5

RETRIEVAL-INDUCED FORGETTING AND THE RESOLUTION OF COMPETITION

Benjamin C. Storm

It may seem that remembering and forgetting reflect two ends of a single continuum—that to remember is to avoid forgetting. Yet, in many instances, forgetting plays an essential and adaptive role in our ability to remember (e.g., E. L. Bjork & Bjork, 1988; R. A. Bjork & Bjork, 1992). Without some means of forgetting information that has become outdated or irrelevant, it would be incredibly difficult to remember information that is relevant. One mechanism that appears to afford this adaptive form of forgetting is inhibition (see, e.g., Anderson, 2003; E. L. Bjork, Bjork, & Anderson, 1998; R. A. Bjork, 1989). A given retrieval cue may activate many items in memory, and inhibition acts to decrease the accessibility of nontarget items in order to facilitate access to target items. This inhibition may explain why retrieving some items from memory causes the forgetting of other items in memory, a phenomenon known as retrieval-induced forgetting (Anderson, R. A. Bjork, & Bjork, 1994). It is argued herein that competition is a critical factor in the inhibitory account of retrieval-induced forgetting and, furthermore, that retrieval-induced forgetting is not as much a consequence of retrieval as it is a consequence of the inhibitory processes that resolve competition *during* retrieval.

THE PHENOMENON OF RETRIEVAL-INDUCED FORGETTING

Retrieval-induced forgetting is often studied using the retrieval practice paradigm (Anderson et al., 1994). In this paradigm, participants first study a list of category-exemplar pairs (e.g., *fruit: lemon, profession: accountant, fruit: orange, profession: dentist*), then, during retrieval practice, they retrieve half of the exemplars from half of the categories via category-plus-two-letter-stem retrieval cues (e.g., *fruit: le*_____). Practiced exemplars are referred to as Rp+ items (i.e., *lemon*), nonpracticed exemplars from practiced categories are referred to as Rp– items (i.e., *orange*), and exemplars from nonpracticed categories are referred to as Nrp items (i.e., *accountant, dentist*). After a brief delay, participants are given a final test for all of the items from the original study phase. As expected, Rp+ items are better recalled than are Nrp items. What is more surprising is that Rp– items are worse recalled than are Nrp items. It is this forgetting of Rp– items relative to Nrp items that is referred to as retrieval-induced forgetting—a finding that has proven to be highly robust and general, emerging in many contexts and with a wide variety of materials (see, e.g., Anderson & Bell, 2001; Bajo, Gómez-Ariza, Fernandez, & Marful, 2006; Carroll, Campbell-Ratcliffe, Murnane, & Perfect, 2007; Ciranni & Shimamura, 1999; Levy, McVeigh, Marful, & Anderson, 2007; Macrae & MacLeod, 1999; Migueles & Garcia-Bajos, 2007; Phenix & Campbell, 2004; Saunders & MacLeod, 2002; Shaw, Bjork, & Handal, 1995; Shivde & Anderson, 2001; Storm, Bjork, & Bjork, 2005).

Theoretical Accounts of Retrieval-Induced Forgetting

The inhibitory account of retrieval-induced forgetting contends that Rp– items are actively inhibited during the retrieval practice of Rp+ items (for reviews, see Anderson, 2003; Levy & Anderson, 2002). According to this account, forgetting is the consequence of inhibitory processes that act to resolve competition during retrieval. Because both Rp+ items and Rp– items are associated to the same retrieval cue, Rp– items may become activated during retrieval practice and compete with the retrieval of Rp+ items. Inhibition is recruited to suppress the Rp– items, which reduces competition, but also makes those items less recallable on the final test.

The term *inhibition* has often been used to refer to any empirical demonstration of performance below baseline. In that sense inhibition is nothing more than a description of the data. It is important to emphasize that the term is used here in a much stronger sense. Specifically, we use the definition provided by R. A. Bjork (1989, p. 324), who referred to inhibition as a "suppression-type process directed at the to-be-inhibited information for some adaptive purpose." In this sense, inhibition is an active and adaptive mechanism that functions with the specific and direct purpose of impairing the accessibility of an item or items in memory. Literally defined, the term *retrieval-induced forgetting* refers to the weaker meaning of inhibition—that retrieving an item or set of items from memory causes the forgetting of other items in memory, regardless of how or why that forgetting occurs.

Unfortunately, the terms *inhibition* and *retrieval-induced forgetting* are often used interchangeably. Although suppression-type inhibition may underlie many effects of retrieval-induced forgetting, it may not underlie all effects of retrieval-induced forgetting. In fact, there are many mechanisms by which retrieval can cause forgetting (e.g., retroactive interference, cue overload, part-set cuing, response competition, output interference, and strategy disruption; for a review of how these and other mechanisms might account for retrieval-induced forgetting, see Anderson & Bjork, 1994). A common theme among most noninhibitory accounts is that retrieval practice strengthens the association between Rp+ items and the associated retrieval cues, which has the side effect of occluding, interfering with, or stealing activation away from other items that are also associated with those cues (see, e.g., Anderson, 1983; McGeoch, 1942; Raaijmakers & Shiffrin, 1981; Rundus, 1973).

Evidence for Inhibition

There has been, and still is, a general reluctance to postulate a role for inhibition in memory (R. A. Bjork, 2007). Many researchers argue that retrieval-induced forgetting can be best explained by mechanisms other than inhibition (e.g., Dodd, Castel, & Roberts, 2006; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Williams & Zacks, 2001). A common argument against the inhibitory account is that forgetting may result from output interference (e.g., Roediger, 1973; A. D. Smith, 1971). That is, Rp– items may be impaired because Rp+ items are outputted first on the final test, which has the consequence of impairing the recall of as of yet nonoutputted Rp– items. However, by employing category-plus-one-letter-stem retrieval cues (e.g., *fruit: l*_____), experimenters have been able to control the order in which items are retrieved on the final test, and retrieval-induced forgetting is observed even when output interference is controlled (e.g., Anderson & Bell, 2001; Anderson et al., 1994; Anderson, E. L. Bjork, & Bjork, 2000; Anderson & McCulloch, 1999; Bäuml & Hartinger, 2002; Storm, Bjork, & Bjork, 2007, 2008; Storm & Nestojko, 2010).

Another possibility is that retrieval-induced forgetting is caused by strength-based associative interference (Anderson, 1983; McGeoch, 1942; Mensink & Raaijmakers, 1988). Retrieval practice strengthens a subset of items associated to a cue, which may have the side effect of making nonpracticed items less accessible given that cue. This blocking or interference-based account is not supported by evidence that retrieval-induced forgetting is cue independent (Anderson & Spellman, 1995). If retrieval-induced forgetting occurs because retrieval practice strengthens the association between the practiced item and its associated retrieval cue, then testing nonpracticed items using a novel retrieval cue—one that is independent from the cue used during retrieval practice—should prevent practiced items from interfering with the recall of nonpracticed items on the final test. Yet, retrieval-induced forgetting is observed even when independent cues are employed (e.g., Anderson & Bell, 2001; Anderson, Green, & McCulloch, 2000; Anderson & Spellman, 1995; Aslan, Bäuml, & Pastötter, 2007; Johnson & Anderson, 2004; Levy et al., 2007; MacLeod & Saunders, 2005; Radvansky, 1999; but see Camp, Pecher, & Schmidt, 2007; Perfect et al., 2004).

Evidence against the interference account has also come from work showing that strengthening practiced items is neither sufficient nor necessary to cause retrieval-induced forgetting (e.g., Anderson et al., 2000; Bäuml, 2002; Ciranni & Shimamura, 1999; Román, Soriano, Gómez-Ariza, & Bajo, 2009; Saunders, Fernandes, & Kosnes, 2009; Storm, Bjok, Bjork, & Nestojko, 2006; Storm & Nestojko, 2010; but see Verde, 2009). If retrieval-induced forgetting is the consequence of strength-based associative interference, then Rp– items should suffer from interference even if Rp+ items are strengthened by means other than selective retrieval. Yet, when participants are re-presented Rp+ items for additional study during what would normally be retrieval practice, the strengthening caused by that re-presentation fails to cause the forgetting of Rp– items on the final test. In general, retrieval-induced forgetting is strength independent—the extent to which Rp+ items are strengthened does not predict the magnitude of retrieval-induced forgetting that is observed.

If inhibition does underlie retrieval-induced forgetting, then individuals who have an inhibitory deficit should demonstrate significantly less retrieval-induced forgetting than individuals who do not have an inhibitory deficit. However, such a correlation should only be observed for inhibitory-based effects of retrieval-induced forgetting. Participants with an inhibitory deficit may show normal or even exaggerated levels of retrieval-induced forgetting when forgetting is caused by noninhibitory mechanisms, such as output interference (cf. Anderson & Levy, 2007). For example, Storm and White (2010) administered the retrieval

practice paradigm to college students diagnosed with attention-deficit hyperactivity disorder (ADHD), a disorder characterized by a deficit in inhibitory control. Individuals with ADHD failed to demonstrate any retrieval-induced forgetting when output interference was controlled, but demonstrated normal levels of retrieval-induced forgetting when output interference was not controlled (for similar results in schizophrenic patients, see Soriano, Jiménez, Román, & Bajo, 2009). The failure to control for output interference may explain why so many studies have observed normal levels of retrieval-induced forgetting in populations with established inhibitory deficits (e.g., Conway & Fthenaki, 2003; Ford, Keating, & Patel, 2004; Moulin et al., 2002; Nestor et al., 2005; Zellner & Bäuml, 2005).

Evidence that individuals with inhibitory deficits demonstrate significantly less inhibitory-based retrieval-induced forgetting is consistent with the idea that executive control mechanisms underlie retrieval-induced forgetting (e.g., Anderson, 2003, 2005). Román et al. (2009) tested this idea further by having participants engage in one of two concurrent tasks during retrieval practice, either a trial-by-trial updating task or a continuous updating task. Both of these tasks were predicted to overload attentional resources and, therefore, impede the ability to inhibit nontarget competitors. Consistent with the executive control account, participants who engaged in a concurrent task demonstrated significantly less retrieval-induced forgetting than participants who did not engage in a concurrent task.

Finally, neuroimaging work has also supported the inhibitory account (e.g., Johansson, Aslan, Bäuml, Gabel, & Mecklinger, 2007; Kuhl, Dudukovic, Kahn, & Wagner, 2007; Kuhl, Kahn, Dudukovic, & Wagner, 2008; Wimber et al., 2008; for a review, see Kuhl & Wagner, 2009). For example, Kuhl et al. (2007) measured neural activation in the prefrontal cortex across several blocks of retrieval practice. They reasoned that if inhibition functions to resolve competition, then retrieval on the final block of retrieval practice should be less competitive than retrieval on the first block of retrieval practice; and, owing to this reduction in competition, the neural regions responsible for detecting and resolving competition should be less engaged during the final block of retrieval practice than during the first block of retrieval practice. Kuhl et al. (2007) observed precisely this pattern of results. Prefrontal activity was reduced and, moreover, the extent to which activity was reduced correlated significantly with the amount of retrieval-induced forgetting that was observed on the final test. These and other results fit well with the inhibitory account and suggest that the prefrontal cortex plays a critical role in the inhibitory mechanisms that underlie retrieval-induced forgetting.

INHIBITORY CONTROL AND THE RESOLUTION OF COMPETITION

Competition is a critical and defining feature of the inhibitory account of retrieval-induced forgetting. In many ways, evidence that retrieval-induced forgetting is competition dependent represents the most compelling line of evidence supporting the inhibitory account. As with cue independence and strength independence, competition dependence cannot be easily explained by noninhibitory interference-based accounts. However, competition dependence also provides evidence supporting the adaptive function that inhibition is presumed to afford—namely, the resolution of competition. The fundamental premise of the inhibitory account is that there exists competition during retrieval, and inhibition is necessary to resolve that competition. It is competition that sets the stage for inhibition to occur. Nondesired items that are associated with the available set of retrieval cues must be suppressed, set aside, or inhibited, in order to facilitate the retrieval of the particular item or items that are desired. In what follows I review evidence that competition is a necessary condition for retrieval-induced forgetting and that inhibition functions to resolve that competition.

Competition as a Necessary Condition for Retrieval-Induced Forgetting

According to the inhibitory account of retrieval-induced forgetting, inhibition is elicited to suppress nontarget items that compete with the retrieval of target items. This account predicts that if an item does not compete with retrieval practice, then that item should not be inhibited and, therefore, that that item should not suffer from retrieval-induced forgetting. The few studies that have manipulated competition during retrieval practice have generally supported this prediction, as it is the items that compete most that are the most susceptible to forgetting (e.g., Anderson et al., 1994; Shivde & Anderson, 2001; Storm et al., 2007; however, see also Williams & Zacks, 2001).

Anderson et al. (1994) provided the first and most widely cited example of competition dependence. In their study, the taxonomic strength of both practiced and nonpracticed items was manipulated. Whereas nonpracticed items of high taxonomic strength (e.g., *orange, lemon*) suffered from substantial effects of retrieval-induced forgetting, nonpracticed items of low taxonomic strength (e.g., *fig, guava*) suffered from significantly less retrieval-induced forgetting. Similar results were observed by Shivde and Anderson (2001), who found that retrieval practice of the subordinate meaning of a homograph caused the forgetting of the dominant meaning, whereas retrieval practice of the dominant meaning did not cause the forgetting of the subordinate meaning.

In both experiments, it was the items that were most likely to intrude or compete with retrieval practice that were the most susceptible to retrieval-induced forgetting. Because weak exemplars and subordinate meanings were unlikely to become activated during retrieval practice, there was no need for them to be inhibited and, therefore, no reason for them to suffer retrieval-induced forgetting. Evidence of competition dependence is problematic for interference-based accounts. If retrieval-induced forgetting was the consequence of interference or blocking at the time of test, then the items strengthened by retrieval practice should have interfered with the recall of weaker items to at least the same extent as they interfered with the recall of stronger items (e.g., Raaijmakers & Shiffrin, 1981).

Storm et al. (2007) reasoned that if retrieval-induced forgetting is competition dependent, then leading participants to believe that they would not be tested on certain information would ironically spare that information from forgetting. Research on directed forgetting has shown that cuing participants to forget an initially presented list of items reduces the extent to which those items proactively interfere with the learning and recall of a new list of items (Bjork, 1970; MacLeod, 1998). If proactive interference is reduced by instructions to forget, then items from to-be-forgotten lists should be less likely to interfere with subsequent retrieval practice and, therefore, less likely to be targeted by inhibition. Consistent with this prediction, Storm et al. (2007) found that items from to-be-remembered lists suffered from a substantial effect of retrieval-induced forgetting, whereas items from to-be-forgotten lists did not suffer from any retrieval-induced forgetting.

An important aspect of Storm et al.'s (2007) study is that the degree of competition that occurred during retrieval practice was manipulated without using different sets of items. The same items were shown to suffer or not suffer from retrieval-induced forgetting, depending on whether an instruction to remember or forget was given prior to retrieval practice. This distinction is important. It suggests that items that are not susceptible to retrieval-induced forgetting under some conditions may become susceptible under other conditions. For example, although weak items may not compete during retrieval practice under normal conditions, providing sufficient exposure to such items may very well cause them to compete during retrieval practice and therefore be targeted by inhibitory control.

Indirect evidence of competition dependence can be seen throughout research on retrieval-induced forgetting. Whether forgetting is or

is not observed in a given study can often be attributed to whether there was competition during retrieval practice. In fact, many of the boundary conditions that constrain retrieval-induced forgetting are directly related to competition. Take, for example, the demonstration that the retrieval of one item fails to cause the forgetting of another item if those two items are well integrated—either due to encoding instructions or to the nature of the materials (e.g., Anderson et al., 2000; Anderson & McCulloch, 1999; Bäuml & Hartinger, 2002; Chan, McDermott, & Roediger, 2006; Migueles & Garcia-Bajos, 2007). Integration has been shown to reduce competition between items associated to the same retrieval cue (e.g., Postman, 1971; Radvansky & Zacks, 1991), and in doing so, integration may effectively reduce or eliminate the need for inhibition. Another factor that has been argued to allay competition is item-specific or distinctive processing (R. E. Smith & Hunt, 2000), which may explain why retrieval-induced forgetting fails to emerge under conditions that promote such processing, such as when one is under stress (Koessler, Engler, Riether, & Kissler, 2009) or in a negative mood (Bäuml & Kuhbandner, 2007).

Finally, it is important to emphasize that only inhibitory-based effects of retrieval-induced forgetting should be competition dependent. Take, for example, the failure of Williams and Zacks (2001) to replicate Anderson et al.'s (1994) finding that exemplars of strong taxonomic strength are more susceptible to retrieval-induced forgetting than exemplars of weak taxonomic strength. As with many studies of retrieval-induced forgetting, Williams and Zacks employed a category-cued final test that failed to control for output interference. Whereas the final recall for items of strong taxonomic strength may have been impaired as a consequence of inhibition during retrieval practice, the final recall for items of weak taxonomic strength may have been impaired as a consequence of output interference on the final test.

Unsuccessful Retrieval, Successful Forgetting

If retrieval-induced forgetting is caused by inhibitory processes that act to resolve competition, then whether retrieval eventually succeeds or fails should not determine whether retrieval-induced forgetting occurs. And, consistent with this assertion, retrieval-induced forgetting is observed even when participants fail to retrieve anything during retrieval practice (Storm, Bjork, Bjork, & Nestojko, 2006; Storm & Nestojko, 2010). Storm and colleagues had participants study a list of category-exemplar pairs and then engage in retrieval practice that consisted of category-plus-stem cues that either did or did not represent the initial letters of any associated exemplar. 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 that had received possible retrieval practice versus exemplars associated with categories that had received impossible retrieval practice.

The above pattern of results is very difficult for noninhibitory accounts to explain. If nothing is retrieved during retrieval practice, then nothing is strengthened and nothing should interfere with the retrieval of nonpracticed items on the final test. According to the inhibitory account, however, inhibition acts to resolve competition, and the consequences of that inhibition should be observed even if retrieval is ultimately unsuccessful. Some might argue that something is still being strengthened by impossible retrieval practice. For example, participants may fail to come up with a viable response, but they may still be coming up with a response, and, even if not viable, that response may interfere on the final test. Two considerations make this possibility unlikely. First, in none of the five experiments that employed impossible retrieval practice did participants who made more responses—regardless of the appropriateness of their responses—demonstrate more retrieval-induced forgetting than participants who made fewer responses. Second, if any items were activated or covertly retrieved during impossible retrieval practice, it would likely have been the items that participants had just previously studied. Thus, nonpracticed items would seem more likely to benefit from impossible retrieval practice than be impaired by it.

Researchers have generally assumed that retrieval-induced forgetting is retrieval specific. That unsuccessful retrieval also causes forgetting supports and refines this assumption. A more accurate characterization of inhibition-based retrieval-induced forgetting is that it is competition specific. It is the competition that arises during retrieval that sets the stage for inhibition to occur, not the retrieval per se. It is ironic that researchers have often been so careful to design studies in such a way that fosters high levels of retrieval practice success. The irony is that by making retrieval practice easier, researchers may have unwittingly made retrieval practice less competitive and, therefore, less likely to result in inhibitory-based retrieval-induced forgetting.

Overcoming Competition During Semantic Generation and Mental Imagery

In most studies of retrieval-induced forgetting, retrieval practice is episodic in nature; that is, participants must retrieve specific items from an earlier phase of the experiment (i.e., the study phase). However, inhibition may be recruited to resolve competition in many situations where

one must bypass inappropriate responses in order to select, retrieve, or generate a weaker, yet desirable, response. For example, if participants are guided to selectively generate items from semantic memory during retrieval practice, that semantic generation leads to just as much forgetting as does the typical episodic-based retrieval practice (e.g., Bäuml, 2002; Johnson & Anderson, 2004; Storm et al., 2006, 2007, 2008; Storm & Nestojko, 2010).

A recent example of a nonretrieval task leading to an effect similar to that of retrieval-induced forgetting is reported by Saunders et al. (2009). During what would normally be retrieval practice, Saunders et al. presented intact category-exemplar pairs from a subset of categories and asked participants to generate mental images of those items. Across several trials, participants generated images focusing on different aspects of each item (e.g., shape, color, size, sound, and texture). This imagery task led to an exceptionally large effect of imagery-induced forgetting. Nonvisualized items from visualized categories were recalled significantly less than were nonvisualized items from nonvisualized categories. Perhaps most impressive was the magnitude of the effect. Normally, when category-plus-stem cued-recall tests are employed, retrieval-induced forgetting effects do not surpass 15%, yet in their Experiment 2, which also employed a category-plus-stem cued-recall test, a 33% effect was observed.

Saunders et al. (2009) argued that the imagery-induced forgetting effect was a consequence of inhibition. Generating mental imagery requires access to semantic knowledge, and as reviewed above, retrieval from semantic memory can cause retrieval-induced forgetting. One possible explanation for the impressive size of their effect may lie in the nature of the imagery task. Increasing the number of retrieval practice trials has been shown to increase the magnitude of retrieval-induced forgetting (e.g., Johnson & Anderson, 2004; Levy et al., 2007; Storm et al., 2008), and this increase may be amplified when the nature or target of retrieval/generation varies across each trial. Normally, when retrieval practice is repeated, the task becomes progressively easier (noncompetitive) as Rp+ items become more accessible owing to the benefits of retrieval practice. Forcing participants to generate imagery related to different aspects of each item may have increased competition during later practice trials, thereby increasing the need for inhibition.

Overcoming Fixation in Creative Problem Solving

Inhibition is generally assumed to stifle creativity, an assumption stemming from observations that individuals who are the least capable of inhibiting their thoughts and actions are often the most creative (e.g., Carson, Peterson, & Higgins, 2003; Eysenck, 1995; Martindale, 1999). However, there are conditions under which inhibition may have the power to enhance creative cognition. The difficulty in many creative tasks lies in the constraining influences of old and inappropriate ideas. Such ideas can cause *mental fixation*, thus impeding the generation or retrieval of new and creative ideas (see S. M. Smith, 2003). Inhibition may facilitate creative problem solving by decreasing the accessibility of strong, yet inappropriate solutions, thereby facilitating access to novel and creative solutions. In other words, inhibition may provide problem solvers a means by which to overcome fixation and achieve a creative solution.

Storm and Angello (in press) tested this idea by measuring retrieval-induced forgetting and correlating that measure with performance on a task commonly used to study creative problem solving, the Remote Associates Test (RAT; Mednick, 1962). To solve a given RAT problem, participants must generate a common associate to each of three cue words (e.g., *manners*, *tennis*, and *round*: solution is *table*), which can be difficult because the strongest associates to each cue word (e.g., *polite*, *ball*, and *square*, respectively) often bear little or no relationship to the other cue words. Once activated, however, these inappropriate associates can cause mental fixation, thereby interfering with the generation of novel and appropriate associates (S. M. Smith & Blankenship, 1991; Wiley, 1998). Storm and Angello manipulated the extent to which each participant experienced mental fixation by exposing half of the participants to misleading associates prior to solving a series of RAT problems. They reasoned that if the mechanism underlying retrieval-induced forgetting functions to resolve competition, then individuals who demonstrate more retrieval-induced forgetting should also demonstrate a superior ability to overcome competition created by exposure to the misleading associates.

Overall, participants who were exposed to the misleading associates performed worse than participants who were not exposed to the misleading associates. However, the degree to which participants suffered from this exposure was moderated by individual differences in retrieval-induced forgetting. Participants who demonstrated the most retrieval-induced forgetting were less affected by exposure than were participants who demonstrated the least retrieval-induced forgetting. Said differently, the more a participant demonstrated retrieval-induced forgetting, the less that participant suffered from fixation during RAT problem solving. This effect became more pronounced as participants continued to try to solve the problems. After 18 minutes of attempted problem solving, participants who demonstrated the least retrieval-

induced forgetting suffered from a 21% fixation effect, whereas participants who demonstrated the most retrieval-induced forgetting suffered from only a 2% fixation effect.

These results provide a stunning demonstration of how the mechanisms underlying retrieval-induced forgetting function to resolve competition—not only during retrieval, but in the context of creative problem solving as well. They also provide a new type of evidence for the inhibitory account. If retrieval-induced forgetting was caused by interference, then individuals who demonstrated more retrieval-induced forgetting should have suffered from more interference, not less interference, while solving the RAT problems. Only the inhibitory account predicts that individuals who suffer from more retrieval-induced forgetting should be better able to overcome fixation.

CONCLUSION

Inhibitory-based effects of retrieval-induced forgetting are competition dependent, meaning that nonpracticed items only suffer from retrieval-induced forgetting to the extent that they compete with retrieval practice. In this sense, retrieval-induced forgetting is not a by-product of retrieval; it is the consequence of adaptive inhibitory processes that act to resolve competition during retrieval. This inhibition is believed to reflect executive control mechanisms that provide flexible control over memory by resolving competition in whatever form it is encountered, whether it is during episodic retrieval, semantic generation, or creative problem solving. Even competition that arises during unsuccessful retrieval attempts is sufficient to elicit the inhibition of competing items. These findings provide compelling evidence for the inhibitory account of retrieval-induced forgetting and, more generally, demonstrate the important role that inhibition plays in resolving competition in memory.

REFERENCES

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49,* 415–445.

Anderson, M. C. (2005). The role of inhibitory control in forgetting unwanted memories: A consideration of three methods. In C. MacLeod & B. Uttl (Eds.), *Dynamic cognitive processes* (pp. 159–190). Tokyo: Springer-Verlag.

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.

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

Anderson, M. C., & Bjork, R. A. (1994). Mechanisms of inhibition in long-term memory: A new taxonomy. In D. Dagenbach & T. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 265–326). New York: Academic Press.

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.

Anderson, M. C., Green, C., & McCulloch, K. C. (2000). Similarity and inhibition in long-term memory: Evidence for a two-factor model. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 1141–1159.

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

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.

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.

Aslan, A., Bäuml, K.-H., & Pastötter, B. (2007). No inhibitory deficit in older adults' episodic memory. *Psychological Science, 18,* 72–28.

Bajo, M. T., Gómez-Ariza, C. J., Fernandez, A., & Marful, A. (2006). Retrieval-induced forgetting in perceptually driven memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1185–1194.

Bäuml, K.-H. (2002). Semantic generation can cause episodic forgetting. *Psychological Science, 13,* 356–360.

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

Bäuml, K.-H., & Kuhbandner, C. (2007). Remembering can cause forgetting—but not in negative moods. *Psychological Science, 28,* 111–115.

Bjork, E. L., & Bjork, R. A. (1988). On the adaptive aspects of retrieval failure in autobiographical memory. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues: Memories in everyday life* (Vol. 1, pp. 283–288). London: Wiley.

Bjork, E. L., Bjork, R. A., & Anderson, M. C. (1998). Varieties of goal directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 103–137). Hillsdale, NJ: Erlbaum.

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior, 9,* 255–268.

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

Bjork, R. A. (2007). Inhibition: An essential and contentious concept. In H. L. Roediger, Y. Dudai, & S. M. Fitzpatrick (Eds.), *Science of memory: Concepts* (pp. 307–313). Oxford, UK: Oxford University Press.

Bjork, R. A., & Bjork, E. L. (1992). A new theory of disuse and an old theory of stimulus fluctuation. In A. Healy, S. Kosslyn, & R. Shiffrin (Eds.), *From learning processes to cognitive processes: Essays in honor of William K. Estes* (Vol. 2, pp. 35–67). Hillsdale, NJ: Lawrence Erlbaum Associates.

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.

Carroll, M., Campbell-Ratcliffe, J., Murnane, H., & Perfect, T. (2007). Retrieval-induced forgetting in educational contexts: Monitoring, expertise, text integration, and test format. *European Journal of Cognitive Psychology, 19,* 580–606.

Carson, S. H., Peterson, J. B., & Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *Journal of Personality and Social Psychology, 85,* 499–506.

Chan, J. C. K., McDermott, K. B., & Roediger, H. L. (2006). Retrieval-induced facilitation: Initially nontested materials can benefit from prior testing of related material. *Journal of Experimental Psychology: General, 135,* 553–571.

Ciranni, M., & Shimamura, A. P. (1999). Retrieval-induced forgetting in episodic memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 1403–1414.

Conway, M. A., & Fthenaki, A. (2003). Disruption of inhibitory control of memory following lesions to the frontal and temporal lobes. *Cortex, 39,* 667–686.

Dodd, M. D., Castel, A. D., & Roberts, K. E. (2006). A strategy disruption component to retrieval-induced forgetting. *Memory and Cognition, 34,* 102–111.

Eysenck, H. (1995). *Genius: The natural history of creativity.* Cambridge, UK: Cambridge University Press.

Ford, R. M., Keating, S., & Patel, R. (2004). Retrieval-induced forgetting: A developmental study. *British Journal of Developmental Psychology, 22,* 585–603.

Johansson, M., Aslan, A., Bäuml, K.-H., Gäbel, A., & Mecklinger, A. (2007). When remembering causes forgetting: Electrophysiological correlates of retrieval-induced forgetting. *Cerebral Cortex, 17,* 548–560.

Johnson, S. K., & Anderson, M. C. (2004). The role of inhibitory control in forgetting semantic knowledge. *Psychological Science, 15,* 448–453.

Koessler, S., Engler, H., Riether C., & Kissler, J. (2009). No retrieval-induced forgetting under stress. *Psychological Science, 20,* 1356–1363.

Kuhl, B. A., Dudukovic, N. M., Kahn, I., & Wagner, A. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. *Nature Neuroscience, 10,* 908–914.

Kuhl, B. A., Kahn, I., Dudukovic, N. M., & Wagner, A. D. (2008). Overcoming suppression in order to remember: Contributions from anterior cingulate and ventrolateral prefrontal cortex. *Cognitive, Affective, and Behavioral Neuroscience, 8,* 211–221.

Kuhl, B. A., & Wagner, A. D. (2009). Forgetting and retrieval. In G. G. Berntson & J. T. Cacioppo (Eds.), *Handbook of neurosciences for the behavioral sciences.* Hoboken, NJ: John Wiley & Sons.

Levy, B. J., & Anderson, M. C. (2002). Inhibitory processes and the control of memory retrieval. *Trends in Cognitive Science, 6,* 299–305.

Levy, B. J., McVeigh, N. D., Marful, A., & Anderson, M. C. (2007). Inhibiting your native language: The role of retrieval-induced forgetting during second language acquisition. *Psychological Science, 18,* 29–34.

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Lawrence Erlbaum Associates.

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., & Saunders, J. (2005). The role of inhibitory control in the production of misinformation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 964–979.

Macrae, C. N., & MacLeod, M. D. (1999). On recollections lost: When practice makes imperfect. *Journal of Personality and Social Psychology, 77,* 463–473.

Martindale, C. (1999). Biological bases of creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 137–152). New York: Cambridge University Press.

McGeoch, J. A. (1942). *The psychology of human learning.* New York: Longmans & Green.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review, 69,* 220–232.

Mensink, G. J. M., & Raaijmakers, J. G. W. (1988). A model of interference and forgetting. *Psychological Review, 95,* 434–455.

Migueles, E., & Garcia-Bajos, E. (2007). Selective retrieval and induced forgetting in eyewitness memory. *Applied Cognitive Psychology, 21,* 1157–1172.

Moulin, C. J. A., Perfect, T. J., Conway, M. A., North, A. S., Jones, R. W., & James, N. (2002). Retrieval-induced forgetting in Alzheimer's disease. *Neuropsychologia, 40,* 862–867.

Nestor, P. G., Piech, R., Allen, C., Niznikiewicz, M., Shenton, M., & McCarley R. W. (2005). Retrieval-induced forgetting in schizophrenia. *Schizophrenia Research, 75,* 199–209.

Perfect, T. J., Stark, L.-J., 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.

Phenix, T. L., & Campbell, J. I. D. (2004). Effects of multiplication practice on product verification: Integrated structures model or retrieval-induced forgetting? *Memory and Cognition, 32,* 324–335.

Postman, L. (1971). Transfer, interference and forgetting. In J. W. Kling & L. A. Riggs (Eds.), *Woodworth and Scholsberg's experimental psychology* (3rd ed., pp. 1019–1132). New York: Holt, Rinehart & Winston.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review, 88,* 93–134.

Radvansky, G. A. (1999). Memory retrieval and suppression: The inhibition of situation models. *Journal of Experimental Psychology: General, 128,* 563–579.

Radvansky, G. A., & Zacks, R. T. (1991). Mental models and the fan effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 940–953.

Roediger, H. L. (1973). Inhibition in recall from cueing with recall targets. *Journal of Verbal Learning and Verbal Behavior, 12,* 644–657.

Román, P., Soriano, M. F., Gómez-Ariza, C. J., & Bajo, M. T. (2009). Retrieval-induced forgetting and executive control. *Psychological Science, 20,* 1053–1058.

Rundus, D. (1973). Negative effects of using list items as recall cues. *Journal of Verbal Learning and Verbal Behavior, 12,* 43–53.

Saunders, J., Fernandes, M., & Kosnes, L. (2009). Retrieval-induced forgetting and mental imagery. *Memory and Cognition, 37,* 819–828.

Saunders, J., & MacLeod, M. D. (2002). New evidence on the suggestibility of memory: The role of retrieval-induced forgetting in misinformation effects. *Journal of Experimental Psychology: Applied, 8,* 127–142.

Shaw, J. S., Bjork, R. A., & Handal, A. (1995). Retrieval-induced forgetting in an eyewitness-memory paradigm. *Psychonomic Bulletin and Review, 2,* 249–253.

Shivde, G., & Anderson, M. C. (2001). The role of inhibition in meaning selection: Insights from retrieval-induced forgetting. In D. S. Gorfein (Ed.), *On the consequences of meaning selection: Perspectives on resolving lexical ambiguity* (pp. 175–190). Washington, DC: American Psychological Association.

Smith, A. D. (1971). Output interference and organized recall from long-term memory. *Journal of Verbal Learning and Verbal Behavior, 10,* 400–408.

Smith, R. E., & Hunt, R. R. (2000). The influence of distinctive processing on retrieval-induced forgetting. *Memory and Cognition, 28,* 503–508.

Smith, S. M. (2003). The constraining effects of initial ideas. In P. Paulus & B. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 15–31). Oxford, UK: Oxford University Press.

Smith, S. M., & Blankenship, S. E. (1991). Incubation and the persistence of fixation in problem solving. *American Journal of Psychology, 104,* 61–87.

Soriano, M. F., Jiménez, J. F., Román P., & Bajo, M. T. (2009). Inhibitory processes in memory are impaired in schizophrenia: Evidence from retrieval-induced forgetting. *British Journal of Psychology, 100,* 661–673.

Storm, B. C., & Angello, G. (In press). Overcoming fixation: Creative problem solving and retrieval-induced forgetting. *Psychological Science.*

Storm, B. C., Bjork, E. L., & Bjork, R. A. (2005). Social metacognitive judgments: The role of retrieval-induced forgetting in person memory and impressions. *Journal of Memory and Language, 52,* 535–550.

Storm, B. C., Bjork, E. L., & Bjork, R. A. (2007). When intended remembering leads to unintended forgetting. *Quarterly Journal of Experimental Psychology, 60,* 909–915.

Storm, B. C., Bjork, E. L., & Bjork, R. A. (2008). Accelerated relearning after retrieval-induced forgetting: The benefit of being forgotten. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 230–236.

Storm, B. C., Bjork, E. L., Bjork, R. A., & Nestojko, J. F. (2006). Is retrieval success a necessary condition for retrieval-induced forgetting? *Psychonomic Bulletin and Review, 13,* 1023–1027.

Storm, B. C., & Nestojko, J. F. (2010). Successful inhibition, unsuccessful retrieval: Manipulating time and success during retrieval practice. *Memory, 18,* 99–114.

Storm, B. C., & White, H. A. (2010). ADHD and retrieval-induced forgetting: Evidence for a deficit in the inhibitory control of memory. *Memory, 18,* 265–271.

Verde, M. F. (2009). The list-strength effect in recall: Relative-strength competition and retrieval inhibition may both contribute to forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 205–220.

Wiley, J. (1998). Expertise and mental set: The effects of domain knowledge in creative problem solving. *Memory and Cognition, 26,* 716–730.

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

Wimber, M., Bäuml, K.-H., Bergström, Z., Markopoulos, G., Heinze, H.-J., & Richardson-Klavehn, A. (2008). Neural markers of inhibition in human memory retrieval. *Journal of Neuroscience, 28,* 13419–13427.

Zellner, M., & Bäuml, K.-H. (2005). Intact retrieval inhibition in children's episodic recall. *Memory and Cognition, 33,* 396–404.