

# RETRIEVAL-INDUCED FORGETTING AND INHIBITION: A CRITICAL REVIEW

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## Abstract

The influence of classic interference theories on contemporary thinking about recall is embodied in the principle of competitor interference, which suggests that forgetting is a direct result of competition among memories associated with a retrieval cue. The inhibition theory of forgetting (Anderson, 2003; Anderson & Bjork, 1994) represents a major departure from the interference tradition in suggesting that an active inhibition mechanism, rather than competition among memories, causes forgetting. This review offers a critical evaluation of the empirical support and the theoretical underpinnings of the case for inhibition and against competitor interference.

## 1. INTRODUCTION

Forgetting is often described in literary and popular culture as the “fading of memory,” a phrase that suggests permanence, an irrevocable decay. But if we broaden our conception of forgetting to encompass all forms of retrieval failure, all instances where we seek something hidden in memory and fail to find it, it is easy to think of examples to suggest that forgetting is often not permanent at all. When glimpsing the face of an actor on a billboard, we sometimes fail to recall the actor’s name immediately but it comes to us hours or days later. More dramatically, memories of childhood we had thought long lost sometimes spring up, surprising and unbidden. Experimental research has historically focused on this form of nonpermanent forgetting. According to interference theory, forgetting may be less about the loss of old experiences than about the accumulation of new ones.

The origins of this view can be traced to the paired-associate learning studies of Müller and Pilzecker (1900), who documented what came to be known as retroactive interference. Participants learned a list of syllable pairs and were asked to recall the list a short time later. When a second list was learned in the intervening period, memory for the original list was worse than when there was no interpolated learning. In other words, it was not just the passage of time but also the acquisition of new material that produced forgetting. The phenomenon of interlist or interitem interference preoccupied learning theories in the decades to follow, and it remained a guiding principle for cognitive theories of memory that emerged onward from the 1970s.

There have been a variety of competing views with regard to the specific mechanisms of interference, and many of the issues surrounding these mechanisms raised during the era of classic interference theory have yet to be fully resolved (Postman, 1976; Postman & Underwood, 1973). Nevertheless, one of the key principles to emerge from interference theory, competitor interference, remains important in contemporary models of memory. Returning to the earlier example of the face on a billboard, why is it difficult to recall the actor’s name? One possibility is that although we may immediately realize that the face belongs to a well-known actor, many such names reside in memory. The retrieval cue, *actor*, is not very specific and potentially activates many candidate names. Alternatively, given Hollywood’s template for beauty, many actors share a physical resemblance. Using facial features as a cue likewise potentially activates many candidates. Both possibilities suggest that retrieval is a process involving competition among many existing memories that share some association with the retrieval cue. Successful recall requires that the desired target memory be selected from among the nontargets. According

to the principle of competitor interference, the presence of multiple representations activated by a cue is a source of retrieval difficulty that directly causes forgetting. New experiences contribute to this difficulty by creating new competitors or increasing the competitive strength of existing competitors. In models that embrace this principle, forgetting is a consequence of the associative structure of memory.

The inhibition theory of forgetting proposed by Anderson and colleagues (Anderson, 2003; Anderson & Bjork, 1994; Anderson, Bjork, & Bjork, 1994) represents a major departure from the tradition of interference theory in rejecting competitor interference as a direct source of retrieval failure. According to inhibition theory, competing memories activated by a cue are a source of potential difficulty that requires the intervention of an executive control mechanism whose role is to actively suppress nontargets in order to facilitate retrieval of the target memory. It is this active inhibition during retrieval, rather than the presence of competitors per se, that produces forgetting.

Over the past two decades, a significant body of research devoted to the phenomenon of retrieval-induced forgetting (RIF) has shown that inhibition theory can account for many of the major findings within the domain of interference theory. More importantly, new findings from this literature seem to be at odds with the principle of competitor interference but are consistent with inhibition. A number of reviews and theoretical papers have presented a persuasive case for inhibition theory (Anderson, 2003; Anderson & Bjork, 1994; Anderson & Levy, 2007). However, any important theory, particularly one that argues for a sweeping reassessment of traditional views, benefits from more critical evaluation. The inhibition account of RIF centers on four key predictions thought to differentiate inhibition from mechanisms based on competitor interference: retrieval dependence, strength independence, interference dependence, and cue independence. The present chapter will argue that the empirical support for these predictions is not as consistent, nor the theoretical case against competitor interference as straightforward, as is often depicted in the RIF literature.



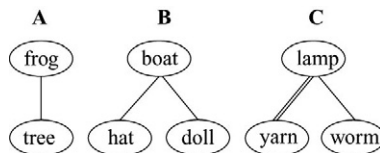
## 2. COMPETITION OR INHIBITION?

Theorists often point to the fundamental role of inhibition at the neuronal level when arguing for the plausibility of inhibitory mechanisms operating in cognitive processes. The usefulness of drawing such parallels is less than clear (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Nevertheless, the desire to link the brain with the mind has a persuasive power, and inhibition has emerged as an explanatory construct in cognitive domains ranging from perception and attention (Neill, 1977; Tipper,

1985) to social categorization (Kunda & Spencer, 2003). One might even argue that the ubiquity of inhibitory explanations across domains makes them all the more plausible in that it points to a basic need for such a mechanism. Anderson (2003) identifies this need is that of having to resist being controlled by dominant or habitual actions in a context where less dominant alternatives are more desirable. He offers an anecdote of knocking a cactus plant from a windowsill and resisting, at the last moment, to catch it as it fell. The normal, habitual reaction to catch a falling object was in this instance overridden by the more beneficial goal of avoiding physical injury.

There are parallels to this form of motor inhibition in our everyday use of memory. If we were asked to name a fruit starting with the letter *p*, the most common examples of fruit, *apple* and *orange*, might come to mind. Although neither is the desired response, their activation by the cue *fruit* is likely immediate and automatic. One can see the usefulness of suppressing these undesired memories. The question is whether a mechanism exists specifically for this purpose. The principle of competitor interference can explain the difficulties that arise when trying to generate examples of fruit, or remember a name, without the need to postulate an inhibitory mechanism. In order to understand the case for inhibition, it is useful to begin with a more detailed description of the noninhibitory account.

Inhibition theory was developed in the context of recall in paired associate learning, and this paradigm will be the basis for the examples to follow. In a typical experiment, participants study pairs of items. These could be word pairs such as *frog–tree*, *boat–hat*, *boat–doll*, *lamp–yarn*, and *lamp–worm*. The episodic representations can be depicted in terms of the items and the associative links between them (Figure 1). Presenting *frog* as a retrieval cue activates its own representation in memory and, via the episodic association, that of *tree* as well (Figure 1A). The cue *boat* activates two associated representations, *hat* and *doll*. Because only one of these can be retrieved at a given time, the two are competitors, each blocking the retrieval of the other (Figure 1B). Increasing the number of items associated with a cue increases the degree of interference. Manipulating the strength of association can also increase interference. If *lamp–yarn* is presented several times while *lamp–worm* is presented only once, the greater number of encoding opportunities leads to a stronger association between



**Figure 1** Episodic representations: Association and interference.

*lamp* and *yarn*. Therefore *yarn* is more likely to be retrieved and more likely to block the retrieval of *worm* (Figure 1C).

Competitor interference can be described in terms of a likelihood ratio:

$$P(R_j|\text{cue}) = \frac{A_j}{\sum A_k}. \quad (1)$$

The likelihood of retrieving the memory representation  $R$  of item  $j$  given the retrieval cue is equal to the ratio of the strength of association between the item and the cue,  $A_j$ , and the summed associative strengths of all  $k$  competing representations, where  $k$  is the set of items associated with the cue. Increasing the number of competitors increases the value of the denominator, reducing the likelihood of retrieving  $R_j$ . Increasing the associative strengths of other competitors similarly increases the value of the denominator. This ratio rule is not by itself a complete model of recall; it lacks details concerning the calculation of associative strengths, the method of recovering and converting memory representations into overt responses, and so on. However, the ratio rule is at the core of many models used to describe interference phenomena in recall. Importantly, it embodies the essential properties that have been used to differentiate competitor interference from inhibition.

An example may be helpful to illustrate how likelihood ratio models have been applied to forgetting. The part-set cueing effect is the counterintuitive finding that providing some studied items as clues during a recall test impairs recall of the remaining items (Nickerson, 1984). In a study by Rundus (1973), participants were shown lists of words belonging to several categories. Written on the answer sheet of the recall test were from zero to four items from each category. The probability of recalling the remaining items decreased as the number of same-category clues increased. Rundus offered a simple likelihood ratio model to account for the cue-induced forgetting.

During recall, a person attempts to retrieve items belonging to a particular category using a sampling-with-replacement process. On each attempt, the likelihood of sampling a given item depends on the strength of its association with the category cue relative to the strengths of other items in the category (Eq. (1)). Each new item sampled is offered as an answer, and already-recalled items are ignored. It is assumed that each successful retrieval constitutes a new learning event that strengthens the association between the retrieved item and the cue. A retrieved item thus becomes increasingly more likely to be sampled on subsequent attempts as its strength increases relative to that of yet-to-be retrieved items, while the latter become increasingly less likely to be sampled. The sampling process is limited to a finite number of attempts, beyond which a person presumably decides that further attempts are no longer productive. Rundus

suggested that presenting an item as a clue on the test strengthens its association with the category, making it more likely to be sampled. Because the items presented as clues become stronger competitors, non-presented items are less likely to be sampled and retrieved before the search is terminated.

The idea that some associates of a cue block others during sampling has been used to explain many aspects of forgetting. Competition among associates, along with fluctuations in their competitive strengths depending on time and context, can account for basic findings surrounding proactive and retroactive interference (Mensink & Raaijmakers, 1988). Output interference, the decline in recall over the course of a memory test, can be attributed to factors like those Rundus described for part-set cuing. Because recalling an item increments its association with the cue, items recalled early in the test tend to block sampling of not-yet-recalled items (Raaijmakers & Shiffrin, 1980). The list-strength effect, in which strongly encoded items have an adverse effect on recall of weakly encoded items, can be similarly explained in terms of the superior ability of strong items to block competitors (Malmberg & Shiffrin, 2005; Ratcliff, Clark, & Shiffrin, 1990; Verde, 2009; Wixted, Ghadisha, & Vera, 2003).

Inhibition theory is based on the premise that competition has the potential to create difficulty during retrieval. However, Anderson (2003) suggests that:

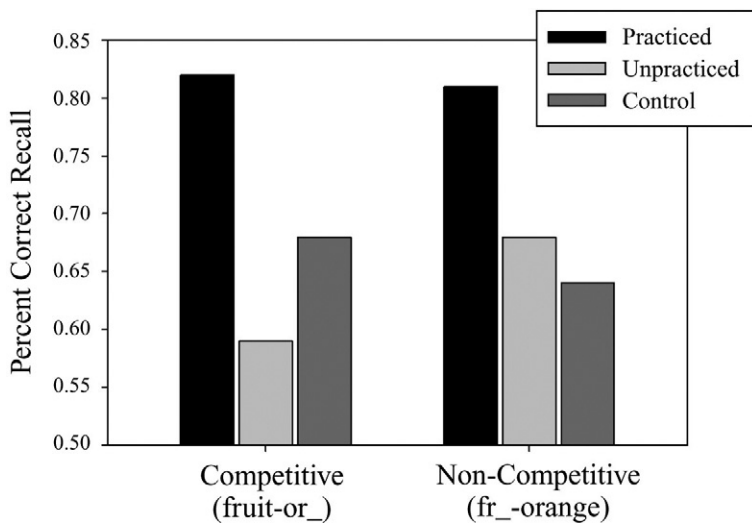
“...it is the executive control mechanism that overcomes interference—inhibition—that causes us to forget, not the competition itself. . . The mere storage of interfering traces is not what causes memories to grow less accessible with time. Rather, forgetting, whether incidental or intentional, is produced as a response to interference caused by activated competitors in memory” (p. 416).

Inhibition theorists have not been specific about the nature of the “interference” that inhibition is meant to overcome or the consequences of failing to deal with such interference (this issue will be returned to in Section 7.1). As for inhibition itself, it is assumed to affect nontarget competitors within the associative networks defined by interference theory. In the example in Figure 1B, recalling *hat* in response to the cue *boat* will inhibit *doll*, rendering the memory representation temporarily inaccessible. Beyond this general description, the mechanisms of inhibition also remain largely unspecified. The case for inhibition has instead been framed in terms of an appeal to its functional necessity combined with considerable evidence from the RIF literature that is seemingly inconsistent with a competitor interference mechanism. The latter is critical: because competitor interference models can account for many aspects

of forgetting, ruling out such a mechanism is a way to justify the additional layer of complexity created by the construct of inhibition. The evidence against competitor interference centers on four testable predictions thought to uniquely support inhibition: retrieval dependence, strength independence, interference dependence, and cue independence. These predictions will be examined in Sections 3–6.

### 3. PREDICTION 1: RETRIEVAL DEPENDENCE

Support for the inhibition account of RIF comes primarily from studies using the retrieval practice paradigm. An example is a study by Anderson, Bjork, and Bjork (2000), in which participants were shown word pairs such as *fruit–orange*, *fruit–lemon*, *metal–iron*, *metal–brass*, etc. The pairs belonged to several different sets, each consisting of members of a semantic category paired at study with the category name (*fruit–orange*, *fruit–lemon*). Following study, half of the pairs from select sets were given retrieval practice, meaning that they were targets in a cued recall test using category–word stem cues (*fruit–or\_*). After a short delay, all studied items were tested for cued recall with category–word stem cues. The results are shown in Figure 2 (competitive condition). Not surprisingly, items tested



**Figure 2** Notes. Results of the final recall test reported by Anderson, Bjork, and Bjork (2000). During the retrieval practice phase, cued recall involved competitive cues (*fruit–or\_*) or noncompetitive cues (*fr\_–orange*). A standard RIF effect is evident in the competitive condition, where recall is lower for unpracticed items from practiced categories relative to control items from unpracticed categories.

during the retrieval practice phase (*orange*) were better recalled in the final test. Of greater interest is that unpracticed items from the practiced categories (*lemon*) were less likely to be recalled than control items from the unpracticed categories (*iron*). This pattern of greater forgetting for unpracticed compared to control items is the typical finding in studies using the retrieval practice paradigm. Anderson et al. suggested that retrieving items during the retrieval practice phase caused the inhibition of categorically related items, resulting in their poorer recall in the final test. This is the standard example of RIF.

The retrieval practice paradigm is a variation of a traditional retroactive interference design. At first glance, Anderson et al.'s (2000) results might be explained in terms of competitor interference. Given the cue *fruit*, associated memory representations for *orange* and *lemon* compete for retrieval. Strengthening the association between *fruit* and *orange* during the retrieval practice phase makes *orange* a stronger competitor and more likely to block retrieval of *lemon*. This blocking effect might explain poorer recall of *lemon* compared to control items from unpracticed categories. According to the inhibition account, on the other hand, blocking is not responsible for this deficit. Instead, during retrieval practice, the attempt to recall *orange* leads to the active inhibition of competitors like *lemon*. The inhibition results in retrieval difficulty during the final test.

The results of the experiment described above do not allow us to distinguish between competitor interference and inhibition. However, in a second experiment Anderson et al. (2000) modified the task used during the retrieval practice phase. In this experiment, the practiced items were tested with cues consisting of the category member and the letter stem of the category name (*fr\_-orange*). If such a cue still enhances the strength of *orange*, then the competitor interference account predicts that it should be more likely to block retrieval of *lemon* in the final test.

The inhibition account, on the other hand, predicts that because there is no need to retrieve *orange*, there is no need to inhibit its competitors. Therefore, *lemon* should not be inhibited and should show no recall deficit in the final test. The results of the second experiment followed the prediction of the inhibition account (Figure 2, noncompetitive condition). There was no significant difference in the recall of unpracticed and control items.

Other studies have attempted to demonstrate that the act of retrieval is crucial to forgetting by comparing the effect of retrieval practice to that of additional study exposures. Ciranni and Shimamura (1999) varied the type of activity required in the practice period between initial study and final recall. In one condition, half of the items from a category were presented as targets in a cued recall test (retrieval condition). In another condition, the same items were presented again for additional study (nonretrieval condition). RIF was observed in the retrieval but not the



nonretrieval condition. Bäuml (2002) and Staudigl, Hanslmayr, and Bäuml (2010) reported similar null effects of additional study. On the other hand, Shivde and Anderson (2001) and Anderson and Bell (2001) found that additional study and retrieval practice produced roughly equal amounts of RIF. Anderson and Bell, however, asked participants whether they had covertly retrieved items during the additional study trials. Only those who claimed a greater propensity to engage in covert retrieval showed a RIF effect. In other words, even though retrieval was not explicitly required during the additional study trials, it may have been the cause of forgetting. A complication is that participants could have covertly practiced retrieving any of the previously studied items. For covert retrieval to selectively impair items related to the those being given additional practice, participants would have had to limit their covert retrieve to the items being presented during the additional study period. It is unclear whether this is a realistic assumption.

A study by Bäuml and Aslan (2004) offers evidence for the ineffectiveness of study exposures in causing forgetting but also raises doubts about the use of covert retrieval as an explanatory device. Bäuml and Aslan were interested in the link between part-set cueing and RIF. Exemplars from a number of semantic categories were presented in a study list, after which some of the items were presented again either for additional study (nonretrieval condition) or as aids to help retrieve items from the same categories (part-set cueing condition). Recall of other items from the same category suffered in the part-set cueing condition, presumably because the instructions associated with part-set cues implicitly encouraged participants to engage in covert retrieval of the cued items. No such effect was observed with additional study. This finding is consistent with others showing that study alone does not produce forgetting of related items. However, the findings also suggest that people are unlikely to spontaneously engage in covert retrieval during study trials.

Covert retrieval could be used to explain cases where forgetting occurs in the absence of overt retrieval, keeping in mind the caveats mentioned above. Controlling for covert retrieval would therefore make for a more convincing case that forgetting occurs in the absence of retrieval. One way to do this is with surprise memory tests. Delprato (2005) exposed participants to an initial list of words followed by either a filler task or an additional list that was presented once or four times. The words were encoded in the guise of an incidental task and there was no warning that the words would have to later be recalled. Compared to the filler condition, there was a significant impairment of first-list recall when it was followed by four interpolated lists. One interpolated list caused a small, nonsignificant impairment. The last point suggests that a null effect of additional study may be due to an insufficiently powerful manipulation.

Verde (2009) also used incidental encoding and surprise memory tests to control for covert retrieval. Participants studied word pairs belonging to overlapping sets (*brick-hair*, *brick-cloud*). For strong/weak sets, half of the pairs (strong pairs) were studied repeatedly while the other half were studied once (weak pairs). For control sets, all pairs were studied once (control pairs). Repeated study of strong pairs impaired recall of the related weak pairs compared to the control condition. Similar to the findings of Delprato (2005), this is evidence that forgetting need not be tied to retrieval. It could be argued that disguising the nature of the task is no guarantee that savvy participants might nevertheless expect and prepare for a memory test using a covert retrieval strategy. Verde conducted a final experiment that controlled the opportunity for covert retrieval. Repeated items offer additional opportunities for covert retrieval practice, and this alone might be responsible for the impairment of once-presented items in the strong/weak sets. To avoid this, additional presentations of strong items occurred at the beginning of the study list before any other items were presented. The additional opportunities for covert retrieval afforded by repetition could therefore not inhibit related weak items because they had yet to be encoded. Following the initial repeated study of the strong items, all pairs in the list were presented once, allowing the same number of covert retrieval opportunities for both conditions. Despite controlling the possibility of differential retrieval practice, recall of weak items was still impaired relative to the control condition.

One might think that decades of research on memory interference would provide a rich source of data with which to confirm or disconfirm the prediction of retrieval dependence. Unfortunately, the methods used during the classic era of interference research typically confounded encoding and retrieval. A standard interference design involved learning  $A-B$  pairs in one list and  $A-C$  pairs in a second list. Learning the pairs, however, usually involved the anticipation method: attempting to recall the second item ( $B, C$ ) given the first ( $A$ ) as a cue, often over multiple trials. Such methods leave uncertain whether memory difficulties resulted from learning overlapping paired associates or from the retrieval that took place during their learning.

A study by Bäuml (1996) offers a comparison of retrieval-based and study-only learning within a classic interference design. In the first experiment, participants studied an initial list of words, after which they studied from zero to four additional lists. After each list, they were prompted to recall all of the items from the list. Following the last list, participants were asked to recall the words from all of the lists, in any order. Recall of words from the initial list declined as a function of the number of interpolated lists, from 20 items with no interpolated lists to 11–13 items following four interpolated lists (Bäuml, 1996: Figure 1, 5-s study condition). A second experiment replicated a portion of the first experiment: an initial

list was followed by four interpolated lists. In this experiment, however, the recall test after each list was replaced with a distractor task. In addition, in the final test for all of the lists, participants were instructed to recall words from the initial list first. Recall for the initial list following four interpolated lists was 13–14 items. Although Bäumel did not directly compare the results of the two experiments, recall was numerically lower in Experiment 1 which had retrieval-based learning of the interpolated lists. However, the size of the effect was quite small relative to the overall deficit produced by interpolated list-learning, especially considering that part of the effect may have been due to output interference that was not controlled in the first experiment.

### 3.1. Summary

Empirical support for retrieval dependence has been inconsistent. A strong version of the prediction, that forgetting occurs only as a result of retrieval, is difficult to justify given that some studies show that the presence of competitors can have a negative effect on recall when there is no overt retrieval and covert retrieval is unlikely. On the other hand, advocates of inhibition theory point out that strengthening competitors without having to retrieve them often fails to affect recall, which they argue is inconsistent with the principle of competitor interference. This argument will be examined more closely in Section 4.2.

## 4. PREDICTION 2: STRENGTH INDEPENDENCE

According to the principle of competitor interference, strengthening the association between a cue and an item in memory will negatively affect the retrieval of other memories associated with the cue. In a likelihood ratio model (Eq. (1)), for example, increasing the association strength of a competitor increases the value of the denominator, reducing the probability of retrieving the target. According to inhibition theory, the association strength between a cue and a target will be independent of forgetting if it is assumed that strengthening can occur in the absence of retrieval. Several of the studies described earlier suggest that this is the case. Anderson et al. (2000) observed RIF when retrieval practice used a competitive test (*fruit-or\_*) but not when it used a noncompetitive test (*f\_-orange*), even though both types of practice improved recall of the practiced item (*orange*) to the same degree. Ciranni and Shimamura (1999) and Staudigl et al. (2010) compared the effects of additional study and retrieval during the practice phase and observed RIF only with retrieval practice. Both manipulations produced similar improvements in the final recall of practiced items. If the ability to recall an item is used as an

operational measure of associative strength, all three findings suggest that strength is independent of the amount of forgetting observed in competitors.

This is a puzzling conclusion given that other studies have shown that strengthening some items can adversely affect the recall of other items, a phenomenon referred to as the list-strength effect. Tulving and Hastie (1972) compared free recall of lists in which all words were presented once to that of lists in which some words were presented once and others twice. Once-presented words showed impaired recall when they were studied in a list with twice-presented words. Tulving and Hastie also found that recall of once-presented words declined as the proportion of twice-presented words in the study list increased. The list-strength effect can be explained in terms of competitor interference: strong (twice-presented) items are more likely to block the retrieval of weak (once-presented) items. The finding has been replicated a number of times in free recall (Malmberg & Shiffrin, 2005; Ratcliff et al., 1990; Wixted, Ghadisha, & Vera, 1997). A similar effect of relative strength has been observed in free-recall latencies (Rohrer, 1996; Wixted et al., 1997).

Inhibition theory offers an alternative account of the list-strength effect in free recall. Recalling an item during a test causes the inhibition of yet-to-be-recalled items. Tulving and Hastie (1972; also Wixted et al., 1997) observed that strong items tend to be produced earlier in the recall sequence than weak items. Weak items are therefore more likely to be inhibited by strong items recalled earlier in the test. The inhibition account thus suggests that the list-strength effect may be an artifact of output position. If this were true, then a reduced or absent list-strength effect would be expected in cued recall, where weak items would not be any more likely than strong items to appear at the end of the list. Consistent with this prediction, Ratcliff et al. found the list-strength effect to be weak and inconsistent in cued recall despite being robust in free recall. Bäuml (1997) tested the inhibition hypothesis explicitly by carefully controlling output position with the use of cued recall. He observed a list-strength effect but found that it was confined to the latter portion of the test list. Weak items did not show impaired recall when presented at the beginning of the test. Bäuml proposed that if retrieval inhibition depends on successful retrieval, then strong items are more likely to suppress weak competitors rather than the reverse, resulting in a list-strength effect. However, this would not be evident at the beginning of the test where there was not yet the opportunity for retrieval inhibition. A puzzling aspect of Bäuml's account is that it contradicts other findings that show that RIF does not depend on successful retrieval, only the retrieval attempt itself (Storm, Bjork, Bjork, & Nestojko, 2007; Storm & Nestojko, 2010). If inhibition does not depend on retrieval success, then no list-strength effect should be observed at all in a cued recall test

where the positions of strong and weak items in the test sequence are equivalent, as was the case in Bäuml's experiment.

Other studies have observed more robust effects of strength-dependent interference using cued recall. Shivde and Anderson (2001) showed participants pairs consisting of a homograph and a word. Each homograph appeared in two pairs, once with a word related to its dominant meaning (*arm-shoulder*) and once with a word related to its subordinate meanings (*arm-missile*). The initial study list was followed by additional study trials in which the subordinate-meaning pairs were studied again from 0 to 20 times. Finally, the dominant-meaning pairs were tested with cued recall (*arm-s*). Recall decreased monotonically with the number of additional study trials given to the subordinate meaning. Delprato (2005) used a similar design. After learning a list of paired associates ( $A-B$ ), a second list containing interfering pairs ( $A-C$ ) was presented from 0 to 8 times. Recall was tested only for items from the first list. Recall decreased with the number of repetitions of the second list.

One could suggest that the strength-dependent forgetting observed by Shivde and Anderson (2001) and Delprato (2005) was due to covert retrieval practice occurring during the additional study presentations of the competitors. However, Verde (2009) found a list-strength effect even when the opportunity for covert retrieval was controlled in various ways. Participants studied sets of overlapping pairs (*brick-hair*, *brick-cloud*). Strengthening some pairs (*brick-hair*) by repeated study impaired cued recall of competitors (*brick-cloud*). This occurred despite the fact that strong items were not included in the test, and it occurred even at the beginning of the test list when there had not yet been the opportunity for retrieval inhibition via output interference.

#### 4.1. Summary

Empirical support for strength independence has been inconsistent. A strong version of the prediction, that the strength of other memories has no effect on forgetting, is difficult to justify given the many studies showing robust strength-dependent interference. One could suggest that covert retrieval rather than strengthening was responsible for forgetting in these cases, although Verde (2009) observed strength-dependent forgetting even when covert retrieval was controlled. Advocates of inhibition theory argue that the reported failures to observe strength-dependent forgetting is a serious problem for the competitor interference account. It is true that a basic likelihood ratio model like the one described by Rundus (1973) is unable to account for these findings. However, it will be shown in the next section that competitor interference models that take a more nuanced approach to memory representation and the meaning of "strength" may be able to accommodate findings of strength independence.

## 4.2. Strength and Memory Representation

In the competition model proposed by Rundus (1973), associative strength and likelihood of recall are one and the same. Increasing the strength of one competitor must necessarily have an adverse effect on the sampling and retrieval of other competitors. Such a model would predict that encoding opportunities that improve recall of one item will increase forgetting of other items associated with the cue. Many of the findings reviewed earlier are clearly inconsistent with this prediction. However, contrary to arguments often put forward in the RIF literature, this does not justify ruling out the principle of competitor interference. More complex competition models can accommodate dissociations between “strengthening” and competitor forgetting.

The Rundus (1973) model depicts memory strength in terms of a single value. However, it is well accepted that memory representations are multifaceted, containing many different aspects of an encoded episode. A common distinction is that between item information, which represents the features of the target stimulus, and associative or contextual information, which represents the features that link the target stimulus to surrounding objects and the environment (Hintzman, 1986; Murdock, 1982; Murnane, Phelps, & Malmberg, 1999). Memory “strength” is not a unitary concept when one considers that different aspects of a memory representation can be more or less strongly encoded. The SAM–REM model described by Malmberg and Shiffrin (2005; see Verde, 2009, for its application to cued recall) is one competitor interference model of recall that takes this more complex view, and it will be used as an example in the discussion to follow. No attempt will be made to fully detail the model here. Rather, the general properties of the model relevant to the issue of competitor interference and forgetting will be described in order to illustrate the theoretical compatibility between competitor interference and findings of apparent strength independence.

In the SAM–REM model, item and context information contribute to recall in different ways. Recall involves a two-stage process of sampling and recovery. The retrieval cue is initially compared to each of the  $k$  representations in memory (as a simplifying assumption, this is limited to the set of items studied in the experiment). In the case of paired associates, each representation is composed of features representing the cue and the target (the context and item, respectively). The features of the retrieval cue are compared to those of each item in memory, taking into account both matching and mismatching features. Each comparison results in a matching strength,  $\lambda$ , where a high value indicates a close match. Memory representations are then sampled serially with replacement. The probability of sampling the representation  $R$  containing the

target item  $j$  given the retrieval cue is equal to:

$$P(R_j|\text{cue}) = \frac{\lambda_j}{\sum \lambda_k}. \quad (2)$$

This is the ratio of the match to the correct representation of  $j$  to the summed matches to all  $k$  representations in the memory set. Strength-dependent competitor interference is captured in this sampling stage. After an item is sampled, its features must be recovered to a degree sufficient to support a response. Successful recovery is a function of the proportion of correctly stored features in  $R_j$ . Sampling and attempted recovery continue until the target is recalled or the process ends in failure after some number of attempts.

During the sampling stage, item and context information both influence the matching value,  $\lambda$ . Consider a typical interference scenario in which two word pairs are studied (*brick-hair*, *brick-cloud*), with the second word in each pair being the potential targets. The episodic representations of the pairs contain similar context features (*brick*) but unique item features (*hair*, *cloud*). Assuming that the features of the two pairs were equally well encoded, the retrieval cue *brick-h* more strongly matches the representation of *brick-hair*. This is because the item features (*h*) match those of *brick-hair* but mismatch those of *brick-cloud*. However, the cue matches the context features of both representations equally well. This partial match to both representations leads to interference at the sampling stage (it increases the denominator in Eq. (2)). During the recovery stage, only item information is important. When the target *brick-hair* is sampled, successful recovery of *hair* will depend on how accurately and completely the item features were originally encoded.

There are several ways in which the SAM-REM model can offer insight into the reported dissociations between strengthening and competitor forgetting. The most important is related to the question of how different manipulations affect the encoding of item and context information. In the model, “strengthening” refers to the successful encoding of episodic features into a memory representation. As noted above, however, the effect of feature encoding on recall depends on what features are encoded; item and context features have different effects on sampling and recovery. Malmberg and Shiffrin (2005) found that the list-strength effect was sometimes present and sometimes absent in free recall. They used several common types of strengthening manipulations: depth of processing, study duration, and study repetition. They found that all three manipulations improved recall for the strengthened items. However, only when strong items were repeated did they impair recall of other studied items.

Competitor interference occurs at the sampling stage and arises because competing representations share context features that match

the retrieval cue. The cue matches an item more strongly as more context features are stored. Malmberg and Shiffrin (2005) suggested that repetition produces a list-strength effect because each repetition is another opportunity for the encoding of contextual information. As the contextual features tying the item to the cue are more completely encoded, the item becomes more likely to be sampled. This in turn blocks the sampling of other items associated with the cue, making their retrieval more difficult. Malmberg and Shiffrin explained the failure of depth of processing and study duration manipulations to produce a list-strength effect by suggesting that only a fixed amount of context is stored with each study presentation. With these manipulations, the number of times strong and weak items are presented remains the same. This means that strong and weak items are encoded with the same amount of context and thus compete equally during the sampling stage. Although depth of processing and study duration have a limited effect on context encoding, they do increase the encoding of item features, and this benefits recall of strong items by improving recovery.

Malmberg and Shiffrin's (2005) fixed-context encoding hypothesis can explain some of the reported failures to observe strength-dependent forgetting. In two studies, Bäuml (1996, 1997) found that varying the strength of some studied items had little effect on the ability to recall other items. In both studies, however, strength was manipulated by increasing study duration which should not differentially affect the context encoding of weak and strong items. It is worth noting that Delprato (2005) used a retroactive interference design similar to that used by Bäuml (1996) but which manipulated strength using repetition rather than duration. This alternative strengthening method did produce a list-strength effect. Finally, Ratcliff et al. (1990) reported inconsistent findings of a list-strength effect in cued recall. Closer examination of their data reveals that the effect arose when they manipulated study repetition but not when they manipulated study duration.

Other dissociations between target strength and forgetting might also be explained by the differential effects of item and context information on recall. In SAM-REM, encoding context aids retrieval of the target and interferes with retrieval of nontargets. Encoding item features aids retrieval of the target and in cued recall reduces interference with nontargets. Several studies have found that although retrieval practice and additional study trials improve memory for practiced items to the same extent, the latter often fails to cause any impairment in the recall of competitors (Anderson & Bell, 2001; Ciranni & Shimamura, 1999; Staudigl et al., 2010; Experiment 5, low covert practice group). This pattern could indicate that a retrieval task such as cued recall tends to encourage the encoding of context features, more so than other encoding



tasks. This may have to do with the way that information is presented and processed, or it may be that participants attend more closely to context features during a retrieval task for strategic reasons (e.g., Conner, 1977; Hockley & Cristi, 1996). Increased context encoding will exacerbate the tendency for the retrieved items to block retrieval of competitors. Unlike retrieval practice, additional study trials may shift the focus to the encoding of item features. This would improve recall but produce relatively little interference.

A final issue to consider is that interference among competitors in the sampling stage depends not only on the overlap of contextual features but also the degree to which contextual features have been encoded. Verde (2009) argued, based on simulations of SAM-REM, that depending on both factors, the list-strength effect may be hard to detect at low levels of a strengthening manipulation but emerge at higher levels. Delprato (2005; Experiment 1) demonstrated this in practice. Participants studied an initial list of word pairs (A-B). This was followed by one, four, or eight presentations of a second list of overlapping pairs (A-C). Recall of the second list increased from 47% to 67% when presentations were increased from one to four. However, the increase in second-list presentations failed to have a statistically significant effect on first-list recall. First-list recall only declined significantly following eight presentations of the second list. Weak strengthening manipulations, in combination with the other issues discussed above, may be a factor in some observations of a null list-strength effect.

In the RIF literature, it is often argued that failure to observe a negative effect on recall when competitors are strengthened allows one to rule out competitor interference as a mechanism of forgetting. This argument is not quite correct. Basic competition models such as the one proposed by Rundus (1973), in which strength is treated as a unitary concept, cannot explain how a manipulation can improve memory for some items associated with a cue while having no affect on the ability to recall other associates. Competition models (such as SAM-REM) that adopt a more nuanced approach to memory representation and the retrieval process can in theory accommodate such results.

### 4.3. Nonstrengthening Retrieval

The previous section described how competitor interference models can account for the absence of RIF despite the strengthening of competitors. A different argument against competitor interference is that RIF can occur even when competitors are not strengthened. In a study by Storm et al. (2007), participants viewed category-exemplar pairs and then completed category-word stem cues (*fruit-or\_*). They were told that the stem completions might or might not come from the studied pairs. In fact,

although the categories were previously studied, none of the stems matched studied exemplars. For some categories, the stems corresponded to real but unstudied exemplars (possible condition), for other categories the stems matched no existing exemplars (impossible condition). Both conditions produced RIF. The magnitude of the effect did not depend on whether retrieval practice took the form of possible or impossible stems.

Storm et al. (2007) noted that forgetting could not have been the result of the strengthening of competitors because none of the studied items were presented during retrieval practice. However, likelihood ratio models also predict interference from increasing the number of competitors associated with a cue. This would have happened in the possible condition which requires the generation of new exemplars. Whether it also happened in the impossible condition is unknown, but one might suppose that when faced with impossible stems, participants may have generated various illegal possibilities. These would not have been produced as answers, but they would have nevertheless become associated with the cue, causing interference. As evidence against this possibility, Storm et al. offered the fact that participants who produced the fewest responses also suffered the greatest amount of RIF. However, this is difficult to interpret because the critical data are not the number of overt responses produced but the number of covert retrievals, which are unknown. It might be that those who failed to produce a response covertly retrieved more illegal items as they continued their efforts to find a legal solution.

Perhaps a better argument against the covert retrieval explanation of impossible stem practice comes from a study by Storm and Nestojko (2009), who replicated the findings of Storm et al. (2007) but also manipulated the amount of time allowed to complete the impossible stem cues. The amount of RIF did not significantly change when the time allowance increased from 4 to 12 s. It might be expected that the increased time would allow participants to generate more illegal items, increasing interference. Still, absent the knowledge of what participants were actually doing covertly, the findings from impossible stem retrieval practice remain enigmatic. An investigation of response latencies may be one way to test the hypothesis that interference is the result of generating illegal items. Increasing the number of competitors is known to affect response latencies in free recall (Wixted & Rohrer, 1994).

## 5. PREDICTION 3: INTERFERENCE DEPENDENCE

The nature of the inhibition mechanism is thought to be shaped by its function. If inhibition serves primarily to preserve the accessibility of weak memories that are in danger of being overshadowed by stronger

ones, as Anderson (2003) suggests, then the degree of inhibition should be proportionate to the need for inhibition. This view leads naturally to the prediction that because strong items are more likely to create interference, they should also suffer a greater degree of inhibition. Weak items, which pose little threat as competitors, may suffer no inhibition at all. This predicted pattern of interference dependence is at odds with the predictions of competitor interference models. According to the basic likelihood ratio model (Eq. (1)), all items associated with a cue should suffer from interference, regardless of strength. Weak items might also be expected to suffer disproportionately from output interference if it is assumed that retrieval increments the strength of association between the cue and the retrieved item. Strong items are more likely to be retrieved early, making them stronger and even more likely to interfere with weak items that have yet to be retrieved.

Anderson et al. (1994) tested the interference dependence hypothesis in the retrieval practice paradigm. Participants studied category–exemplar pairs in which some of the exemplars were strongly associated with the category (*fruit–orange*, *fruit–banana*) and others were weakly associated (*fruit–guava*, *fruit–raisin*). This was followed by retrieval practice for half of the items. In a final free recall test, RIF was observed for both strong and weak associates. However, the effect was both absolutely and proportionally smaller for weak associates. When free recall was replaced in the final test with category–word stem cued recall (*fruit–or\_*), RIF was no longer observed for the weak associates. Interestingly, the size of the RIF effect on strong associates was the same regardless of whether practiced items were strong or weak associates. Similarly, Shivde and Anderson (2001) also observed no RIF for the subordinate meanings of homographs (*arm–missile*) despite finding the effect with dominant meanings (*arm–shoulder*). Anderson et al. also found that weak associates did not suffer from output interference. Whereas recall of strong associates declined from the first to the second half of the test, recall of weak associates remained unchanged over the course of the test. Bäuml (1998) reported a similar finding.

Storm, Bjork, and Bjork (2007) used directed forgetting instructions to manipulate competitor strength. Participants studied a series of short lists of category–exemplar pairs. After each list, a prompt indicated either that a memory test for the list was likely to follow (remember condition) or that there would be no memory test (forget condition). Participants then completed a retrieval practice task in which they generated four new members of studied categories. Storm et al. posited that the studied exemplars should be inhibited during the generation task because of their tendency to interfere with the generation of new exemplars. However, because instructions to forget are known to suppress memory accessibility (MacLeod, 1998), the potential for studied items to interfere should be

reduced in the forget condition. Storm et al. therefore predicted that studied items in the forget condition would suffer less inhibition compared to the remember condition. At the end of a series of study and generation lists, memory for all studied items was tested with cued recall (*flower-t*). Consistent with Storm et al.'s prediction, RIF was observed for items in the remember condition but not the forget condition. A difficulty that arises with the use of category-exemplar cued recall, however, is that participants may rely to some extent on guessing rather than episodic memory (the cues are fairly constraining). Recall in the forget condition was generally suppressed relative to control items in the remember condition, suggesting that the directed forgetting instructions hampered access to episodic memory. As a result, recall performance in the forget condition may have been based to a large extent on guessing. If RIF is a phenomenon of episodic memory (see Section 6), this may offer an alternative explanation for the lack of RIF in the forget condition.

Other studies offer little support for interference dependence. Using procedures similar to those of Anderson et al. (1994), Williams and Zacks (2001) observed no difference in the susceptibility of strong and weak category associates to RIF. Brown, Zoccoli, and Leahy (2005) found no evidence that strong associates were particularly susceptible to output interference in a task requiring the serial retrieval of category exemplars. Jakab and Raaijmakers (2009) noted that members of a category studied earlier in a list tend to be more memorable. They reasoned that because early-position items are stronger competitors, there should be a greater need to inhibit them during retrieval practice. However, they found no interaction between study position and the size of the RIF effect. Finally, Garcia-Bajos, Migueles, and Anderson (2009) observed a pattern opposite to that predicted by interference dependence. Retrieval practice had little effect on memory for actions highly typical of a witnessed event script (a robbery) but led to forgetting of atypical actions. In addition, RIF was caused by the practice of atypical but not typical actions

A puzzling aspect of Anderson et al.'s (1994; Experiments 2 and 3) results is that retrieving weak category associates failed to cause the inhibition of other weak associates. Not only does this contradict the results of Garcia-Bajos, Migueles, & Anderson (2009), it is also at odds with the numerous findings of robust RIF effects with ad-hoc or episodically defined categories (Anderson & Bell, 2001; Ciranni & Shimamura, 1999; Dodd, Castel, & Roberts, 2006; Gomez-Ariza, Lechuga, Pelegrina, & Bajo, 2005; Hauer, Wessel, Merckelback, Roefs, & Dalgleish, 2007; Iglesias-Parro & Gomez-Ariza, 2006; Koutstaal, Schacter, Johnson, & Galluccio, 1999; MacLeod, 2002; MacLeod & Saunders, 2005; Macrae & MacLeod, 1999; Migueles & García-Bajos, 2007; Saunders & MacLeod, 2002, 2006; Shaw, Bjork, & Handal, 1995; Storm, Bjork, & Bjork, 2005). For example, in a category such as "objects found in Thompson's house"

(Saunders & MacLeod, 2006), the associations between the cue (Thompson's house) and the items (objects) are arbitrary and created during the learning session. The cue–item associations should not be any stronger than between a category name and a weak associate paired together in a study list. One would therefore assume the degree of competition among items to be similar in both cases. The implication is that either Anderson et al.'s finding is an outlier, or that people process category–exemplar paired associates differently than episodically defined paired associates.

### 5.1. Summary

Empirical support for interference dependence has been inconsistent. The problem may be in part a matter of too little data, as relatively few studies have focused on the question of interference dependence. However, theoretical details of the prediction also remain underdeveloped. Notably, it is unclear whether inhibition should depend on the relative or the absolute strength of competitors. The data from studies using episodically defined categories suggest that relative strength may be the important factor in producing RIF, but this is at odds with Anderson et al.'s (1994) finding that weak associates do not inhibit other weak associates.

## 6. PREDICTION 4: CUE INDEPENDENCE

Competitor interference is intrinsically context dependent because competition is defined by the associative network surrounding a specific retrieval cue. A memory may be difficult to retrieve with a cue that activates many competitors, but the same memory may be more easily retrieved with a different cue that activates fewer competitors. Inhibition theory, on the other hand, suggests that forgetting occurs because the memory representation itself becomes inaccessible. Retrieval failure will persist despite changes in the retrieval cues. Inhibition is cue independent and therefore context independent (Anderson, 2003).

### 6.1. Novel Test Cues

A direct way to test cue independence is to show that RIF persists even with the use of novel retrieval cues. In a study by Anderson, Green, and McCulloch (2000), participants viewed exemplars from explicitly presented semantic categories (*red: heart, tomato*). Some of the items from a category were given retrieval practice with the studied category names as cues (*redhe\_*). During the final cued recall test, the unpracticed items were tested with novel cues, category names that fit the studied items but had

never been explicitly presented during study (*food to*\_). Even with the novel cues, earlier retrieval of related items (*heart*) suppressed recall of unpracticed items (*tomato*). A number of studies using the retrieval practice paradigm have reported similar findings with the use of novel cues in the final recall test (Anderson & Bell, 2001; Aslan, Bäuml, & Grundgeiger, 2007; Aslan, Bäuml, & Pastötter, 2007; Saunders & MacLeod, 2006), although the finding has not been universal (Camp, Pecher, & Schmidt, 2007; Shivde & Anderson, 2001<sup>1</sup>).

Some critics have pointed out that the use of novel cues does not rule out the possibility that participants are conscious of previous learning and retrieval episodes during a later test. In fact, participants may implicitly reinstate the original retrieval cues despite being presented only with novel cues (Camp, Pecher, & Schmidt, 2005, 2007; Camp, Pecher, Schmidt, & Zeelenberg, 2009; Perfect et al., 2004). Camp et al. (2005), in an initial experiment, observed the persistence of RIF in cued recall with novel test cues. However, in a second experiment they attempted to control the tendency for participants to consciously draw upon previous learning by using an implicit memory test. The second experiment was identical to the first save that the task made no reference to the previously studied items. Participants were simply asked to generate category exemplars from the novel cues. Participants were also given an awareness questionnaire at the end of the experiment. Those who claimed to be aware of the relationship between the implicit test and the previously studied material showed a RIF effect. Those who displayed no awareness showed no RIF effect.

In Anderson et al.'s (2000) study, the novel categories used to cue retrieval in the final test overlapped considerably with studied categories. For example, half of the items in the explicitly studied category *red* were also members of the novel category *food*. Perfect et al. (2004) noted that given its salience, the relationship between the novel and studied cues was likely apparent to participants. This may have encouraged them to aid their retrieval by making use of the original cues, a useful strategy given the high degree of overlap between the novel and studied categories and given the likely effectiveness of the original cues due to encoding specificity (Tulving & Thomson, 1973). Camp et al. (2009) investigated the tendency for people to covertly reinstate cues in this way. Participants studied word pairs (*rope–sailing*). The first word of each pair served as a potential cue. Some of these cue words were given additional exposures prior to studying the word pairs so as to make them more accessible later. The second word was used as a target in a subsequent recall test, during

<sup>1</sup> Shivde and Anderson (2001, Experiment 2) found that recall with novel cues decreased as a function of the number of retrieval practice trials, a trend they attributed to inhibition. However, retrieval practice did not result in lower recall than the no-practice baseline condition, which is the standard measure of RIF.

which only novel cues were used (*sport-sailing*) to help recall the target. Although the studied cues (*rope*) were not presented in the recall test, recall was higher for targets studied with pre-exposed cues. Camp et al. argued that the manipulation of the studied cues affected recall because participants were more likely to covertly reinstate the pre-exposed cues due to their enhanced salience and accessibility.

In another study, Camp et al. (2007) examined the effect of minimizing the likelihood that participants would attempt to reinstate the original cues. A study list of category-exemplar pairs (*animal-horse*, *animal-rat*) was followed by retrieval practice. A standard RIF effect was observed when the studied categories were presented as cues in the final test. However, RIF was absent when the final test used novel cues that were unrelated to the studied categories and specific to each item (*cowboy-h*, *poison-r*). Camp et al. argued that the null RIF effect occurred because the item-specific cues discouraged reinstatement of the original cues. It should be noted that Aslan, Bäuml, and Pastötter (2007) and Saunders and MacLeod (2006) both reported RIF with the use of item-specific novel cues. However, neither study directly compared the effect of such cues with that of the original cues. The comparison is important; the crucial point made by the Camp et al. study is not that novel item-specific cues can never lead to cue reinstatement but that reducing the likelihood of cue reinstatement seems to reduce RIF.

One interpretation of Camp et al.'s (2005, 2007) findings is that RIF is associated with the original retrieval context (i.e., the practice phase). Perfect et al. (2004) examined this possibility by manipulating the match between the cues presented during retrieval practice and those used in the final recall test. In an initial experiment, participants studied category-exemplar pairs. Each pair was accompanied by a unique face. Retrieval practice consisted of category-word stem cues. During the final test, participants were given one of three types of retrieval cues: the category name by itself, the category name and a face, or only a face. In the first condition, participants were to recall all items from the category, while in the latter two conditions they were to recall the item that was originally paired with the cued face. RIF was observed in the category-only condition, but it was absent in the category + face and face-only conditions. A second experiment was identical to the first, except that during retrieval practice the studied face was provided with each category-stem cue. In the final test, RIF was observed in the category-only condition, as before, but it was also observed in the category + face condition. It remained absent in the face-only condition. Perfect et al.'s findings suggest that RIF does not necessarily generalize to all retrieval cues. Rather, RIF seems to be context specific, depending on the match between the cues present during the current test and earlier retrieval.

The issue of cue reinstatement may be relevant to the finding of lateral spreading inhibition demonstrated by Anderson and Spellman (1995). Studied items were category–exemplar pairs (*green–emerald*, *green–lettuce*, *soup–mushroom*, *soup–chicken*) in which two explicitly presented categories (*green*, *soup*) overlapped such that they both included members of an implicit category (*lettuce* and *mushroom* belonged to the category *vegetable*). Retrieval practice of one category (*green–emerald*) suppressed recall not only of unpracticed items from the same category (*green–lettuce*) but of items from the other category that were semantically related to the suppressed items (*soup–mushroom*) due to their common membership in the implicit category. Anderson and Spellman argued that inhibition works by suppressing the semantic features of unpracticed items (*lettuce*). Other items that share these features (*mushroom*) also suffer from inhibition. Anderson and Spellman further noted that because the laterally inhibited items (*mushroom*) had no direct connection with the practiced cue (*green*), the finding was evidence of cue independence. However, the point made by Perfect et al. (2004) and Camp et al. (2007) that a high degree of overlap between explicitly cued and noncued categories can encourage reinstatement of the latter may be relevant. In theory, when presented with the cue *soup*, reinstatement of the cue *green* should be helpful because of the number of items belonging to both categories. Doing so, however, also reinstates the inhibitory context. Success at replicating the findings of Anderson and Spellman has been mixed.<sup>2</sup> Williams et al. (2001) failed to find lateral inhibition using similar materials, although Saunders and MacLeod (2006) did so with different materials.

## 6.2. Novel Tasks

When retrieval practice takes the form of a cued recall test, using a different memory task is another way to alter the retrieval cues. If it is assumed that different retrieval tasks access the same underlying memory representation, inhibition theory predicts that RIF should still be observed. There is extensive evidence for RIF in recognition. Retrieval practice with recall has been shown to decrease recognition accuracy for related items (Gomez-Ariza et al., 2005; Hicks & Starns, 2004; Racsmány, Conway, Garab, & Nagymate, 2008; Saunders & MacLeod, 2002; Spitzer & Bäuml, 2007, 2009; Spitzer, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2009; Verde, 2004b; Verde and Perfect (2011) but see Koutstaal et al., 1999), although some studies have observed the effect in response latencies rather than accuracy (Racsmány et al., 2008; Veling & van

<sup>2</sup> Perfect et al. (2004) questioned whether Spellman and Anderson (1995) themselves provided strong evidence of lateral inhibition, arguing that their claim relied on the use of an inappropriate baseline.



Knippenberg, 2004). These findings have been put forward as strong evidence for cue independence.

Verde and Perfect (2011), however, have argued that the case for cue independence based on recognition data is less clear than it might seem. It has often been suggested that recognition may depend on multiple retrieval processes. This view is most commonly associated with dual-process theories, which hold that recognition judgments draw upon the output of two distinct processes, familiarity and recollection (Yonelinas, 2002). Familiarity is a relatively fast process that produces a context-free sense of “oldness.” Recollection is a slower search for specific episodic details and context. Cue independence predicts that retrieval practice should have a negative effect on both familiarity and recollection; if an underlying memory representation is rendered inaccessible, retrieval failure will result no matter the route of access. The difficulty is that this prediction cannot be verified by examining recognition performance if the relative contribution of the component processes is unknown (see Verde, 2004a, b). Decreased accuracy following retrieval practice could be due to a diminished output of familiarity, recollection, or both. Findings from recognition studies provide strong support for cue independence only if it can be verified that both processes suffer from the effects of RIF.

Spitzer and Bäuml (2007) compared the ability of several formal models to accommodate their data showing RIF in recognition. They found that the fits of two formal dual-process models localized the RIF effect to familiarity rather than recollection. This is a surprising result, first because it is predicted by no extant theory, and second because RIF is observed in source recognition (Hicks & Starns, 2004; Spitzer & Bäuml, 2009) and associative recognition (Verde, 2004b), memory tasks that rely on recollection. Spitzer and Bäuml also found that neither of the dual-process models fit the data as well as a unidimensional signal-detection model. The latter model is often associated with familiarity-based theories. However, because the model is also open to dual-process interpretation (Verde & Perfect, 2011; Wixted & Mickes, 2010), its ability to accommodate the data says little about whether RIF affects familiarity, recollection, or both.

Other empirical evidence suggests that RIF may be specific to recollection. Verde (2004b) manipulated study duration in an associative recognition task. Because recollection depends on more complex and detailed information than familiarity, limiting encoding time should limit the utility of recollection. A RIF effect was observed following long but not short study durations. Verde and Perfect (2011) manipulated the availability of recollection at retrieval using a response deadline in an item-recognition task. A RIF effect emerged when recognition was self-paced but not when participants were forced to make their judgments very quickly. Both sets of findings suggest that when participants are

forced to rely primarily on familiarity, RIF disappears. This is inconsistent with cue independence if it is assumed that recollection and familiarity draw upon the same memory representation. If RIF is indeed specific to recollection, this undermines the usefulness of recognition as support for cue independence in another way. Recollection is similar to recall both theoretically and in its empirical properties (Verde, 2004a, b). If people who rely on recollection in recognition are essentially using a form of recall, then the implicit reinstatement of original retrieval cues becomes as much an issue in recognition as it is in recall.

Although changing the retrieval task from recall to recognition has been generally found to preserve RIF, the results have been far less consistent with implicit tasks which do not ask participants to draw on memory for previously encountered materials. Bajo, Gómez-Ariza, Fernandez, and Marful (2006) observed RIF in a word stem completion task using categories consisting of orthographically related words. Butler, Williams, Zacks, and Maki (2001) and Perfect, Moulin, Conway, and Perry (2002) reported no RIF in word fragment and word stem completion using semantic categories. Veling and van Knippenberg (2004) observed RIF in lexical decision, whereas Racsmany and Conway (2006) found that RIF was often absent in lexical decision. Perfect et al. (2002) observed no RIF in a task requiring the generation of category exemplars, although Camp et al. (2005) found it in a subset of participants, and Brown et al. (2005) found that exemplar generation produced output interference. Perfect et al. (2002) observed no RIF in a task requiring the verification of category membership, and no RIF in perceptual identification.

In recall, it has been suggested that RIF may occur with novel cues because people covertly reinstate the original cues used during retrieval practice (Camp et al., 2005, 2007, 2009; Perfect et al., 2004). A similar explanation might be applied to the findings from implicit memory tasks. The use of an implicit task does not rule out the possibility that participants covertly relate the task to prior learning episodes. However, it does make participants less likely to do so, which may be the reason that RIF is much less consistently found in implicit tasks compared to explicit tasks like recall and recognition. Two studies support this explanation by showing that RIF in implicit tasks may rely on conscious reference to the original retrieval cues. Camp et al. (2005) observed RIF in an exemplar generation task but only among participants who reported consciously trying to remember items from an earlier part of the experiment. Racsmany and Conway (2006) found that participants who studied category–exemplar pairs (*fruit–orange*) showed a RIF effect in lexical decisions for the exemplar when primed with the explicitly studied category (*fruit*) but not with a novel category (*food*).

### 6.3. Summary

The majority of studies have shown that recall practice produces RIF even when the subsequent test of memory involves recall with novel cues or recognition. However, RIF has been observed much less consistently when subsequent tests involve implicit rather than explicit memory tasks. A number of findings suggest that RIF may emerge only when the details of an earlier retrieval context are accessible. This is less likely to happen with implicit tasks, which may explain the frequent absence of RIF. The possibility of implicit cue reinstatement also means that the use of novel cues and tasks does not constitute a strong test of the cue independence prediction unless cue reinstatement is controlled.



## 7. CONCLUSION

The principle of competitor interference suggests that forgetting is the product of competition among memories associated with a retrieval cue. In rejecting this principle, the inhibition theory of forgetting proposed by Anderson and colleagues (Anderson & Bjork, 1994; Anderson et al., 1994) represents a major departure from the classic interference theories whose influence continues to shape current thinking about recall. According to inhibition theory, forgetting is not due to competition among memories but rather is the product of active inhibition that occurs during retrieval. A large literature on RIF has focused on four predictions made by inhibition theory that its advocates argue are fundamentally inconsistent with competitor interference. RIF is predicted to be retrieval dependent, strength independent, interference dependent, and cue independent. Previous reviews have described a wealth of evidence for these predictions (Anderson, 2003; Anderson & Levy, 2007). The present review of the literature, however, points out that the empirical support for the predictions has been inconsistent. Moreover, there are a number of theoretical reasons to question whether the predictions are sufficient to differentiate between inhibition and competitor interference.

According to the retrieval-dependence prediction, strengthening a memory in a way that does not involve retrieval should have no deleterious effects on the ability to recall other memories. A number of findings are inconsistent with this prediction. The inhibition account can explain such findings by suggesting that participants sometimes engage in covert retrieval practice even when not directed to do so. Although Anderson and Bell (2001) have offered evidence linking RIF to self-reported tendencies to use covert practice strategies, other studies have reported forgetting even when covert retrieval was controlled. According to the strength independence prediction, strengthening a memory does not by

itself affect the ability to recall other memories. A number of studies have shown that improving an item's memorability without requiring its retrieval, such as with additional study trials, can have little effect on memory for other items. Competitive interference models can explain such findings by suggesting that different tasks promote the encoding of different types of information. Retrieval tasks may emphasize the encoding of contextual information which particularly exacerbates interference. In short, although the inhibition and competitor interference accounts do make predictions with regard to retrieval dependence and strength independence, both can in theory accommodate discrepant findings. Post-hoc explanations based on covert retrieval and differential encoding need to be systematically investigated.

According to the interference dependence prediction, the degree of inhibition should depend on the need for inhibition. In other words, strong competitors should suffer the most inhibition because they are most likely to interfere with the retrieval of other memories. Only a handful of studies have focused on interference dependence. Although some have observed greater inhibition for strong than for weak competitors, others have found no difference or even the opposite pattern. The lack of clarity might be attributed in part to the limited amount of data available. However, theoretical details of the interference prediction may require development before progress can be made.

According to the cue independence prediction, RIF should not depend on whether the retrieval cues at inhibition match those present at subsequent retrieval attempts. Many studies have shown that recall practice impairs memory even when later tests involve novel recall cues or a shift to another explicit memory task such as recognition. However, RIF has been observed inconsistently when later tests involve implicit memory tasks. Importantly, the disappearance of RIF in both explicit and implicit memory tasks has been observed specifically when access to the original inhibitory context is limited. This has led some to suggest that RIF is context-specific but can occur despite changes in retrieval cues because participants often covertly reinstate the original inhibitory context (Camp et al., 2009; Perfect et al., 2004). The covert reinstatement hypothesis allows the competitor interference account to accommodate findings of cue independence. The failure to observe RIF following a change of cues is a problem for the inhibition account if it is assumed that retrieval practice and subsequent tests draw upon a common memory representation. One way to deal with this problem is to assume that an item may have different levels of representation in memory. For example, if a practice task causes the inhibition of an item's episodic representation while a later task draws upon its semantic representation, RIF might be not be observed. Allowing for multiple levels of representation may

allow the inhibition account to explain the disappearance of RIF, but this is an aspect of the theory that has yet to be explored.

### 7.1. Why Inhibition?

The evaluation of the inhibition account of RIF offered here is more critical than in previous reviews of the literature. At an empirical level, a large number of findings, many reported in recent years, do not support the predictions of the inhibition account. At a theoretical level, for each of the key predictions, interpretations of the data exist which are compatible with competitor interference but have yet to be elaborated or explored. In making these points, the intent is neither to diminish the significance of inhibition theory's contribution to current thinking about recall, nor to suggest that competitor interference remains the superior approach to forgetting. As should be clear from the summary above, it is difficult at present to be wholly satisfied with either the inhibition or competitor interference account of RIF.

The inhibition theory of forgetting was proposed as an alternative to traditional approaches based on competitor interference. However, the difficulty of ruling out competitor interference suggests that a way forward may be to focus on the development of inhibition theory itself. Perhaps the most puzzling ambiguity of the theory lies in the question of what exactly inhibition is meant to overcome. Inhibition theory is based on the premise that competitors associated with a cue pose difficulties during the retrieval process. Competitor interference suggests that this difficulty is the potential for retrieval failure. In rejecting a role for competitor interference in forgetting, the implication is that the difficulty lies elsewhere. For example, it might be that competitors do not cause retrieval failure but only slow down the retrieval process. However, many competition models (such as SAM-REM described earlier) assume that speed and accuracy trade off, so that slowing the retrieval process may lead to retrieval failure due to premature search termination.

A possibility that has been relatively neglected is that the purpose of inhibition is to overcome competitor interference. The case for inhibition has been advanced largely by arguing for the inadequacy of competitor interference models. However, it is logically possible that competitor interference and inhibition coexist, the former reflecting the passive role that memory structure plays in causing retrieval difficulty and the latter reflecting a more active response meant to overcome this difficulty. A serious objection to this possibility is the lack of parsimony: if competitor interference contributes directly to forgetting, then why is it necessary to propose what is essentially another layer of complexity in the concept of inhibition? The answer may lie in showing that directed inhibition has a

purpose, such as to accomplish short-term goals (Storm & Angello, 2010) or to suppress unwanted associations in the long term (Anderson & Green, 2001; Anderson & Levy, 2007).

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