp− cues appeared before any Rp+ cues in each category block. Cues were presented individually and remained in view until the participant responded or until 10 s elapsed.

Results and Discussion

Experiment 2. Participants generated a unique subordinate of a studied exemplar on 94.7% of the trials and successfully retrieved the studied category on 92.7% of the trials.

The data are presented in the left panel of Figure 2. Overall, recall for Rp+, Rp−, and Nrp items differed, $F(2, 50) = 109.96$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .82$. More specifically, planned comparisons revealed that participants recalled more Rp+ items than nonpracticed items, $t(25) = 13.65$, $SE = .03$, $p < .001$, $\eta_p^2 = .88$, and, importantly, participants recalled fewer Rp− items than Nrp items, $t(25) = 5.38$, $SE = .03$, $p < .001$, $\eta_p^2 = .54$.

Experiment 3. Participants generated a subordinate of a studied exemplar on 90.2% of the trials and successfully retrieved the studied category on 89.7% of the trials.

The data are shown in the right panel of Figure 2. Overall, recall for Rp+, Rp−, and Nrp items differed, $F(2, 50) = 21.12$, $MSE = 0.52$, $p < .001$, $\eta_p^2 = .46$. Planned comparisons were represented differently for Experiment 3 to account for the output order control. To equate testing order for Rp+ and Rp− items with Nrp items, Nrp items from each category were divided into two sets—one containing items from testing positions 1 to 3, and the other containing items from testing positions 4 to 6. Using this separation, Rp− recall could be compared to the recall of Nrp items from the first half of the testing positions, and Rp+ recall could be compared to the recall of Nrp items from the second half. Thus, the orthogonal planned comparisons involved a contrast of Rp+ items with second-half Nrp items, and a contrast of Rp− items with first-half Nrp items (+1, 0, 0, −1, and 0, +1, −1, 0, for Rp+, Rp−, first-half Nrp, and second-half Nrp, respectively). Participants recalled more Rp+ items than second-half Nrp items, $t(25) = 4.34$, $SE = .05$, $p < .001$, $\eta_p^2 = .43$, and fewer Rp− items than first-half Nrp items, $t(25) = 2.83$, $SE = .04$, $p < .01$, $\eta_p^2 = .24$.

Experiments 2 and 3 showed reliable RIF despite there being no competition among exemplars during the modified retrieval practice phase (and hence no need to suppress related unpracticed exemplars). These two experiments replicate each other. According to inhibition theory, there should not have been any cost for Rp− items because there was no competition among exemplars (i.e., there should not have been RIF). The cost to Rp− items in these experiments calls into question the fundamental competition assumption of the inhibition explanation of RIF.

General Discussion

In this series of experiments, we set out to test a fundamental assumption of the inhibition theory of RIF—that inhibition operates during retrieval practice to suppress related competitors that would otherwise undermine retrieval. Experiments 1, 2, and 3 all employed a semantic generation task, which involved generating a subordinate to a studied exemplar. In Experiment 1, this failed to produce RIF. According to inhibi-

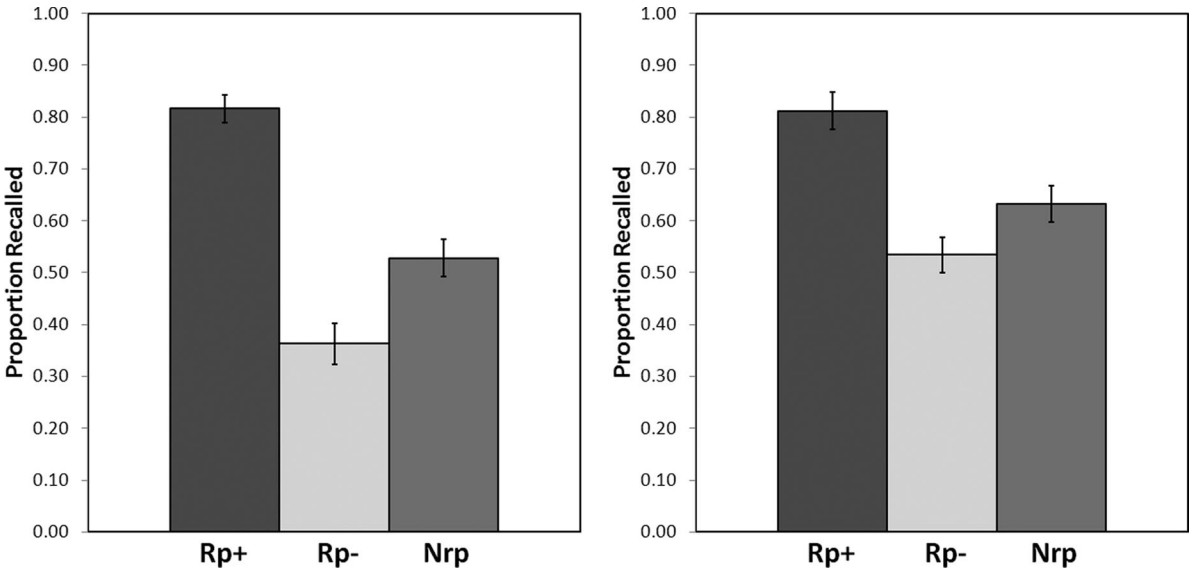

Figure 2. The mean proportions of exemplars correctly recalled on the final cued-recall test in Experiments 2 (left panel) and 3 (right panel). The error bars represent one standard error of their respective means. Nrp exemplars are those from categories where no semantic generation occurred; these represent the baseline condition. Although Nrp items are split into first half ($M = .66$) and second half ($M = .60$) for analysis, they are represented in one bar for simplicity. For categories where semantic generation did occur, Rp+ refers to those exemplars involved in subordinate generation and Rp− refers to those exemplars not involved in subordinate generation.

tion theory, competing exemplars would not need to be suppressed during semantic generation when the exemplar was provided. Yet when the semantic generation task and the category retrieval task (see Appendix) were carried out together in Experiments 2 and 3, RIF was observed, even when controlling for output interference (Experiment 3). This finding cannot be explained by inhibition theory, as the presence of RIF without competition at the same level conflicts with the critical competition assumption of inhibition theory.

Inhibition theory has been the dominant explanatory framework for RIF since the initial demonstration of RIF by Anderson et al. (1994; see Verde, 2012 for a review). Inhibition theory has also been a leading theory for other cognitive effects, like negative priming (e.g., Tipper, 1985, 2001), inhibition of return (e.g., Posner & Cohen, 1984), task switching (e.g., Mayr & Keele, 2000), and directed forgetting (e.g., Basden, Basden, & Gargano, 1993; Weiner & Reed, 1969). However, mounting evidence against inhibition theory as an explanation for various cognitive phenomena challenges the validity and reliability of inhibition theory for many of these effects, at the very least providing plausible noninhibitory accounts (for a selective review, see C. M. MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

According to Anderson (2003), there are four properties of RIF that provide unique support for an inhibitory mechanism. These properties are cue independence, strength independence, retrieval specificity, and interference dependence. However, as we discussed earlier, many researchers have failed to replicate these "pillars" of evidence for inhibition theory (see Verde, 2012, for a recent summarization of this work).

Our line of research targets interference dependence—what we (and others; see Raaijmakers & Jakab, 2012) have called the competition assumption. This assumption asserts that competition between related exemplars during retrieval practice is necessary for producing inhibition; that is, if an exemplar does not compete—and cause interference—with the target exemplar during retrieval practice, it will not be inhibited (Anderson, 2003; Anderson et al., 1994). Inhibition theory does not predict RIF for any of our experiments because of the absence of retrieval interference between exemplars. Indeed, while performing the generation task in Experiments 1, 2, and 3, participants rarely produced one of the other studied exemplars or the studied category ($<1\%$)[2] instead of a subordinate item. Yet when we tested this competition assumption directly with a task that requires semantic retrieval and a category-retrieval task, we found RIF. Based on our findings, we conclude that competition between exemplars during retrieval practice is not a necessary condition for producing RIF, and therefore that inhibition theory alone, as it currently stands, fails to account for our findings.

As a prominent theory with no strong alternative, our goal was solely to test a key assumption of inhibition theory. However, inquisitive researchers will wonder about alternative explanations for the present findings. In fact, a strong contending theory has yet to step forward, so we did not attempt to undertake testing an alternative. However, we can entertain approaches that hold some merit.

These data might be explained by an item-based differential strengthening account. This account emphasizes strengthening of the category-exemplar association during retrieval practice (Raaijmakers & Jakab, 2012). Specifically, when a category word is presented as a cue for retrieval on the final test, the Rp+ items cause substantial interference because they are strongly associated with the category word (due to earlier retrieval practice). This interference could come about in a variety of ways (see Anderson et al., 1994, for possible approaches to interference) but, regardless of the underlying mechanism, results in impaired recall of the Rp− items. This theory could explain our data in the following way: The act of semantic generation paired with category retrieval strengthens the Rp+ items such that, during the final recall test, the test cue (i.e., the category cue) easily triggers the recall of the practiced items; these items dominate recall and are difficult to overcome when trying to access Rp− items, hence interfering with Rp− recall during test. According to this approach, RIF did not occur in Experiment 1 because the category-exemplar association was not strengthened in the absence of category retrieval. Critically, this account emphasizes interference on the final recall test rather than enduring inhibition from the earlier retrieval practice task. It is important to note, however, that this approach cannot explain all RIF findings as it stands (see Anderson, 2003).

Another promising account is a context-based approach; Verde and Perfect (2011) suggest that RIF might be produced through the recollection of episodic information (see also Perfect et al., 2004; Verde, 2012). Under such a view, cues on the final test might lead participants to be more likely to recall the recent retrieval-practice/semantic-generation task (where only the Rp+ items appeared) than the initial study phase (where both Rp+ and Rp− items appeared). Consequently, participants would more readily access the Rp+ items than the Rp− items, resulting in RIF. Based on the growing body of findings that challenge inhibition theory, together with findings from Verde and Perfect (2011), this noninhibitory alternative approach certainly warrants further investigation and testing.

In conclusion, our set of experiments provides a test of a key component of inhibition theory. We have taken the direct approach of testing the competition assumption—a necessary condition—of inhibition theory. In so doing, we have observed RIF even under conditions of no interexemplar interference. These findings add to a body of evidence that challenges the inhibition explanation of RIF, further emphasising both the shakiness of inhibition theory and the need for an alternative account of RIF.

[2] In Experiment 1, 30 participants produced a total of 746 subordinate generations (averaging 24.9 generations each); five of these were a production of a studied exemplar in place of a subordinate item (0.7%), and two were a production of the studied category in place of a subordinate item (0.3%). In Experiment 2, 26 participants produced a total of 665 generations (averaging 25.6 generations each); five of these were a production of a studied exemplar in place of a subordinate item (0.8%); participants never produced the studied category in place of a subordinate item. In Experiment 3, 26 participants produced a total of 633 generations (averaging 24.4 generations each); three of these were a production of a studied exemplar in place of a subordinate item (0.5%), and four were a production of the studied category in place of a subordinate item (0.6%). Thus, the rate of exemplar production was virtually nil.

Résumé

La récupération de certaines informations peut mener à une moins bonne restitution de renseignements connexes, phénomène appelé « l'oubli induit par la récupération ». Ce phénomène serait le résultat de l'inhibition d'information connexe pendant un rappel (Anderson, 2003). Une hypothèse de base pour expliquer la manifestation d'une telle inhibition est que l'information connexe doit être en concurrence avec l'information cible au moment de l'exercice de récupération. L'article décrit trois expériences qui cherchaient à vérifier cette hypothèse de concurrence. Dans une expérience, il n'y a pas eu d'oubli induit par la récupération en l'absence d'un exercice de récupération précis des éléments cibles lorsque se faisait la génération d'éléments sémantiques subalternes. Toutefois, dans deux autres expériences, l'oubli induit par la récupération s'est produit lorsque la tâche de génération sémantique a été doublée d'une récupération par catégorie. Même s'il n'y avait pas nécessairement concurrence entre l'information cible et l'information connexe dans le cadre de ces expériences, le phénomène de l'oubli induit par la récupération a été constaté. Les résultats de ces expériences vont à l'encontre de l'hypothèse de la concurrence, et donc, celle de l'inhibition.

Mots-clés : oubli induit par la récupération, mémoire, inhibition, hypothèse de la concurrence, dépendance, interférence.

References

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanism of forgetting. *Journal of Memory and Language, 49,* 415–445. doi:10.1016/j.jml.2003.08.006

Anderson, M. C., & Bell, T. (2001). Forgetting our facts: The role of inhibitory processes in the loss of propositional knowledge. *Journal of Experimental Psychology: General, 130,* 544–570. doi:10.1037/0096-3445.130.3.544

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1063–1087. doi:10.1037/0278-7393.20.5.1063

Anderson, M. C., Bjork, E. L., & Bjork, R. A. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review, 7,* 522–530. doi:10.3758/BF03214366

Anderson, M. C., Green, C., & McCulloch, K. C. (2000). Similarity and inhibition in long-term memory: Evidence for a two-factor theory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1141–1159. doi:10.1037/0278-7393.26.5.1141

Anderson, M. C., & Levy, B. J. (2007). Theoretical issues in inhibition: Insights from research on human memory. In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 81–102). Washington, DC: American Psychological Association. doi:10.1037/11587-005

Anderson, M. C., & McCulloch, K. C. (1999). Integration as a general boundary condition on retrieval-induced forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 608–629. doi:10.1037/0278-7393.25.3.608

Anderson, M. C., & Spellman, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review, 102,* 68–100. doi:10.1037/0033-295X.102.1.68

Basden, B. H., Basden, D. R., & Gargano, G. J. (1993). Directed forgetting in implicit and explicit memory tests: A comparison of methods. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 603–616. doi:10.1037/0278-7393.19.3.603

Bäuml, K. H. (2002). Semantic generation can cause episodic forgetting. *Psychological Science, 13,* 356–360. doi:10.1111/j.0956-7976.2002.00464.x

Bäuml, K. H., & Hartinger, A. (2002). On the role of item similarity in retrieval-induced forgetting. *Memory, 10,* 215–224. doi:10.1080/09658210143000362

Bäuml, K. H., Pastötter, B., & Hanslmayr, S. (2010). Binding and inhibition in episodic memory—Cognitive, emotional, and neural processes. *Neuroscience and Biobehavioural Reviews, 34,* 1047–1054. doi:10.1016/j.neubiorev.2009.04.005

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger and F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Camp, G., Pecher, D., & Schmidt, H. G. (2007). No retrieval-induced forgetting using item-specific independent cues: Evidence against a general inhibitory account. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 950–958. doi:10.1037/0278-7393.33.5.950

Camp, G., Pecher, D., Schmidt, H. G., & Zeelenberg, R. (2009). Are independent probes truly independent? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 934–942. doi:10.1037/a0015536

Darley, C. F., & Murdock, B. B. (1971). Effects of prior free recall testing on final recall and recognition. *Journal of Experimental Psychology, 91,* 66–73. doi:10.1037/h0031836

Goodmon, L. B., & Anderson, M. C. (2011). Semantic integration as a boundary condition on inhibitory processes in episodic retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 416–436. doi:10.1037/a0021963

Jakab, E., & Raaijmakers, J. G. W. (2009). The role of item strength in retrieval-induced forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 607–617. doi:10.1037/a0015264

James, W. (1890). *The principles of psychology.* New York, NY: Holt. doi:10.1037/11059-000

Johnson, S. K., & Anderson, M. C. (2004). The role of inhibitory control in forgetting semantic knowledge. *Psychological Science, 15,* 448–453. doi:10.1111/j.0956-7976.2004.00700.x

Jonker, T. R., Seli, P., & MacLeod, C. M. (2011). Less we forget: Retrieval cues and release from retrieval-induced forgetting. Manuscript submitted for publication.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 163–214). San Diego, CA: Academic Press.

MacLeod, M. D., & Macrae, C. N. (2001). Gone but not forgotten: The transient nature of retrieval-induced forgetting. *Psychological Science, 12,* 148–152. doi:10.1111/1467-9280.00325

Macrae, C. N., & Roseveare, T. A. (2002). I was always on my mind: The self and temporary forgetting. *Psychonomic Bulletin & Review, 9,* 611–614. doi:10.3758/BF03196320

Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129,* 4–26. doi:10.1037/0096-3445.129.1.4

McDaniel, M. A., & Masson, M. E. J. (1985). Altering memory representations through retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 371–385. doi:10.1037/0278-7393.11.2.371

McDaniel, M. A., Roediger, H. L., & McDermott, K. B. (2007). Generalizing test-enhanced learning from the laboratory to the classroom. *Psychonomic Bulletin & Review, 14,* 200–206. doi:10.3758/BF03194052

McGeoch, J. A. (1942). *The psychology of learning.* New York, NY: Longman, Green.

Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology, 64,* 482–488. doi:10.1037/h0045106

Perfect, T. J., Stark, L., Tree, J. J., Moulin, C. J. A., Ahmed, L., & Hutter, R. (2004). Transfer appropriate forgetting: The cue-dependent nature of retrieval-induced forgetting. *Journal of Memory and Language, 51,* 399–417. doi:10.1016/j.jml.2004.06.003

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In D. Bouma & D. Bouwhuis (Eds.), *Attention and performance* (Vol. 10, pp. 531–566). Hillsdale, NJ: Erlbaum.

Raaijmakers, J. G. W., & Jakab, E. (2012). Retrieval induced forgetting without competition: Testing the retrieval-specificity assumption of inhibition theory. *Memory & Cognition, 40,* 19–27.

Roediger, H. L. (1974). Inhibiting effects of recall. *Memory & Cognition, 2,* 261–269. doi:10.3758/BF03208993

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science, 17,* 249–255. doi:10.1111/j.1467-9280.2006.01693.x

Saunders, J., & MacLeod, M. D. (2006). Can inhibition resolve retrieval competition through the control of spreading activation? *Memory & Cognition, 34,* 307–322. doi:10.3758/BF03193409

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 37,* 571–590.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review of integration of conflicting views. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 54,* 321–343. doi:10.1080/02724980042000183

Verde, M. F. (2012). Retrieval-induced forgetting and inhibition: A critical review. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 56, pp. 47–80). New York: Academic Press.

Verde, M. F., & Perfect, T. J. (2011). Retrieval-induced forgetting in recognition is absent under time pressure. *Psychonomic Bulletin & Review, 18,* 1166–1171.

Weiner, B., & Reed, H. (1969). Effects of the instructional sets to remember and to forget on short-term retention: Studies of rehearsal control and retrieval inhibition (repression). *Journal of Experimental Psychology, 79,* 226–232. doi:10.1037/h0026951

Williams, C. C., & Zacks, R. T. (2001). Is retrieval-induced forgetting an inhibitory process? *The American Journal of Psychology, 114,* 329–354. doi:10.2307/1423685

Wundt, W. (1902). *Grundzüge de physiologischen Psychologie* [Principles of physiological psychology] (5th ed.). Leipzig, Germany: Engelmann.

Appendix

A Replication of Anderson, Bjork, and Bjork's (2000) Category Retrieval Task

Method

Participants

Participants were 5 males and 22 females, with ages ranging from 18 to 23 years (M = 19.9 years). All participants were recruited from the same pool and with the same constraints as in Experiment 1.

Materials

Stimuli and testing equipment were identical to those used in Experiment 1.

Procedure

The study was identical to that of Experiment 1. Following study, participants performed a category retrieval task (i.e., the retrieval practice phase). This task was similar to the noncompetitive condition in Anderson, Bjork, et al. (2000); participants retrieved the category name from the provided exemplar. An output order control (like that of Experiment 3) was implemented on the final test. That is, participants were prompted to output Rp− items before Rp+ items, with blocked presentation of items from the same category.

Results and Discussion

Participants retrieved the studied category on 93.0% of the retrieval practice trials.

Overall, recall for Rp+, Rp−, and Nrp items differed, $F(2, 52) = 10.61$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .29$.

Participants recalled more Rp+ items (M = .74) than second-half Nrp items (M = .60), $t(26) = 4.34$, $SE = .03$, $p < .001$, $\eta_p^2 = .42$, but the recall proportion of Rp− items (M = .58) did not differ from the proportion of first-half Nrp items (M = .60), $t(26) = 0.53$, $SE = .04$, $p = .60$. Thus, this pattern replicates the findings from Anderson, Bjork, et al. (2000).

Received October 28, 2011
Accepted January 17, 2012 ■