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Los Angeles

Challenging the Contextual-Cuing Account of Retrieval-Induced Forgetting

A dissertation submitted in partial satisfaction  
of the requirements for the degree of Doctor of Philosophy  
in Psychology

by

Dorothy Rose Buchli

2015

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## ABSTRACT OF THE DISSERTATION

Challenging the Contextual-Cuing Account of Retrieval-Induced Forgetting

by

Dorothy Rose Buchli

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2015

Professor Robert A. Bjork, Co-Chair

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Most laypersons assume that remembering and forgetting occur along a single continuum. That is, to remember is to avoid forgetting. To the contrary however, over 20 years of research suggests that forgetting can actually be incredibly adaptive, and indeed quite essential for the efficient functioning of the memory system. Forgetting serves as an updating mechanism, allowing for the successful retrieval of current information that is relevant, at the expense of irrelevant or outdated information. One very illustrative example of such adaptive forgetting is a phenomenon known as retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994). While information that is retrieved is strengthened in memory and thus becomes more recallable than it would have been otherwise, related items in competition with that which is retrieved become less recallable. This decrement in recall for related, competing information is referred to as retrieval-induced forgetting.

Investigations of retrieval-induced forgetting typically employ a standard retrieval-practice paradigm that consists of three phases. During the initial learning a phase, a series of

category-exemplar pairs, drawn from a number of different categories, are presented to the participant for study (e.g., *fruit: orange, drinks: whiskey, trees: elm*). Subsequently, during the retrieval-practice phase, a subset of the pairs are retrieved in response to category-plus-two-letter-stem cues (e.g., *fruit:or, drinks: wh*). After a brief distractor task, participants are prompted to retrieve all of the initially presented pairs in response to category-plus-one-letter stem cues (e.g., *fruit; o, drinks:w*). This retrieval-practice paradigm creates three types of items: *Rp+* items that were retrieved during the retrieval-practice phase (e.g., *fruit: orange*), related *Rp-* items that share the same category cue but were not retrieved during retrieval-practice (e.g., *fruit: apple*), and baseline or *Nrp* items from nonpracticed categories that did not receive retrieval-practice (e.g., *trees: elm*). Not surprisingly, *Rp+* items that were given retrieval practice after study are recalled better than related *Rp-* items from the same categories that were not practiced.

Interestingly however, relative to nonpracticed items from nonpracticed categories, (i.e. *Nrp* items), *Rp-* items are impaired. Said differently, on average, participants recall fewer *Rp-* items than *Nrp* items. This decrement in recall for *Rp-* items relative to *Nrp* items is referred to as retrieval-induced forgetting.

Such retrieval-induced forgetting is assumed by many to reflect inhibitory mechanisms recruited during retrieval of target items to decrease the accessibility of related, nontarget items. In Chapter 1, I will briefly review the literature on retrieval-induced forgetting.

Recently however, Jonker, MacLeod, and Seli (2013) proposed an alternate account that emphasized the role of context in producing retrieval-induced forgetting. In this framework, the study and retrieval-practice phases are represented as two disparate contexts. While the study context includes all of the studied items – that is, the *Rp+*, *Rp-*, and *Nrp* items – the practice context only contains the *Rp+* items. Critically, while the *Nrp* or baseline items are only present

in the study context, the Rp- cues are associated with both the study context and the retrieval-practice context. Thus, at test, participants may search the retrieval practice context first which then makes it more difficult to recall items from the study context. The Nrp cues, however, are only associated with the study context, and are therefore very effective at reinstating the initial study context.

In evidence of this account, Jonker et al. (2013) showed that even restudy practice—which is assumed by the inhibitory account to be insufficient to cause forgetting—can cause forgetting when a mental context change is inserted between study and restudy. In Chapter 2, I present a series of experiments designed to replicate this finding while also testing the possibility that a far mental context change would cause more forgetting than a near mental context change.

An important assumption of the contextual-cuing account is that if only the practice context is reinstated at final test, retrieval-induced forgetting will occur because participants are unable to access Rp- items. In contrast, if the study context is reinstated at test, because all items are available, retrieval-induced forgetting should be eliminated. To test this critical assumption, in Chapter 3, several experiments are presented in which subjects were encouraged to reinstate the appropriate context regardless of whether a given item was practiced or unpracticed. Finally, in Chapter 4, a summary and interim conclusions are given, as well as future directions that may be fruitful in this domain of research.

The dissertation of Dorothy Rose Buchli is approved.

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### Articles Under Review

- Buchli, D.R., Storm, B.C., & Bjork, R.A. (under review). Mental context change between study and restudy is not sufficient to cause forgetting. *Quarterly Journal of Experimental Psychology*.
- Giebl, S., Storm, B.C., Buchli, D.R., Bjork, E. L., & Bjork, R.A. (under review). Remembering the past and imagining the future. *Quarterly Journal of Experimental Psychology*.

### Manuscripts in Preparation

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Buchli, D.,R., Nestojko, J.,F., and Bjork, R., A. (2011). *The competition dynamics of spaced vs. massed study in the retrieval-practice paradigm.* Poster presented at the 21st Annual Meeting of the Western Psychological Association

Buchli, D.,R., Nestojko, J.,F., and Bjork, R., A. (2012). *Episodic strength as a modulating factor in retrieval-induced forgetting.* Poster presented at the 23st Annual Meeting of the Association for Psychological Science

Buchli, D.R. (2009). *Context, trial spacing, and the effect of successful recall on retrieval-induced forgetting.* Poster presentation at the 11th Annual IRCS Undergraduate Summer Workshop

## CHAPTER 1

### Introduction and Overview

#### **What is retrieval-induced forgetting?**

Human memory is a complex, multifaceted system that has been a subject of inquiry among psychologists and philosophers alike for centuries. Perhaps in an attempt to better understand the structure and dynamics of memory, many have proposed metaphors for human memory. Roediger (1980) compiled a “fairly complete, but certainly not exhaustive (p.232)” list of 36 memory metaphors used by psychologists and philosophers from Plato until modern times, sometimes in jest, but more often quite seriously. Plato for instance, likened memory to a wax tablet onto which information and experiences are imprinted. Socrates’ view of the mind was much more complex, comparing the memory system to an aviary full of birds, such that in infancy the birdhouse is close to empty, but as information is acquired, one, two, and eventually flocks of birds, of many different types, are added. Furthermore, as Roediger notes:

The aviary view employs an explicit search process for retrieval. Socrates thinks of the person as ‘hunting once more for any piece of knowledge that he wants, catching and holding it, and letting it go again’ (Hamilton, 1961, p. 904). This brings about the distinction between possessing and having knowledge. Possessing knowledge is like having a bird in the enclosure somewhere; in Tulving and Pearlstone's (1966) somewhat more recent terms, such birds are like information that is available in memory, but which may not be accessible or retrievable. Having knowledge is like recapturing the birds and holding them in hand. Thus the basic distinction is one of having something currently in consciousness or possessing it in some larger store (or aviary). The acquisition and retrieval of information is conceived as an active process. Errors are possible as when ‘in

hunting for some particular piece of knowledge, among those that are fluttering about, he misses it and catches hold of a different one ... as he might catch a dove in place of a pigeon (Hamilton, 1961, p. 906, as cited in Roediger, 1980, p. 232).

Socrates' characterization of memory is quite impressive in that it includes many of the principles that psychologists now believe to govern memory, such as the context or cue dependent nature of retrieval. That is, while what is encoded properly is stored and therefore available in memory indefinitely, what is accessible or easy to recall at any given moment is determined by a variety of incidental factors. Namely, not just by the strength of the item, or its strength relative to other items but also by the cues that are available to guide retrieval. As such, what is inaccessible at one point in time may later become recallable in the presence of the appropriate cues. Similarly, Socrates alludes to the seemingly fragile state of our memories; that is, despite one's best efforts to remember all that was at one point deemed to be important, retrieval failure is an all too common experience. Taken together, these qualities are illustrative of one of the peculiarities of memory, the fact that despite having a virtually limitless capacity to store information, retrieval capacity is severely limited.

More recently, cognitive scientists have attempted to elucidate the complexities of memory by transferring knowledge from a much more concrete and better understood domain – the mechanics and underlying structure of man-made devices, such as a tape recorder or computer (Atkinson & Shiffrin, 1968; Posner & Warren, 1972). In the last 30 years however, a variety of developments in the behavioral, clinical, and neuroscientific domains have suggested that this approach is obsolete. While it is beyond the scope of the present paper to review such developments in detail, one particularly problematic aspect of these models is that they assume that retrieval is a passive process, whereby information that is stored is retrieved just as it was;

thus, the act of retrieval does little more than reveal the content within our memories. Much evidence suggests, to the contrary, that retrieval is a “memory modifier” (Bjork, 1975), with both positive and negative (arguably, still adaptive) consequences. That is, information that is retrieved becomes more recallable than it would have been otherwise, while information that is not retrieved becomes less accessible (Bjork & Bjork, 1988; Bjork, 1989; Bjork & Bjork, 1992).

Such retrieval-induced forgetting is a fairly robust phenomenon and has been shown with a variety of different materials including category-exemplar pairs (Anderson, Bjork, & Bjork, 1994), phonological categories (Bajo et al., 2006), visuospatial materials (Ciranni & Shimamura, 1999), text passages (Little, Storm & Bjork, 2011), factual propositions (Anderson & Bell, 2001), eyewitness memory (Shaw, Bjork & Handal, 1995), autobiographical memories (Barnier, Hung, & Conway, 2004; Storm & Jobe, 2012), and creative problem solving (Storm, 2011; Storm, Bjork & Angello, 2011; Storm & Koppel, 2012).

Studies of retrieval-induced forgetting typically employ the retrieval-practice paradigm, which consists of three phases. During the study phase, participants are presented with a series of category-exemplar pairs drawn from a number of different categories (e.g., *fruits: orange, drinks: rum, professions: nurse*). Subsequently, during the retrieval-practice phase, participants are asked to repeatedly retrieve half of the items from half of the studied categories in response to a series of category-plus-two-letter-stem retrieval cues (e.g., *fruits: or\_\_*, *drinks: ru\_\_*). After a 20 minute distracter task, participants are given a category-plus-one-letter-stem cued recall test on all of the items presented during the study phase (e.g., *fruits: o\_\_*, *drinks: r\_\_*). Not surprisingly, items that receive retrieval-practice during the retrieval-practice phase (e.g., *fruit: orange*) are recalled better at test than nonpracticed items from the same categories (e.g., *fruit: lemon*). Interestingly however, relative to control items from unpracticed categories (e.g.,



*profession: accountant*), recall for unpracticed items from practiced categories (e.g., *fruit: lemon*) is impaired.

### **Purported Causal Mechanisms: Interference vs. Inhibition**

Interest in retrieval-induced forgetting has been renewed since the creation of the retrieval-practice paradigm (Anderson, Bjork & Bjork, 1994) almost 20 years ago, but was a subject of inquiry among psychologists and in particular interference theorists, long before that. Most broadly, interference refers to “the impaired ability to remember an item when it is similar to other items in memory” (Anderson & Neely, 1996, p. 237). For example, when parking one’s car at a shopping center one has never visited before it is fairly easy to recall where it is a short time later. If however, one parks there frequently it becomes more difficult to remember one’s current parking spot, as opposed to where one parked on previous visits. This example illustrates a typical case of retrieval failure (i.e. forgetting) arising from interference. Research on interference was an exciting and fruitful domain within psychology for many, many years. Consequently, there are numerous conceptions of how forgetting resulting from interference occurs. Each of these theories is just one hypothesized mechanism by which retrieval modifies memory.

There are a number of basic assumptions that approaches to interference share. Many of them for instance characterize retrieval as a progression from one or more retrieval cues to items stored in memory by way of associative links. Retrieval cues can be components of the desired memory that were explicitly associated with it or incidental features tied to the item during its encoding. Thus, recalling where one’s car is parked might involve the activation of a number of different things including features of the car (e.g., size, color, etc.), the layout of the parking lot, the time of day, and so on. The probability that one will successfully progress from the provided

cues to the target memory depends upon a number of factors including the number of cues available during the retrieval attempt, the strength of the association between each respective cue and the target memory, as well as the associative strength of other items that are also tied to the cue or combination of cues. Successful retrieval thus depends on how strongly the cue is linked to the target as well as how strongly the cue is related to other items in memory. Many interference theories also assume that when a cue is linked to more than one item in memory, those items compete with the target for access to conscious awareness (Anderson, 2003; Anderson & Bjork, 1994; Anderson, Bjork, & Bjork, 1994; Anderson & Neely, 1996). Thus, the term interference is frequently used to describe impaired memory performance due to this competition.

Another fundamental assumption shared by many approaches to interference is that interference owing to the mechanisms of competition increases as the number of items linked to the cue increases (Watkins, 1978). These two laws – the competition assumption and the cue-overload principle – form the basis of *response competition theory* (McGeoch, 1942). That is, McGeoch assumes that attaching more than one response to a given retrieval cue causes those responses to compete for access when the cue is presented on a subsequent test. Therefore, the greater the number of competing responses, or the stronger a given competitor, the more difficult it should be to recall the appropriate response. In essence, this theory posits that the addition of newer or stronger items in memory leads to the occlusion or blocking of a target event.

For example, consider an experimental task in which participants are asked to learn two lists of unrelated word pairs (e.g., *dog-rock*, *couch-bag*). On the first list, each participant sees the pair *dog-rock* for instance, and is instructed to learn it for a later memory test. On the second list each participant sees the same stimulus term (e.g., *dog*) but it is now paired with a new

response (e.g., *sky*). Interference was commonly studied using this paired-associate paradigm, with the objective of examining the effect of new learning on recall performance of the initially studied associate (e.g., *rock*). Using the above examples, the presentation of *dog* should induce competition between *rock* and *sky*, such competition being greater if either response is more strongly associated to the cue than the other. That is, competition is assumed to be *strength dependent* in that the interference exerted by an item increases with its memory strength (Anderson & Neely, 1996; Bjork, Bjork & Anderson, 1998). Thus, response competition theory assumes that retrieval doesn't modify the target's representation or its association to the cue; rather, the effectiveness of the association linking the cue to the target is assumed to decrease as links between the cue and competitors become more effective, inducing greater competition during retrieval.

Response competition theory assumes that forgetting arises when the association between the cue and a competitor gain strength and as a consequence, block or occlude recall of the target response. It is also possible for the cue target association to progressively weaken as a consequence of learning new information that is linked to the same cue. According to the unlearning hypothesis (Melton & Irwin, 1940), interference effects are caused in part by the unlearning of associative connections linking a retrieval cue to a response. Specifically, when a person is trying to recall a newly learned response (e.g., the new phone number for a friend), previously learned responses to that same cue (e.g., the old phone number for that friend) may sometimes be elicited accidentally. Elicitation could take the form of an overt or covert intrusion of the unwanted item. To the extent that the older response is incorrect, it was thought to go "unreinforced," and therefore suffer extinction effects analogous to those exhibited by animals in conditioning experiments. Associative unlearning was a critical component of Melton and

Irwin's classical two-factor theory of interference, which also incorporated response competition. The researchers proposed the addition of a separate unlearning mechanism after conducting a series of experiments examining the effect of interpolated learning on retroactive interference, in which they increased the learning trials of second list items (e.g., *dog-sky*) to 10, 20, 30, or 40 trials respectively. Response competition theory predicts strength dependent forgetting, such that forgetting should be accompanied by increases in intrusions of stronger, second list items. However, they observed that even as intrusions of stronger, list two items began to decrease, retroactive interference continued to increase. Because retroactive interference continued to increase, they assumed that some additional factor must be at work. The modern descendants of this view include the many connectionist learning systems that might attribute forgetting in part to the alteration of weights between representational units.

Melton & Irwin (1940) argued that the impaired recall of *dog-rock* that was typically observed in experiments employing the paired-associate paradigm was not merely the result of occlusion from the recently strengthened *dog-sky* response. *Dog-rock* was also recalled less well because the association linking the cue to the target was gradually weakened during the learning of *dog-sky*. Yet another possibility is that in the process of learning a particular cue-target association of an excitatory nature, such that presentation of a particular cue (e.g., *dog*) yields a certain response (e.g., *sky*), participants also learn an inhibitory association, whereby they learn NOT to respond to the same cue with a different, incorrect response (Osgood, 1946; 1948). Thus, as subjects learn the *dog-sky* association, they also simultaneously learn an inhibitory *dog-(not)rock* association. Thus, Osgood's framework assumes that successful retrieval of the target is dependent upon strengthening of the cue target association, as well as the inhibition of any competing, inappropriate responses.

A related, though considerably more radical, approach was proposed by Postman and colleagues (Postman et al., 1968). Previous theories posited that forgetting was a reflection of the effects of competition between alternate responses, or the weakening of associations by general, all-purpose learning mechanisms. However, Postman proposed the existence of highly specialized mechanisms much more advanced and sophisticated than those purported under traditional learning frameworks. According to his response-set suppression hypothesis, interference in the traditional paired-associate paradigm was caused by the active suppression of response members from the initial list. Suppression was thought to occur during the acquisition of the second list of pairs by what Postman referred to as a “selector mechanism.” The function of the selector mechanism was to both enhance the representations of responses that were intended to be part of the current response set and to suppress outdated response sets. The suppression process helped to reduce proactive interference caused by the initial list, and to effectively “shift” into a “response set” more appropriate to the current task. Thus, all list one items (e.g., *dog-rock*) are suppressed in order to facilitate subsequent recall of list two items (e.g., *dog-sky*). Importantly, unlike other purposed mechanisms of associative interference, like occlusion or unlearning, response set suppression was theorized to affect the representations of responses. Thus, response set suppression attributes the decrement in performance observed in interference studies to changes within the target memories themselves.

Thus, there are a myriad of potential mechanisms by which selective retrieval of some memories can impair subsequent recall of similar items. If a given retrieval cue becomes associated with multiple items, strengthening the association between the cue and a subset of those items can sometimes cause stronger items to occlude or block weaker items, thus keeping them out of awareness (McGeoch, 1942). When acquiring a new response to a previously studied

cue, the older and now inappropriate association may progressively become weakened as the new association becomes stronger, causing unlearning or forgetting of the initial response (Melton & Irwin, 1940). In the process of learning to associate a new response to a given cue, an inhibitory association may also be acquired, such that one learns to provide the correct response and also not to provide the incorrect response (Osgood, 1946; 1948). Lastly, if several responses become linked to a particular cue, and one must subsequently learn a host of new responses to the same cue, one might suppress the earlier set in order to facilitate the acquisition of new responses (Postman et al., 1968). Another potential mechanism yet to be discussed, but similar in many ways to Postman's response set suppression mechanism is inhibition or direct suppression. The inhibitory account maintains, as do most interference theories, that when selectively retrieving relevant information from memory, related but *irrelevant* information associated with the same retrieval cue(s) also become activated and begin to compete for access. In order to successfully retrieve only that which is most relevant, and to bypass such retrieval competition, irrelevant information is selected against and suppressed.

Several of the fundamental assumptions of McGeoch's response-competition theory are acknowledged in the current inhibitory approach. For instance, the presentation of a retrieval cue is assumed to activate all associated responses according to the strengths of their association to the cue. Furthermore, these responses are also thought to compete with one another for access to conscious awareness. Critically, it is this retrieval competition that precipitates the need inhibition. According to the inhibitory account, however, this competition alone is usually not enough to impair recall of a target because inhibitory processes may be deployed to overcome the competition. The empirical relationship between the number of competing responses and the probability of recalling a target item is also accepted by the theory, along with the notion that

strengthening a competing response is empirically associated with a decrement in recall for a target.

The inhibitory account is also not unlike Melton & Irwin's unlearning hypothesis in many important ways. For one, intrusion of unwanted memory responses during retrieval necessitates subsequent forgetting of those intruding items. Furthermore, both the inhibitory account and the unlearning hypothesis posit a process by which intrusions are altered in such a way as to render them less likely to interfere in the future. That is, some aspect of the intrusion's representation is changed. There are several significant differences between the two approaches however, the most critical one being the nature of the mechanism itself. While unlearning is presumed to occur as a result of a decrement in the associative bond linking a cue to a target, the inhibitory account attributes impairment to suppression of the target itself.

Osgood's reciprocal theory of inhibition, as the first to attribute interference to an inhibitory mechanism, is also not totally dissimilar from the inhibitory account. Like Osgood, inhibitory theorists assume that impairment is the direct result of inhibition of an inappropriate response. However, Osgood makes two assumptions that are not included in the present inhibitory account: (1) that semantic antagonism between two responses is necessary for inhibition to occur and (2) that an inhibitory association between a stimulus and an unwanted response is developed simultaneously with the excitatory response. Instead, the inhibitory account assumes that when a cue is presented that activates an unwanted response, inhibitory mechanisms can be recruited to suppress the item. Frequent attempts to suppress the memory may result in the creation of an inhibitory association later on, but that is beyond the scope of the theory.

Lastly, like Postman's response set suppression theory, the inhibitory account attributes forgetting to a mechanism that directly suppresses response representations that are no longer relevant. Importantly however, the 'selector mechanism' proposed by Postman was postulated to operate at the level of response repertoires. That is, groups or sets of responses were suppressed in service of facilitating the successful retrieval of other sets. In contrast, the inhibitory account assumes that suppression occurs at the level of individual responses. Accordingly, the response set suppression account presumes that if a participant learns a list of 20 pairs, and then learns a second list of 20 pairs, every item from the initial list will be suppressed, regardless of whether or not the stimulus member presented on a given first-list item was also used in the second list. The set of first list responses is suppressed as a whole, and the set of second list responses is facilitated. Thus, the inhibitory approach is much more flexible, allowing for suppression of specific competing responses associated to the same cue.

As an aside, those wishing to formalize inhibition as a separate and discernible mechanism by which forgetting occurs have faced considerable obstacles, perhaps the greatest of which is a desire to keep the virtue of parsimony (Bjork, 2007). If interference effects can be explained in terms of cognitive processes that have been thoroughly researched and are therefore better understood, such as blocking or unlearning for instance, then why is it necessary to postulate an inhibitory mechanism that is poorly understood in comparison? A related issue is that while many have experienced the frustration of trying to recall something from memory, only to have something you know to be incorrect block it from awareness, few have had the subjective experience of inhibiting or suppressing something. Another challenge is that the term inhibition has historically been associated with controversial and poorly understood clinical phenomena, such as the Freudian notion of repression. Finally, even when inhibition is



appropriately used as a scientific term, there is the danger of circularity. That is, sometimes inhibition is a measurable phenomenon – specifically, as a term used to describe performance below some sort of baseline criterion – or as the cause for that phenomenon. The term inhibition in the case of the inhibitory account takes on the latter denotation.

In any event, while there has historically been opposition to the formalization of inhibition as a scientific concept, there are several reasons why forgetting owing to such inhibition is an important process in memory, and in particular, one that is adaptive. The adaptive nature of forgetting is due in large part to one of the great peculiarities of memory. That is, though human memory is characterized by an impressive storage capacity that is virtually unlimited, it is coupled with a retrieval capacity that is severely limited. Thus, while we are able to accumulate vast amounts of knowledge and expertise, much of what we know remains inaccessible (Bjork, 1989; Bjork, 2011; Bjork & Bjork, 1988; Bjork & Bjork, 1992; Bjork, Bjork & Anderson, 1998; Storm & Levy, 2012). The inability to recall information we know to be stored in our memories is a frustrating experience and such retrieval failure is widely regarded as an inherent flaw or failure of the memory system. However, consider the alternative. A memory system that grants access to everything that has ever been stored would inevitably give way to a slow, error-prone retrieval process in which everything comes to mind and what is relevant is selected according to some sort of a decision process. As William James (1890) was one of the first to emphasize, “If we remembered everything, we should on most occasions be as ill off as if we remembered nothing” (p. 680).

The fact that we can only recall a fraction of what is available in memory at any given time necessitates that what is accessible remains current. That is, we need to remember where we parked our car today, not where it was parked several weeks ago; we need to remember our

current phone number not one used previously and so on. Thus, inhibition acts as an updating mechanism in memory, such that only information that is relevant at any given point is made accessible. Critically, this enhancement of the accessibility of relevant information occurs at the expense of no-longer-relevant items, such that information that is now out of date and could be a source of errors and confusion is selected against and inhibited.

### **A Brief Survey of the Evidence in Favor of Inhibition**

As this brief review suggests, there are several potential mechanisms by which retrieval can impair access of unretrieved items, some inhibitory and some noninhibitory. In some ways they cannot be (nor should they be) distinguished from one another. For instance, the response competition that occurs when multiple items become associated to a cue, as well as the subsequent strengthening of some items and the resultant blocking of weaker items is exactly the situation in which the need for inhibition arises. Thus, it is likely that both interference and inhibition contribute to retrieval-induced forgetting. There are however certain aspects of retrieval-induced forgetting that are difficult to account for by purely noninhibitory mechanisms. Thus, considerable research has been conducted that provides evidence in support of inhibition. Such evidence will be reviewed in the following section, not to underemphasize the role of interference, but rather to suggest that interference is necessary but not sufficient to cause all instances of retrieval-induced forgetting. That is, to demonstrate that some patterns of forgetting emerge that cannot be fully explained by noninhibitory processes. Furthermore, these patterns are often what we would expect if the function of forgetting, and of inhibition in particular, is to select against information that interferes during retrieval.

#### *Cue-independence*

Many theories of interference assume that forgetting is strongly cue-dependent

(McGeoch, 1942; Rajaamakers & Shiffrin, 1981; Mensik & Rajaamakers, 1988). The response competition theory described above for example, asserts that the strengthening of some exemplars through retrieval practice impairs recall of other exemplars at test because the presentation of their shared cue causes the strengthened exemplar to intrude perseveratively, blocking the weaker item. Similarly, the unlearning hypothesis assumes that forgetting is the result of a gradual weakening of the original cue-target association as newer responses are acquired. In contrast, the inhibitory account predicts that forgetting is cue-independent - that is, that the impairment observed should generalize to novel test cues not used during retrieval practice. This prediction follows because the impairment is believed to result from suppression of the competing memory itself, rather than damage to any particular association (Anderson, 2003). In order to successfully differentiate between the inhibition and interference theories of retrieval-induced forgetting, Anderson & Spellman (1995) developed the independent-probe technique. In this procedure, independent cues (those that are unassociated with the competing item) are used during the test phase of the experiment to test memory for the target item. The response competition account of retrieval-induced forgetting assumes that if participants study the pairs *fruit:orange* and *fruit:banana*, subsequently strengthening *fruit:orange* through retrieval practice, the existing association between *orange* and the category *fruit* would impair retrieval of *banana* when cued with the same category. However, if *banana* is cued with a novel category (i.e. *monkey*), all associative interference is eliminated. Thus, the forgetting of *banana* is contingent upon whether one uses the retrieval practice cue or an independent cue to test the critical item. The inhibitory account of retrieval induced forgetting on the other hand, contends that retrieval practice of the pair *fruit:orange* suppresses the competing exemplar (i.e. *banana*). If the competing item itself is inhibited, forgetting should result regardless of whether the item is

tested with the original cue or a novel cue.

In their study, Anderson & Spellman (1995) asked subjects to study a series of exemplars from several categories. This experiment differed from other retrieval-induced forgetting studies in that each of the categories were related. For example, subjects studied 'Blood' and 'Tomato' under the 'Red' category and 'Radish' and 'Cracker' under the 'Food' category. 'Tomato' was studied in the 'Red' category, but 'Tomato' is also a food. 'Radish' was studied under the 'Food' category, but it is also a red thing. The critical question was whether or not retrieval practice on items like 'Red-Blood' would result in the inhibition of other red items (i.e. Radish) that were not studied explicitly under the category. Interference-based theories predict that retrieval practice of 'Red-Blood' should fail to induce impairment in recall for 'Radish' because it is tested with a different retrieval cue. Therefore, even if retrieval-practice strengthens the association between 'Red-Blood' and weakens the 'Red-Radish' association, 'Radish' should remain unimpaired. It is also possible however, that retrieval practice of 'Red-Blood' activates all of the red items, creating interference and triggering the need for inhibition. If this were the case, suppression of 'Radish' would be observable when it is tested with the food category. This exact pattern of data was found, suggesting that competing memories remain less accessible regardless of what cue is used to test them. Several subsequent studies have demonstrated cue-independent forgetting using the retrieval practice paradigm (Anderson, Green & McCulloch, 2000; Anderson & Bell, 2001; Anderson & Green, 2001; Anderson et. al, 2004; Aslan, Bauml, & Pastotter, 2007).

A related paradigm that is often used to investigate inhibitory processes in long term memory is the think/no think paradigm (Anderson & Green, 2001). Cue-independence has also been established using this procedure. Experiments of this kind require participants to study

several unrelated word pairs (i.e. *ordeal:roach*, *flag:sword*). After study, subjects are trained to supply the second word after the first word is given as a cue. Following training, during the think/no think phase, participants are given the first word (*ordeal*) for a subset of the pairs and are told to either recall the word and say it aloud as before (the ‘think’ condition) or to prevent the appropriate word from entering into consciousness (the ‘no think condition’). Finally, during the test phase, participants are given the cue for each of the studied word pairs and asked to supply the corresponding word for each of them. As to be expected, words that subjects attempt to keep out of consciousness are typically impaired relative to baseline pairs that are studied initially but not seen during the think/no think phase. Anderson & Green (2001) modified the test phase to investigate whether the impairment observed is cue-independent by presenting novel test cues with a single letter stem (*insect:r*) and asking participants to give the response word. Forgetting of the target item persisted, both when original test cues and independent cues were provided, lending evidence to the inhibition-based account of forgetting. Cue-independent forgetting has also been confirmed using the stop-signal paradigm (Anderson & Weaver, 2009) as well as the part-list cuing paradigm (Aslan, Bauml, & Grundeiger, 2007).

While all of these studies provide clear and direct evidence in support of inhibition-based theories of forgetting, some experiments have suggested that the independent-probe method may not utilize truly independent cues. One potential problem with this technique is covert cuing (Anderson et. al, 2000, Anderson, 2003; Camp, Schmidt, & Zeelenberg, 2009). Covert cuing occurs when participants make use of retrieval cues not provided at test. In the retrieval practice paradigm for instance, participants may use the original studied category to retrieve the target item even when the independent cue is given at test. Anderson et. al (2000) asked participants in a post-experimental questionnaire if they had thought back to the studied

categories to help them come up with responses to the independently-cued items. On average, participants assigned a 2.68 rating on a 5 point scale, suggesting that previously studied cues were used to retrieve target items. For example, if participants studied items such as Red-Blood and Red-Tomato, performed retrieval practice on Red-Blood, and were subsequently asked to recall Tomato with the cue Food:T, they may have thought back to the earlier category 'Red things.' Using the studied and independent cues together gave subjects a slight recall advantage - subjects who adopted this strategy showed modestly reduced inhibition effects compared to subjects who did not use the strategy. Anderson (2003) proposes several methods to reduce the likelihood of covert cuing when using the independent probe procedure. First, he recommends that the independent cue be as strongly related to the target item as possible; poorly related cues may encourage the participant to search for additional information to supplement recall. Secondly, he states that it is important to use an item specific cue (i.e. a letter stem) to focus subjects' attention to a particular item. Also, by limiting the amount of time a subject has to provide an answer during the test phase, the experimenter can discourage the use of recall strategies like covert cuing. Lastly, Anderson suggests that experimenters using the independent probe technique administer post-experimental questionnaires to determine if these strategies were effective in eliminating the use of covert cuing strategies.

Camp, Pecher, Schmidt, and Zeelenberg (2009) attempted to provide a more direct test for the critical criterion of independence in independent cues. The authors developed a procedure designed to ensure that studied cues would not interfere with independent cues during the test phase of the experiment. Participants initially studied a subset of cues (*rope*) that were later paired with a target item that was unrelated to the cue (*sailing*). In the final test phase, participants were presented with an independent cue (*sports*) and asked to recall an item from the

studied list that fit into the category. Results demonstrated that previous study of the target item facilitated recall at test, even though the original cue was not presented. This study provides the first direct evidence of covert cuing, but also challenges the effectiveness of many of the strategies proposed by Anderson (2003). For example, the authors also investigated whether limited response time at test reduced the covert cuing effect (Experiment 2). Limiting retrieval time to 5 seconds failed to eliminate the finding. Furthermore, the effect was found to generalize to independent probes that incorporated letter stems (Experiment 3). Thus, at first glance it appears that many of the tactics outlined in Anderson, 2003 may fail to reduce the likelihood of covert cuing.

Importantly however, Huddleston & Anderson (2012) found that the cue-enhancement effects observed by Camp et al. disappeared when the semantic relationships between studied and independent cues were adequately controlled. Closer inspection of Camp et al.'s stimuli revealed that despite using association norms to minimize probe–cue relationships, their probes and cues were in fact related. For instance, the independent cue for the pair *beak-duck* was *bird*. Clearly, beak and bird are semantically related to one another. Accordingly, perhaps when probed for *duck* with *bird* participants sometimes recalled *beak* and it helped them recall duck. Participants need not have used a covert-cuing strategy in this case, as they may have just recalled it accidentally by virtue of its semantic association to the studied cue.

Further evidence of covert cuing was obtained by Camp, Pecher, and Schmidt (2005). After completing an implicit memory task that utilized independent cues in the final test phase, participants were asked if they were aware of the relationship between the study phase and the test phase. Retrieval-induced forgetting was found in participants who claimed to be aware of the relationship; however participants who claimed that they were unaware of any relationship

showed no impairment in recall at test. The authors contended that aware participants chose to make use of retrieval strategies involving the studied categories, providing an additional example of covert cuing. Unlike the Anderson et. al (2000) study, where covert cuing seemed to improve recall and mask the effects of inhibition, this study suggests that covert cuing can result in a greater degree of retrieval-induced impairment. One reason why this might happen is that although presented with a new cue at test, participants may strategically use the studied cue to covertly mediate their retrieval attempt. If participants use this type of covert-cuing strategy, then they may experience interference from items associated with the studied category that were strengthened, suggesting that even independent cues may be vulnerable to interference. Hulbert, Shvide, & Anderson (2011) however found little support for the conjecture that associative blocking caused by covert-cuing is responsible for cue-independent retrieval-induced forgetting. Presumably, if this were the case, *food-strawberry* would suffer retrieval-induced forgetting due to the fact that participants use the independent category cue (e.g., *food*) to covertly generate the practiced category (e.g., *red*) and in so doing incur associative blocking from practiced items (e.g., *red-blood*). If forgetting is solely a consequence of items that are strongly linked to the cue blocking access of weaker items, strengthening items by any means should cause considerable retrieval-induced forgetting. However, strengthening items with extra study exposures failed to produce cue-independent retrieval-induced forgetting. This suggests that associative interference from strengthened items alone is not sufficient to produce the effect.

In sum, future research is needed to determine the consequences of covert cuing on the degree of forgetting observed in the retrieval-practice paradigm and the think/no think paradigm. However, the fact that covert cuing has been observed challenges the assertion that independent cues are truly independent. The critical criterion of independence is, after all, that recall is



uninfluenced by the original cues presented during study. This presents a problem for those wishing to use the independent probe technique in order to differentiate between the interference and inhibition accounts of forgetting. It is worth noting that while it has been argued that retrieval-induced forgetting is cue-independent because inhibition acts at the level of the item's representation, it may operate at other levels as well. For example, Storm & Levy (2012) argue that interfering items could potentially be inhibited in a cue specific manner that makes them less recallable when paired with the particular cues that prompted their inappropriate activation. Were this the case, inhibition would still serve its alleged purpose of resolving interference by diminishing the accessibility of nontarget items, but it would only do so in the appropriate context, as determined by the cues available.

### *Retrieval Specificity*

In addition to questioning the validity of the cue independence procedure, (Camp, Pecher, & Schmidt 2005; Camp, Pecher, & Zeleenberg, 2009), some researchers have failed to establish cue independence, both in the retrieval practice paradigm (Camp, Pecher & Schmidt, 2007; Perfect et. al, 2004; Williams & Zacks, 2001) and the think/no think paradigm (Bulevich, Roediger, Balota, & Butler, 2006; Wessel, Wetzels, Jelicic, & Merckelbach, 2005). Because of these findings, it has become increasingly important to find other means of differentiating between the inhibitory and noninhibitory accounts of forgetting. In addition to cue-independence, there are several properties of retrieval-induced forgetting that provide support for the inhibitory account. For example, according to the response competition hypothesis, presenting the retrieval practice category during the final test phase causes practiced items to intrude perseveratively, blocking weaker items belonging to the same category. If this were the case, than the strengthening of target items in any way should impair recall for competitors at

test. Several studies have addressed this possibility (Anderson & Bell, 2001; Anderson, Bjork, & Bjork, 2000; Anderson & Schvde, 2001; Bauml, 2002; Huddleston & Anderson, 2012; Saunders, Fernandes, & Kosnes, 2009) by manipulating whether to be practiced items were strengthened by retrieval practice, or simply additional study exposure. Across multiple studies, results show that although both strengthening methods successfully facilitate recall of strengthened items, only the retrieval practice condition leads to retrieval-induced forgetting. In this way, retrieval-induced forgetting appears to be retrieval specific, suggesting that the inhibition that characterizes retrieval-induced forgetting is driven by the need to resolve interference from competing items during the selective retrieval of the target (Anderson, 2003).

### *Strength Independence*

A third property of retrieval-induced forgetting that has also been established in many of the studies included in this discussion is strength independence (Anderson, 2003; Anderson, Bjork, & Bjork, 1994; Anderson, Bjork, & Bjork, 2000; Anderson & Shivde, 2001) That is, the degree to which practiced items are strengthened fails to predict the degree of retrieval-induced forgetting that is observed. Recall that one of the central tenets of response competition theory is that the strengthening of target items and the resultant occlusion of competitors is what ultimately leads to forgetting. However, it is possible for practiced items to be significantly strengthened without causing impairment. Items strengthened via study exposure, or those given retrieval-practice that is noncompetitive for example will not cause nonstrengthened items to be forgotten.

In the preceding studies, the extent to which practiced items were strengthened was almost exactly the same in conditions that did and did not show retrieval-induced forgetting. This pattern of results indicates that insufficient strengthening of practiced items is unlikely to be the

cause of differential impairment. However, one might reasonably still be concerned that the degree of strengthening was not manipulated strongly enough to reveal impairment. To address this, Shivde and Anderson (2001) performed a parametric manipulation of the number of retrieval practice trials given to a practiced item. To manipulate the degree of interference, Anderson and Shivde used asymmetric homographs, pairing each one with one word related to its dominant sense (*e.g., Arm Shoulder*) and another related to its subordinate sense (*e.g., Arm Missile*). Participants were then asked to perform retrieval practice 0, 1, 5, or 20 times on either the dominant or the subordinate associate. After retrieval practice, participants were tested on the alternate associate that they did not practice, with either the originally studied cue or an independent cue. Performing retrieval practice on the dominant sense (*e.g., Arm Shoulder*) did not impair the later recall of the subordinate sense (*e.g., Arm Missile*) at all, even though retrieval practice yielded substantial retrieval-based strengthening for the practiced item. Practice on the subordinate sense, however, caused retrieval induced forgetting of the dominant sense. Similar results were obtained, regardless of whether participants were tested on the unpracticed competitor with the homograph (*e.g., Arm M\_\_\_*) or the independent test cue (*e.g., Target M\_\_\_*). Thus, even when participants completed as many as 20 retrieval practice trials on the dominant sense, little retrieval-induced forgetting was observed.

Intuitively, one might assume that retrieval success is necessary in order for retrieval-induced forgetting to occur. However, according to the inhibitory perspective, forgetting may persist in the absence of high levels of retrieval practice success. Because retrieval-induced forgetting is presumably strength-independent, failing to retrieve and therefore strengthen items during retrieval practice should not diminish the amount of forgetting that is observed. Also, if inhibitory mechanisms are recruited to resolve interference that occurs between competing items

during retrieval, the consequences of those inhibitory processes should remain regardless of whether or not the retrieval attempt is successful. It is the competition that arises during retrieval that creates the need for the inhibition, not the retrieval itself. Interference accounts of retrieval-induced forgetting assume that because the degree of retrieval success determines the extent to which practiced items are strengthened, the magnitude of the retrieval-induced forgetting effect should increase with retrieval success. To test each of these assumptions, Storm, Bjork, Bjork, & Nestojko (2006) directly manipulated whether retrieval practice was successful or unsuccessful. Participants were asked to study a list of category-exemplar pairs and then engage in retrieval practice. Items in the ‘possible retrieval practice condition’ contained category plus two letter stem cues with the initial letters of exemplars associated with the category (*e.g. fruit:or*). Items in the ‘impossible retrieval practice condition’ consisted of categories with letter stems that failed to match any of the items appropriate to the category (*fruit:wo*). Significant retrieval-induced forgetting was observed in both cases. Importantly, the size of the effect was the same for exemplars associated with categories receiving impossible retrieval practice and those receiving possible retrieval practice. This experiment was recently replicated (Storm & Nestojko, 2010) and has been cited as compelling evidence in favor of the inhibitory account.

### *Interference Dependence*

Retrieval-induced forgetting is also interference-dependent. This means that the degree to which a competing item interferes with a target item during retrieval practice determines the magnitude of retrieval-induced impairment that is observed (Anderson et. al, 2000; Anderson, 2003; Storm, Bjork, & Bjork, 2007). For example, Anderson, Bjork, & Bjork (1994, Experiment 3) found that items of low taxonomic frequency (*e.g., mango, guava*) showed a lesser degree of retrieval-induced impairment at test than items of high taxonomic frequency (*e.g. bananas,*

*oranges*). The authors contended that because items of low taxonomic frequency were weakly associated to the retrieval practice cue (e.g., *fruit*), they were less likely to create competition and trigger the need for inhibitory control. Anderson et. al (2000) demonstrated this property by manipulating the interference demands of the retrieval-practice task. Subjects in the competitive retrieval practice group were given a category and two letter stem during retrieval practice, as is typically done (e.g., *fruit: or*). Participants in the noncompetitive retrieval practice condition were presented with the first two letters of the category name, followed by the complete exemplar (e.g., *fr: orange*). A significant retrieval-induced forgetting effect was found in the competitive retrieval practice condition. However, no effect was observed in the noncompetitive condition. This difference was found despite the presence of retrieval in both conditions and considerable strengthening of retrieval practice items in both conditions. Therefore, when the retrieval task does not require the resolution of interference, little retrieval induced forgetting occurs. It should be noted that Williams & Zacks (2001) attempted to replicate Anderson, Bjork & Bjork's (1994) results and instead found that items of low taxonomic strength suffered from just as much forgetting as items of high taxonomic strength. Critically however, unlike Anderson et al., Williams & Zacks failed to employ a category-plus-letter-stem to adequately control for output interference, making it very difficult to distinguish inhibitory from noninhibitory influences on subsequent forgetting.

Storm et al., (2007) developed a new test of interference dependence by examining how the intent to remember and forget influences the susceptibility of memories to retrieval-induced forgetting. Research on directed forgetting (Anderson & Neely, 1996; Bjork, Bjork & Anderson, 1998) has shown that instructing participants to forget an initially presented list of items can dramatically decrease the proactive interference that would normally be observed owing to that

list's presentation on the recall of a subsequently presented list of items. That is, participants in directed-forgetting experiments are often able to recall significantly more items from a second list after being cued to forget the items from a first list (compared to when they are told to continue remembering the items from the first list). Combining a procedure similar to that of directed forgetting with a new variant of the retrieval practice paradigm, participants were cued either to remember or to forget a list of words prior to receiving retrieval practice. Storm et al. predicted that the intention to remember the initial list of items would make those items more likely to interfere during retrieval practice and therefore more likely to be inhibited. In contrast, the intention to forget the initial list of items, should make those items less likely to interfere during retrieval practice and therefore less likely to be inhibited. Thus, as counterintuitive as it may seem, while the intention to remember may lead one to forget, the intention to forget may lead one to remember. As predicted, items from lists that participants were told to forget did not suffer from retrieval-induced forgetting, while items from lists that participants were told to remember suffered from a considerable amount of retrieval-induced forgetting. These results are consistent with the interference or competition dependent nature of inhibition. That is, if inhibition serves the purpose of reducing the accessibility of competing items that interfere during retrieval, then the need for inhibitory action should depend on the degree to which competing items interfere. Consistent with this hypothesis, whereas items that participants sought to maintain in memory during retrieval practice were inhibited, items that had already been dismissed as irrelevant or to-be-forgotten were not. *Retrieval-induced forgetting and the ability to overcome competition*

While experiments demonstrating that inhibition is competition dependent suggest that competition triggers the need for inhibitory control, such studies fail to test the hypothesis that

resolving this competition facilitates retrieval. One way that researchers have examined this issue is to measure individual differences in retrieval-induced forgetting, to see whether such differences predict the ability to overcome competition on other tasks. If retrieval-induced forgetting is caused by an inhibitory mechanism recruited to overcome interference in memory, individuals who exhibit more retrieval-induced forgetting should be able to overcome interference in other situations as well. Storm & Angello (2010) tested this prediction directly by correlating individual differences in retrieval-induced forgetting with participants' performance on a separate RAT problem solving procedure. While the relationship between retrieval-induced forgetting and creative problem solving may not be clear on the surface, it becomes much more apparent when one considers the nature of the tasks involved. Just as competing or irrelevant items can disrupt successful retrieval of target items in memory, there are other situations in which we are vulnerable to the negative consequences of unwanted information. That is, retrieval is just a single instance in which we suffer the effects of *mental fixation*. Mental fixation occurs when, due to interference from contextually-inappropriate information, we are unable to perform some sort of cognitive task or operation (Smith, 2003). While mental fixation can occur when trying to do any number of cognitive tasks, it has been examined most thoroughly by cognitive psychologists interested in creative problem solving using the Remote Associates Task (Mednick, 1962). In this procedure, participants are shown 3 cue words (e.g., manners, tennis, round) and are asked to generate a target associate that is semantically related to all 3 items (e.g., table). This task is challenging because the strong associates for each cue (e.g., polite, ball, square) bear no relationship to the other cues, and are therefore not viable solutions. Fixation in creative problem solving, like blocking or interference in memory, can be experimentally induced by the introduction of misleading hints and inappropriate answers (Smith &

Blankenship, 1991). By exposing participants to incorrect associates prior to problem solving, Smith & Blankenship (1991) impaired participants' performance on a subsequent problem solving task, presumably because interference from these items exaggerated existing fixation effects. First, susceptibility to retrieval-induced forgetting was measured using the retrieval-practice paradigm (Anderson, Bjork, and Bjork, 1994). Thus, participants studied 48 category-exemplar pairs, then generated new exemplars for half of the categories, and were finally tested on all of the category-exemplar pairs that they initially studied. In a separate task, participants were asked to solve 20 RAT problems. Critically, like Smith & Blankenship (1991) they manipulated the degree to which participants experienced interference from irrelevant information prior to problem solving. In the fixation condition, participants studied a series of interfering cue target responses (e.g., manners-polite, tennis-ball, round-square) before attempting to solve RAT problems. After studying the pairs, participants practiced retrieving the response words given cue-plus-one-letter retrieval cues. Misleading associates were chosen based on measures of forward association strength; only the strongest associates, and thus those most likely to interfere, were selected. In the baseline condition, participants simply solved the RAT problems.

Replicating the pattern of results demonstrated by Smith and Blankenship (1991), Storm and Angello (2010) found that participants in the fixation condition successfully solved significantly fewer RAT problems than participants in the baseline condition. Even more interestingly, individual differences in retrieval-induced forgetting predicted the degree to which participants suffered from fixation when attempting to solve the RAT problems. While participants who exhibited the most retrieval-induced forgetting were able to solve 93% of the problems in the fixation condition that they would have been able to solve in the baseline



condition, participants who exhibited the least amount of retrieval-induced forgetting were only able to solve 47% of the problems in the fixation condition that they would have been able to solve in the baseline condition. Thus, it appears that individual differences in retrieval-induced forgetting reflect, not just one's ability to overcome interference in memory retrieval, but in creative problem solving as well.

Results from this study can be added to the large body of evidence in support of the inhibitory account of retrieval-induced forgetting. Recall that some have suggested that retrieval-induced forgetting can be better explained by blocking or interference alone. Were this indeed the case, one would predict that individuals who exhibit more retrieval-induced forgetting would be *more* susceptible to interference, and should thus perform more poorly on creative problem solving tasks that elicit mental fixation. In contrast, inhibitory theorists assume that individuals who suffer from more retrieval-induced forgetting are better able to overcome interference from irrelevant information, and thus are better at creative problem solving tasks than individuals who are less susceptible to retrieval-induced forgetting. This is in fact what the results show.

Numerous other experiments have revealed a similar pattern of results. Aslan and Bäuml (2011), for instance, investigated the potential relationship between retrieval-induced forgetting and working-memory capacity. If retrieval-induced forgetting were caused by interference alone, then we would expect individuals with greater working-memory capacity to show less retrieval-induced forgetting. However, Aslan and Bäuml found that individuals with greater working-memory capacity suffered from more retrieval-induced forgetting than individuals with less working-memory capacity. Storm and White (2010) were the first to examine retrieval-induced forgetting in populations with attention-deficit/hyperactivity disorder (ADHD). Because this disorder is believed to cause impairment in inhibitory control, making it especially difficult to

overcome interference or distraction from competing information, again differing predictions emerge. If retrieval-induced forgetting is caused by interference, then individuals with ADHD should exhibit more retrieval-induced forgetting than individuals without ADHD. Yet, as predicted by the inhibitory account, individuals with ADHD exhibited significantly less retrieval-induced forgetting than did individuals without ADHD.

While results by Storm and Angello (2010) suggest that inhibition may aid individuals in overcoming fixation and therefore facilitate successful problem solving, their work does not provide direct evidence that this is the case. Were it true that an inhibitory mechanism allows participants to forget fixation-inducing incorrect associates when attempting to solve a problem, we should see evidence of such inhibition on a subsequent memory test. That is, the items causing fixation should become less recallable on a subsequent memory test than items not causing fixation. Storm, Angello, and Bjork (2011) tested this prediction by showing participants a series of cue-target pairs before asking them to solve RAT problems. Half of the studied pairs contained misleading associates for the to-be-solved RAT problems, and the other half were unrelated. As predicted, recall performance on the cued response test was significantly lower for items causing fixation than for unrelated items. In other words, participants were significantly less likely to recall response words associated with cues that had been presented in the problem solving phase than response words associated with cues that had not been presented in the problem-solving phase. Thus, this study provided direct evidence of *problem-solving-induced forgetting*.

Results of Storm, Angello, and Bjork (2011) demonstrated that problem solving causes forgetting. In a second experiment, Storm and colleagues attempted to replicate this finding, and also to determine if solving impossible RAT problems would lead to forgetting. Impossible RAT

problems are those for which the 3 cue words do not share a common associate. Motivations for this experiment were two-fold. First, as there is evidence that retrieval success is not a necessary condition for retrieval-induced forgetting ( Storm, Bjork, Bjork, & Nestojko, 2006), there is reason to expect that likewise, problem-solving success may not be a necessary condition for problem-solving-induced forgetting. Additionally, prior research has shown that increasing the number of retrieval-practice trials can increase the magnitude of retrieval-induced forgetting (Storm, Bjork, & Bjork, 2008). Perhaps forcing participants to spend a longer amount of time attempting to solve a given problem would likewise increase the magnitude of the problem solving-induced forgetting effect. Choosing impossible problems also allowed the authors to manipulate time spent solving the problem – 20 seconds and 60 seconds respectively.

Performance on the final cued response test revealed that participants' ability to recall response words decreased as a function time spent trying to solve the problem. That is, response words associated with the 20 second problems were recalled better than response words associated with the 60 second problems, suggesting that spending more time solving a problem does indeed produce greater forgetting at test. Additionally, the problem solving-induced forgetting effect was significant for problems solved in 20 seconds and for problems solved in 60 seconds. Taken together, these results (a) provide additional evidence that solving a problem can induce forgetting of information that is not relevant to the problem (e.g., problem solving-induced forgetting) and (b) that problem solving success is not a necessary condition for problem solving-induced forgetting.

In summary, forgetting is widely regarded as a nuisance and inherent failure of the memory system, results from countless studies suggest that it is an adaptive and critical function that facilitates successful remembering. By forgetting irrelevant or outdated information, we are

better able to retrieve that which is most relevant to us. This kind of adaptive forgetting is made possible by inhibitory mechanisms recruited to overcome interference from competing information. That is, in the context of memory, retrieval of target items is facilitated by the inhibition and subsequent forgetting of nontarget items. Similarly, when engaging in creative problem solving, inhibition facilitates the generation of viable solutions in the face of interference from nonviable solutions. While more research is necessary, inhibition may have the capacity to facilitate any act of remembering, thinking, or problem solving that relies on the ability to overcome the fixating consequences of interfering information.

#### *The durability of retrieval-induced forgetting*

Another question of interest to those studying retrieval-induced forgetting is whether the impairment observed is temporary or endures across a delay. Researchers subscribing to the inhibitory account generally assume that forgetting owing to inhibition is transient and need not persist beyond a brief retention interval (MacLeod & Hulbert, 2011; MacLeod & Macrae, 2001). This supposition follows because items are presumed to be suppressed for the express purpose of facilitating retrieval of target items. Once associative interference arising from competing items has been eliminated and targets have been successfully retrieved, the mechanism has served its purpose and continued suppression would be counterproductive. Indeed, data from numerous experiments suggests that retrieval-induced forgetting is eliminated when the final test is administered 24 hours after retrieval-practice (Chan, 2009; Carroll et al., 2007; MacLeod & Macrae, 2001; Saunders et al., 2009; Saunders & MacLeod, 2002).

On the other hand, some have found reliable retrieval-induced forgetting at much longer delays (Garcia-Bajos, Migueles, & Anderson, 2009; Migueles & Garcia-Bajos, 2007; Saunders et al., 2009; Storm et al., 2006). Storm et al. (2012) contend however that one limitation of these

studies is that the final delayed test is confounded with an earlier test on the same items. That is, in many of these studies participants are tested initially immediately following retrieval practice, and given another test on the same items 24 hours or 1 week later. Given this repeated test design, it is possible that baseline items that were initially recalled better than unpracticed items from practiced categories are again recalled better on the final retention test, as a consequence of the testing effect (Roediger & Karpicke, 2006b). A second limitation of the aforementioned studies is that they failed to control for output interference by implementing a category-plus-one-letter-stem cued recall test, making final test performance an inadequate assessment of inhibitory-based forgetting.

Storm et al. (2012) attempted to correct for these shortcomings by administering a category-plus-one-letter-stem-cued recall test for half the studied items 5 minutes after retrieval-practice, and the remaining items 1 week after retrieval practice. That is, participants studied 48 category-exemplar pairs, practiced retrieving other exemplars from half the categories, and were given a recall test for half of the studied exemplars at a 5-minute retention interval and the remaining half at a week-long retention interval. A second objective of the experiment was to examine the long-term consequences of restudy on previously forgotten items. Recall that Storm et al. (2008) and Little, Storm & Bjork (2012) found that reexposing participants to untested items as well as control items can eliminate or even reverse retrieval-induced forgetting. While this finding is no doubt a relief to educators concerned about the negative consequences of selective retrieval for nontested information, namely that previously forgotten information can regain accessibility at an accelerated rate, this pattern of results has yet to be demonstrated after a lengthy delay. As predicted, the results revealed significant retrieval-induced forgetting after a

week delay, but the effect was eliminated when participants were reexposed to unpracticed items following retrieval-practice.

Storm et al. caution that although their results indicate that retrieval-induced forgetting can potentially persist for a week or more, this pattern does not imply that such forgetting is permanent or even long-lasting. Furthermore, even in the event of restudy, items subject to retrieval-induced forgetting are still less likely to be retrieved and are therefore less likely to be integrated with new information. Thus, memory traces for items that are frequently inhibited and rarely retrieved may gradually weaken, while items that are frequently in use and are rarely inhibited are strengthened. Thus, like Bäuml and Samenieh (2010; 2012), Storm et al. suggest that the dynamics underlying forgetting and facilitation operate in service of updating memory. That is, old or irrelevant information is cast aside in favor of new and more relevant information. If information continues to be or is again deemed relevant, there are likely to be recurrent relearning opportunities; if not, such information may become increasingly forgotten following the retrieval of competing information.

### **What is the contextual-cuing account?**

As the evidence presented above strongly suggests, interference alone is necessary but not always sufficient to produce retrieval-induced forgetting. The active suppression of competing exemplars is a critical feature of RIF in many cases, and that fact should not be overlooked or underemphasized. In spite of this compelling evidence, recently Jonker, MacLeod, and Seli (2013) proposed a new theoretical account of RIF that also attributes the effect to a noninhibitory mechanism. Jonker and colleagues' alternate account emphasizes the role of context. In this framework, the study and retrieval-practice phases are represented as two disparate contexts. While the study context includes all of the studied items – that is, the Rp+,

Rp-, and Nrp items – the practice context only contains the Rp+ items. Critically, while the Nrp or baseline items are only present in the study context, the Rp- cues are associated with both the study context and the retrieval-practice context. Thus, at test, participants may search the retrieval practice context first which then makes it more difficult to recall items from the study context. The Nrp cues, however, are only associated with the study context, and are therefore very effective at reinstating the initial study context. Thus, Nrp items are better recalled than Rp- items because they benefit from context reinstatement, while Rp- items do not.

### **What is the evidence in favor of the contextual-cuing account?**

In their first experiment, Jonker and colleagues asked participants to study a series of category-exemplar pairs in the initial learning phase, and then to restudy a subset of them prior to the final test. Critically, a mental context change was inserted between the study and restudy phases. In this task, participants were asked to imagine their parents' house and draw a diagram of the layout. Though retrieval-practice after learning reliably produces RIF, as one would expect, restudy does not (Anderson et al., 2000; Bauml, 2002). The authors reasoned however, that perhaps RIF is absent following restudy because restudy and the initial learning episode are represented as one large context, rather than two different contexts. Study and extra study are highly similar, and there is no change to retrieval processing, which has been shown before to elicit a context shift. If indeed study and extra study were represented as one context, then any cue presented during the final test would prompt the retrieval of this one context, where all of the items reside. Therefore, there would be no RIF effect because Rp- and Nrp would benefit equally from context reinstatement. If however, a context shift occurs between study and restudy, and they once again become represented as two disparate contexts, RIF should occur because two distinct contexts would cause participants to reinstate the more recent extra study context,

leading to a lack of a reinstatement benefit for the Rp- items. This is exactly what the authors found.

If the study context were reinstated rather than the extra study context however, the context account predicts that the Rp- items would now benefit from context reinstatement, much like the Nrp items, and no RIF effect would occur. To test this possibility, the authors inserted a reinstatement task immediately prior to the final test. In this task, participants were asked a series of questions that were designed to encourage them to think about the beginning of the experiment and the study phase. For example, “What did you notice when you first entered the room for the experiment?” They also employed the Star Wars theme song at the beginning of the experiment to provide a kind of distinct anchor to signal the beginning of the experiment. As predicted, when participants engaged in this reinstatement task, no RIF occurred.

In experiment 2, the standard RIF paradigm was used. That is, participants first studied category-exemplar pairs, then performed retrieval practice on half of the items from half of the categories, and were later tested on all of the exemplars using category cued word stems. However, during study and during retrieval practice, the items were presented along with different videos. These videos depicted everyday contexts, such as the first-person perspective of walking downstairs or the panoramic view of a kitchen.

The pairs were first studied along with one context video. That is, all items in one category were paired with the same video, such that when fruit – orange appeared, it was presented along with stairs, then later when fruit – orange appeared, it was also paired with stairs. Then, during retrieval practice, the practiced fruit items were paired with a new video, such as a park scene. Therefore, in the study context, fruit was paired with stairs, whereas in retrieval practice, fruit was paired with the park. One of the two videos were used at test as a cue



for that context.

One group of participants received the retrieval practice video, thereby reinstating the practice context, and depriving the Rp- items of context reinstatement benefit. RIF was predicted in this condition. A second group of participants received the study video thereby reinstating the study context, and providing the Rp- items with context reinstatement benefit. Therefore, the context account predicts no RIF in this condition. Once again, this is exactly the pattern revealed by the data: as predicted, RIF occurred when participants were cued to reinstate the study context, but not when they were cued to reinstate the retrieval practice context.

### **What is the evidence against the contextual-cuing account?**

While the data presented above may appear convincing, there have been some failures to replicate these findings. For example, Miguez et al. (2014) followed the standard RIF paradigm, but placed participants in one physical context (A or B) for study and the other for retrieval practice. Then, participants were either tested in the study context (ABA) or the retrieval practice context (ABB) at test. Context A was a small office with white test booklets, a female experimenter, and instructions that were delivered via audio recordings and played through headphones. Context B was a spacious classroom with a male experimenter, orange test booklets, and instructions that were spoken aloud to participants. The contextual-cuing account would predict RIF in the ABB condition and no RIF in the ABA condition – significant RIF however, was observed in both conditions.

In addition to this recent failure to replicate the findings reported by Jonker and colleagues, much of the data present in the extant literature on RIF is at odds with the predictions made by the contextual-cuing account. Several examples are cited below.

### ***No RIF when a forget instruction is interpolated between study & test phase***

Forget instructions induce a mental context change (Sahakyan et al., 2007). Despite this shift between study and retrieval practice, no RIF occurs (Storm, Bjork, and Bjork, 2007: *competition dependence*). Although inconsistent with the contextual-cuing account, this finding is entirely consistent with the inhibitory account in that a forget instruction eliminates the proactive interference caused by previously learned material, therefore circumventing any competition and by association, any need for inhibition.

***No RIF when retrieval practice is performed under divided attention***

The context account predicts greater RIF due to more difficult retrieval and dramatic context shifts are induced by dual task procedures, yet no RIF occurs (Roman et al, 2009). Again, this result is entirely consistent with the inhibitory account. Performing retrieval practice under divided attention, particularly while engaging in a dual task that requires executive control, detracts limited cognitive resources away from the process of inhibition, thereby reducing or eliminating the effect of retrieval-induced forgetting.

***No RIF when negative mood and/or stress are induced prior to retrieval practice***

These manipulations constitute significant emotional/physiological changes that reliably induce context shifts, but still no RIF occurs (Bauml et al, 2007). Like dual tasks that require executive control, stress and/or mood disturbance draws on attentional and inhibitory resources significantly enough to eliminate retrieval-induced forgetting, while also encouraging relational processing, an encoding style demonstrated to promote integration of exemplars, a process which has also been shown to abolish retrieval-induced forgetting.

***Taxonomic frequency effects***

Though both require active search and retrieval, strong categories are susceptible to significantly greater retrieval-induced forgetting than weak categories (Anderson, Bjork, and

Bjork, 1994). This phenomenon is unique to predictions made by the inhibitory account. Strong categories, by nature of the fact that they are highly accessible, intrude perseveratively during retrieval practice and generate a lot of competition. Thus, more inhibition is required to suppress competitors belonging to strong categories than competitors belonging to weak categories.

***Extralist paradigm***

Retrieval-induced forgetting persists even when participants are explicitly told that Rp+ items will not be tested, thus deactivating the retrieval practice context (Bauml, 2002).

## CHAPTER 2

### **Mental Context Change Between Study and Restudy is Not Sufficient to Cause Forgetting**

Forgetting, though often regarded as a frustrating or maladaptive failure of memory, is an adaptive process that is essential for successful remembering. The task of recalling relevant information that is pertinent in the present would be difficult or impossible, for example, without some way of setting aside outdated or irrelevant information. One mechanism that has been proposed to underlie such adaptive forgetting is inhibition (e.g., Anderson, 2003; Bjork, 1989). The basic idea is that retrieving some target information from memory requires not only selecting that information, but also selecting against competing information—that is, other information associated with the same cue or cues, which presumably becomes activated and competes for access. This inhibition has been argued to explain a rather unintuitive empirical observation—that retrieving some items from memory causes the forgetting of related items, a phenomenon known as retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994).

Retrieval-induced forgetting is a fairly robust phenomenon. It has been observed with a variety of materials and in a number of applied contexts (for an extensive review of retrieval-induced forgetting in context, see Storm et al., 2015). Studies of retrieval-induced forgetting typically employ a three-phase retrieval-practice paradigm. During study, participants are presented with a series of category-exemplar pairs drawn from several categories (e.g., *fruits-orange*, *drinks-rum*, *professions-nurse*). Subsequently, during retrieval practice, participants are asked to repeatedly retrieve half of the items from half of the categories in response to selective retrieval cues (e.g., *fruits: or \_\_\_*, *drinks: ru \_\_\_*). After a brief delay, participants are tested on all of the items, often via category-plus-one-letter-stem retrieval cues (e.g., *fruits: o \_\_\_*, *drinks: r \_\_\_*). The retrieval-practice paradigm produces three types of items: *Rp+* items refer to

<sup>1</sup>practiced items from practiced categories; *Rp-* items refer to unpracticed items from practiced categories; *Nrp* items refer to items from nonpracticed categories.

Not surprisingly, *Rp+* items are recalled better at test than *Rp-* items, a finding that is consistent with research on the testing effect (see, e.g., Bjork, 1975; Roediger & Karpicke, 2006). Interestingly, recall for *Rp-* items is impaired relative to *Nrp* items. This decrement in recall for *Rp-* items relative to *Nrp* items reflects the phenomenon of retrieval-induced forgetting. Critically, the term retrieval-induced forgetting refers to an empirical effect (that recalling a subset of information impairs subsequent recall for related information)—it does not stipulate the mechanism presumed to underlie the effect.

The theoretical explanations that have been put forth to explain retrieval-induced forgetting can be broadly grouped into *inhibition-based theories* and *competition-based theories*. For example, whereas inhibition-based theories assume that an active control mechanism is recruited during retrieval practice to suppress the accessibility of competing information in order to facilitate the retrieval of target information, and that it is this inhibition that renders *Rp-* items less recallable than *Nrp* items (Anderson, 2003; Anderson et al., 1994; Storm & Levy, 2012), competition-based theories assume that retrieval-induced forgetting can be explained completely by strength-based competition at test and other non-inhibitory mechanisms (Raaijmakers & Jakab, 2013; Verde, 2012). For example, the retrieval of a subset of items may strengthen those items and cause them to interfere with, or block the recall of, weaker items, thus preventing them

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<sup>1</sup> *Chapter 2 is taken verbatim from the following article:*

Buchli, D.R., Storm, B.C., & Bjork, R.A. (under review). Mental context change between study and restudy is not sufficient to cause forgetting. *Quarterly Journal of Experimental Psychology*.

from becoming accessible at test. Although strength-based interference likely does play some role in observations of retrieval-induced forgetting, there is now substantial evidence implicating a role for inhibition as well (for recent qualitative and quantitative reviews, see Storm & Levy, 2012, and Murayama, Miyatsu, Buchli, & Storm, 2014, respectively).

Recently, an intriguing new account of retrieval-induced forgetting has been put forth. This account, referred to as the context-based account (Jonker, Seli, & MacLeod, 2013), contends that retrieval-induced forgetting is a consequence of inappropriate contextual cuing at test. The study and retrieval-practice phases in the retrieval-practice paradigm are assumed to represent two disparate contexts, and while items associated with practiced cues (Rp+ and Rp- items) are associated with both the study context and the retrieval-practice context, items associated to non-practiced cues (Nrp items) are only associated with the study context. Thus, when cued with a practiced category cue at final test, participants may inappropriately search for Rp- items in the retrieval-practice context while not doing so for Nrp items, making it relatively more difficult to access Rp- items than Nrp items and thus leading to retrieval-induced forgetting. Said differently, because the categories associated with Rp- items were practiced during retrieval practice, participants may search the retrieval-practice context for Rp- items at test, rendering those items less accessible not because they were inhibited, but because participants were not able or inclined to effectively target the appropriate context in their attempt to recall them. Nrp items, on the other hand, would not suffer this type of inappropriate contextual cuing because items in the Nrp category were only encountered in the study context, making it more likely that subjects would reinstate the study context when attempting to recall those items.

Jonker and colleagues (2013) conducted several experiments to garner evidence in

support of the context-based account. In one experiment, participants were asked to study a series of category-exemplar pairs in the initial study phase, and then to restudy a subset of those pairs prior to final test. Although this sort of extra-study practice has typically not been shown to cause the forgetting of related non-practiced items (Anderson et al., 2000; Bäuml, 2002; Jonker et al., Experiment 1)—a result often cited as evidence against competition-based accounts and in support of inhibitory-based accounts (Anderson, 2003; Storm & Levy, 2012)—Jonker et al. argued that the lack of forgetting might be attributed to the fact that restudy practice typically fails to induce a change in context between study and practice. That is, the initial study phase and the restudy phase may be represented as one large context, presumably because retrieval practice induces a shift in context owing to the change in task demands and processing between study and retrieval, whereas restudy does not. Jonker et al. predicted that by implementing a context shift between study and restudy—leading, in their view, to the study and restudy phases becoming represented as two separate contexts—non-practiced items associated with restudied categories would suffer forgetting, which is exactly what the authors found. Specifically, by inserting a mental context change manipulation between study and restudy (i.e., asking participants to imagine their parents' house and draw a diagram of the layout), restudy practice caused non-practiced items from practiced categories to suffer significant forgetting.

In a follow-up experiment (Experiment 2b), Jonker et al. examined whether context reinstatement might eliminate the effect of forgetting caused by extra study. Specifically, the authors inserted a reinstatement task immediately prior to the final test. In this task, participants were asked a series of questions that were designed to encourage them to think about the study phase at the beginning of the experiment. For example, “What did you notice when you first entered the room for the experiment?” They also employed the Star Wars theme song at the

beginning of the experiment to provide a kind of distinct anchor to signal the beginning of the experiment. As predicted, when participants engaged in this reinstatement task, no retrieval-induced forgetting was observed, presumably because participants were now able to effectively target the study phase at test when attempting to retrieve Rp- items, thus reducing the costs associated with inappropriate contextual cuing.

In their third experiment, Jonker et al. (2013) employed the standard retrieval-practice paradigm in which participants first studied category-exemplar pairs and then performed retrieval practice on half of the items from half of the categories. However, during study and retrieval practice, the items were presented along with videos depicting everyday contexts, such as the first-person perspective of walking downstairs or a panoramic view of a kitchen. The pairs were first studied along with one context video. That is, all items in one category were paired with the same video. Then, during retrieval practice, the practiced cues were paired with a new video. At test, one of the two videos was provided. Presumably, when participants received the retrieval-practice video, they would be likely to search the retrieval-practice context. When participants received the study video, however, they would be likely to search the study phase, thus reinstating the study context and reducing the effects of inappropriate contextual cuing. In support of this assumption, and of the context-based account, retrieval-induced forgetting was observed in the former condition where the retrieval-practice context was reinstated, but not in the latter condition where the study context was reinstated.

### **Logic of the Present Studies**

The findings of Jonker et al. (2013) suggest that context, and particularly the contextual cues participants sample at test, play a critical role in determining the occurrence of restudy-



induced forgetting and retrieval-induced forgetting. In the present research, we sought to replicate and extend one of the critical findings observed by Jonker et al.—specifically, that inducing a change in context between study and extra study practice is sufficient to cause non-practiced items from practiced categories to be forgotten. In addition to replicating this finding, we sought to extend it by examining whether the magnitude of the forgetting effect would be influenced by the magnitude of the contextual shift between study and restudy practice.

To investigate this possibility, we borrowed two context manipulations employed by Delaney, Sahakyan, Kelley, and Zimmerman (2010). In one manipulation—which we adapted for Experiment 1—participants were asked to imagine either visiting their family within their home country (near-imagination task) or going on a vacation outside their home country (far-imagination task). In the other manipulation—which we adapted for Experiments 2 and 3, and which was used by Jonker and colleagues—participants were asked to either imagine the layout of their own home (near-imagination) or of their parents’ home (far-imagination). Delaney et al. found that the far-imagination tasks disrupted memory performance for a previously studied word list to a greater extent than the near-imagination task, presumably because the far-imagination tasks led to a stronger shift in context and thus a reduced ability of participants to reinstate the original study context at test. Based on these results, in the present context, one might expect that separating the study and restudy practice phases with a far-imagination task would lead to a larger forgetting effect than separating them with a near-imagination task. On the other hand, any form of context shift may be sufficient for non-practiced items from practiced categories to suffer forgetting, in which case the near and far imagination tasks may be equally effective in causing forgetting.

## Experiments 1 and 2

In summary, the aims of the first two experiments were twofold: (1) to replicate the finding observed by Jonker et al. (2013) that inserting a context change manipulation between study and restudy practice results in the forgetting of non-practiced items from practiced categories, and (2) to determine if the magnitude of the context change manipulation dictates the degree that such forgetting is observed. To investigate these issues, four between-subject conditions were employed in both Experiments 1 and 2: a typical retrieval-practice group, a restudy group without context change, a restudy group with near-imagination context change, and a restudy group with far-imagination context change. Based on Jonker et al.'s context account, the restudy groups without context change should fail to exhibit forgetting, whereas the retrieval-practice groups and the restudy groups with context change should exhibit significant forgetting. Moreover, based on the results of Delaney et al. (2010), we endeavored to see if the magnitude of the context shift determines the degree to which participants become prompted to search the inappropriate context at test. If it does, then participants in the far-context-change groups should exhibit greater levels of forgetting than participants in the near-context-change groups.

### Method

**Participants and design.** In total, 480 (240 in experiment 1 and 240 in experiment 2) students from the University of California, Los Angeles (UCLA) participated for credit in an introductory psychology course. Retrieval-Practice Status (Nrp vs. Rp- vs. Rp+) was manipulated within subjects. Experimental condition (no-context-change restudy vs. no-context-

change retrieval practice vs. near-context-change restudy vs. far-context-change restudy) was manipulated between subjects.

**Materials.** Eight categories were selected, each consisting of six high frequency exemplars for a total of 48 category-exemplar pairs (taken directly from Anderson et al., 1994). The pairs were counterbalanced such that each item served equally often as an Rp+ item, Rp- item, and Nrp item.

**Procedure.** Participants were randomly assigned to one of the four conditions described below.

***No-Context-Change Restudy.*** This condition was identical for participants in Experiments 1 and 2. During the initial study phase, 48 exemplar pairs were presented via computer at a rate of one pair every 4 seconds. Order was set randomly, with the constraint that no two consecutive pairs could be shown from the same category. Immediately following the completion of the study phase, participants were prompted to restudy half of the exemplars from half of the categories. There were three rounds of practice such that the 12 restudied pairs were presented three times each for 7 seconds, resulting in a total of 36 restudy trials. After the restudy phase, a category-plus-one-letter-stem cued recall test was administered in which participants were given 6 seconds to recall each exemplar. To control for output interference, the final test was divided into two test blocks, with Rp- items and half of the Nrp items (Nrp- items) tested in the first block, and Rp+ items and the other half of the Nrp items (Nrp+ items) tested in the second block. The particular set of Nrp items serving as Nrp- and Nrp+ items was counterbalanced across participants.

***Near-context-change restudy.*** This condition was the same as the no-context-change restudy condition except for one important difference. Specifically, in experiment 1, between the

study and restudy phases, participants were asked to describe a vacation within the USA that took place within the last three years. A recruitment procedure was implemented, such that participants were selected only if they had taken a vacation outside of their home state in the past 3 years. Participants were prompted to describe what they saw, felt, smelled, and experienced with all of their senses during the vacation. In experiment 2, participants were asked to write a detailed description of the interior and exterior of their home as they mentally walked through each of the rooms. They were given one minute to complete this task. All participants completed the experiment in a single room, accompanied by an experimenter to ensure that they appropriately complied with all instructions.

***Far-context-change restudy.*** This condition was also the same as the no-context-change restudy condition except for what participants did between the study phase and the restudy phase. In experiment 1 participants were asked to describe a vacation outside of the USA that took place within the last 3 years. Once again, only individuals who met this requirement were allowed to participate. International exchange students were also excluded. In experiment 2, participants were asked to provide a detailed description of the exterior and interior of their *parents'* home as they mentally walked through each room. All participants were accompanied by an experimenter to ensure that they complied with instructions.

***No-context-change retrieval practice.*** This condition, which was the same in experiments 1 and 2, was identical to the no-context-change restudy condition except that participants were given retrieval practice for half of the exemplars from half of the categories instead of restudy practice. Specifically, as typically employed in studies of retrieval-induced forgetting, participants were given category-plus-two-letter stem cues for 7 s each (e.g., fruit- or \_\_\_\_ ) and asked to recall the appropriate exemplar from the appropriate studied category. As

in the restudy conditions, there were three blocks of practice, with participants attempting to retrieve each of the 12 to-be-practiced exemplars three times each, resulting in a total of 36 trials.

For the sake of simplicity, and to facilitate the readers' comprehension of our results, we will refer to practiced and non-practiced items from practiced categories as Rp+ and Rp- items, respectively, regardless of the nature of the practice that participants performed.

## Results

**Retrieval-Practice Performance.** Participants recalled the appropriate exemplar on 89% and 90% of the retrieval-practice trials in experiment 1 and 2, respectively.

**Final Recall Performance for Practiced Items and Baseline Controls.** As can be seen in Figure 1, a significant facilitation effect was observed in all four conditions in experiment 1 and 2, such that Rp+ items were recalled significantly better than were Nrp+ items (all  $p$  values < .001).

**Final Recall Performance for Non-practiced Items from Practiced Categories and Baseline Controls.** Recall performance in experiments 1 and 2 for Rp- and Nrp- items on the final test is shown as a function of condition in Figure 1 and was analyzed using a 2 (Rp- vs. Nrp-) X 4 (Near vs. Far vs. Retrieval Practice vs. Restudy) mixed Analysis of Variance (ANOVA). In experiment 1, although the main effects of retrieval-practice status,  $F(1, 236) = .00$ ,  $MSE = .02$ ,  $p = .97$ , and context-change condition,  $F(1, 236) = .03$ ,  $MSE = .05$ ,  $p = .61$ , were not significant, a significant interaction was observed,  $F(3, 236) = 2.71$ ,  $MSE = .02$ ,  $p < .05$ . In experiment 2, the effects of retrieval-practice status,  $F(1, 236) = 19.01$ ,  $MSE = .31$ ,  $p = .01$  and context change condition,  $F(1, 236) = 4.18$ ,  $MSE = .18$ ,  $p = .01$ , were significant, as was the interaction,  $F(3, 236) = 63.98$ ,  $MSE = 1.06$ ,  $p = .01$ .

As can be seen in Figure 1, in experiment 1, forgetting was observed in the retrieval-practice condition, with Rp- items ( $M = .66$ ,  $SE = .02$ ) recalled significantly less well than Nrp items ( $M = .72$ ,  $SE = .02$ ) items,  $t(59) = 2.00$ ,  $p < .05$ . The same pattern was observed in experiment 2 (Nrp:  $M = .71$ ,  $SE = .02$ ; Rp-:  $M = .64$ ,  $SE = .02$ ),  $t(59) = 2.78$ ,  $p = .01$ . These findings replicate the standard effect of retrieval-induced forgetting. Contrary to the results of Jonker et al. (2013), however, no evidence of forgetting was observed in any of the restudy conditions. Specifically, in experiment 1, Rp- items were not recalled differently than Nrp items in the no-context-change condition (Rp- items:  $M = .70$ ,  $SE = .02$ ; Nrp items:  $M = .66$ ,  $SE = .02$ ),  $t(59) = 1.57$ ,  $p = .12$ , the near-context-change condition (Rp- items:  $M = .65$ ,  $SE = .02$ ; Nrp items:  $M = .66$ ,  $SE = .02$ ),  $t(59) = .31$ ,  $p = .76$ , or the far-context-change condition (Rp- items:  $M = .68$ ,  $SE = .02$ ; Nrp items:  $M = .66$ ,  $SE = .02$ ),  $t(59) = .91$ ,  $p = .37$ . Again, the same pattern was observed in experiment 2, such that Nrp items were not recalled differently than Rp- items in the no-context-change condition (Rp- items:  $M = .69$ ,  $SE = .03$ ; Nrp items:  $M = .68$ ,  $SE = .02$ ),  $t(59) = .98$ ,  $p = .33$ , the near-context-change condition (Rp- items:  $M = .67$ ,  $SE = .02$ ; Nrp items:  $M = .67$ ,  $SE = .02$ ),  $t(59) = .28$ ,  $p = .78$ , or the far-context-change condition (Rp- items:  $M = .68$ ,  $SE = .02$ ; Nrp items:  $M = .70$ ,  $SE = .02$ ),  $t(59) = .91$ ,  $p = .40$ .

Two 2 (Nrp vs. Rp-) X 3 (No-Context-Change vs. Near-Context-Change vs. Far-Context-Change) ANOVAs examining the three restudy conditions failed to reveal a significant interaction in experiment 1,  $F(1, 178) = 1.03$ ,  $MSE = .02$ ,  $p = .36$ , or experiment 2  $F(1,178) = .75$ ,  $MSE = .02$ ,  $p = .47$ , thus confirming that rates of forgetting did not differ significantly between the three restudy conditions.

One advantage to our design, compared to that of Jonker et al. (2013), is that we measured the consequences of retrieval practice and restudy within the same experiment, thereby

allowing us to compare rates of forgetting in the two conditions directly. First, we examined whether retrieval practice elicited a greater forgetting effect than restudy without context change. A 2 (Nrp vs. Rp-) X 2 (Retrieval Practice vs. No-Context-Change Restudy) ANOVA revealed a significant interaction such that the forgetting effect was significantly larger in the retrieval-practice condition than in the no-context-change restudy condition (experiment 1:  $F(1, 118) = 6.39$ ,  $MSE = .02$ ,  $p = .01$ ; experiment 2:  $F(1,118) = 7.24$ ,  $MSE = .02$ ,  $p = .01$ ). These results replicate the typical finding of retrieval-specificity and strength-independence that retrieval practice causes more forgetting than restudy practice (see e.g., Murayama et al., 2014).

Next, we examined whether retrieval practice caused significantly more forgetting than restudy even when restudy was accompanied by a context-change manipulation between study and restudy. For this analysis, we combined the near- and far-context-change conditions in each experiment to create overall context-change conditions. Two 2 (Nrp vs. Rp-) X 2 (Retrieval Practice vs. Context-Change Restudy) ANOVAs revealed significant interactions in both experiments, such that the forgetting effect observed in the retrieval-practice condition was significantly larger than that observed in the context-change condition (Experiment 1:  $F(1, 178) = 4.02$ ,  $MSE = .02$ ,  $p < .05$ ; Experiment 2:  $F(1,178) = 4.60$ ,  $MSE = .02$ ,  $p = .03$ ). Thus, contrary to the predictions of the context account, restudy with context change did not lead to as much forgetting as retrieval practice. Note that the interaction was also significant when we compared the retrieval-practice condition directly with the far-context-change condition (experiment 1:  $F(1, 118) = 4.48$ ,  $MSE = .02$ ,  $p = .04$ ; experiment 2:  $F(1, 118) = 6.65$ ,  $MSE = .02$ ,  $p = .01$ ).

### **Experiment 3**

Experiments 1 and 2 attempted to extend Jonker et al.'s finding that an effect like retrieval-induced forgetting can be observed following restudy practice as long as such practice

is accompanied by a mental-context change. Across both experiments, significant forgetting was observed in the standard retrieval-practice condition, but not in any of the restudy conditions. These findings are inconsistent with the predictions of the context account, and suggest that a mental-context change between study and restudy practice is not sufficient to cause forgetting.

There are a number of small differences between the procedure we employed and that employed by Jonker and colleagues that could potentially account for the discrepancy in the results. For instance, Jonker et al. (2013) allotted 5 seconds for study and 10 seconds for restudy or retrieval practice, while we allotted 4 and 7 seconds respectively. Jonker and colleagues asked participants to study 6 categories comprised of 8 items each, while we used 8 categories comprised of 6 items each. Furthermore, while Jonker et al. (2013) asked participants to include a sketch of the layout of the home they were describing during the context change manipulation, we asked participants to only write descriptions of the home. Previous research has suggested that producing sketches can affect processes of retrieval and context establishment (e.g., Dando et al., 2009), so it seems possible that omitting this component contributed to the null effect of context change. To rule out this possibility, a third experiment was conducted, in which the exact procedure adopted by Jonker and colleagues was carried out.

## **Method**

**Participants and design.** A total of 296 UCLA students participated for credit in an introductory psychology course. Retrieval-Practice Status (Nrp vs. Rp- vs. Rp+) was manipulated within subjects. Experimental condition (no-context-change restudy vs. no-context-change retrieval practice vs. near-context-change restudy vs. far-context-change restudy) was manipulated between subjects.



**Materials.** Six categories were selected, each consisting of eight high frequency exemplars for a total of 48 category-exemplar pairs (taken directly from Anderson et al., 1994). The pairs were counterbalanced such that each item served equally often as an Rp+ item, Rp- item, and Nrp item.

**Procedure.** Participants were randomly assigned to one of the four conditions described below. All participants completed the experiment in a single room, accompanied by an experimenter to ensure that they appropriately complied with all instructions.

***No-Context-Change Restudy.*** This condition was identical to that implemented in Experiments 1 and 2, except that during the initial study phase, 48 exemplar pairs were presented via computer at a rate of one pair every 5 seconds. Once again, order was set randomly, with the constraint that no two consecutive pairs could be shown from the same category. Immediately following the completion of the study phase, participants were prompted to restudy half of the exemplars from half of the categories. Again, there were three rounds of practice such that the 12 restudied pairs were presented three times, but they were now presented for 10 seconds, resulting in a total of 36 restudy trials. After the restudy phase, a category-plus-one-letter-stem cued recall test was administered in which participants were given 6 seconds to recall each exemplar.

***Near-context-change restudy.*** This condition was the same as it was for Experiment 2, except that participants were asked to sketch the layout of their home as they mentally walked through each of the rooms. Participants were given one minute to complete this task.

***Far-context-change restudy.*** This condition was identical to that of Experiment 2, except that participants were asked to sketch the layout of their parents' home as they mentally walked through each of the rooms. Participants were given one minute to complete this task.

*No-context-change retrieval practice.* This condition was identical to that implemented in Experiments 1 and 2, except that as participants attempted to retrieve each of the 12 to-be-practiced exemplars 3 times, each category-plus-two-letter stem cue was presented for 10 seconds.

## Results

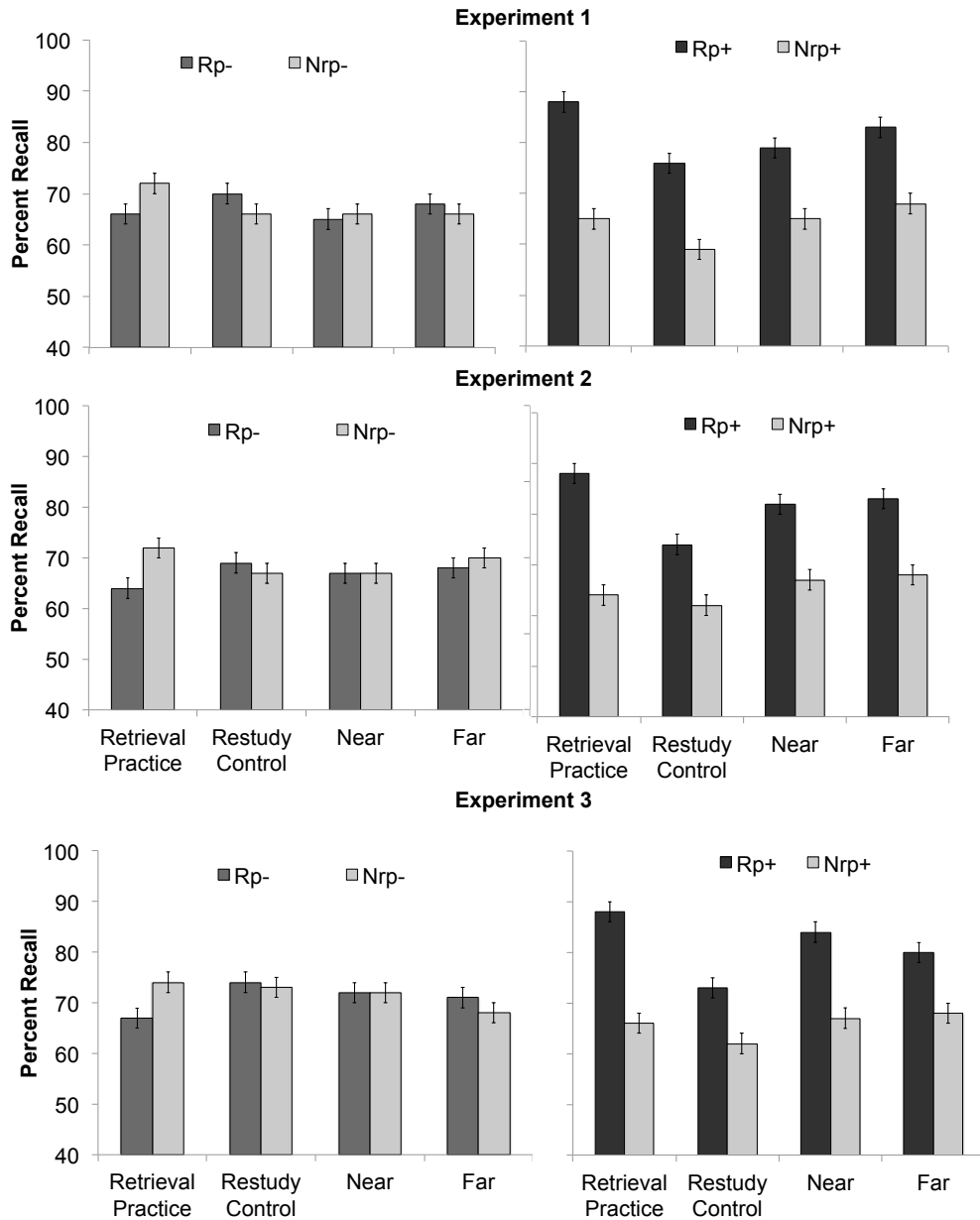
**Retrieval-Practice Performance.** Participants recalled the appropriate exemplar on 89% of the retrieval-practice trials.

**Final Recall Performance for Practiced Items and Baseline Controls.** As can be seen in Figure 1, a significant facilitation effect was observed in all four conditions, such that Rp+ items were recalled significantly better than were Nrp+ items (all  $p$  values  $< .001$ ).

**Final Recall Performance for Non-practiced Items from Practiced Categories and Baseline Controls.** Recall performance in for Rp- and Nrp- items on the final test is shown as a function of condition in Figure 1 and was analyzed using a 2 (Rp- vs. Nrp-) X 4 (Near vs. Far vs. Retrieval Practice vs. Restudy) mixed Analysis of Variance (ANOVA). Although the main effects of retrieval-practice status,  $F(1, 292) = .40$ ,  $MSE = .02$ ,  $p = .53$ , and context-change condition,  $F(1, 292) = .14$ ,  $MSE = .06$ ,  $p = .93$ , were not significant, a significant interaction was observed,  $F(3, 292) = 4.52$ ,  $MSE = .02$ ,  $p < .05$ .

As can be seen in Figure 1, forgetting was observed in the retrieval-practice condition, with Rp- items ( $M = .67$ ,  $SE = .02$ ) recalled significantly less well than Nrp items ( $M = .73$ ,  $SE = .02$ ) items,  $t(73) = 2.97$ ,  $p < .05$ . Once again, this finding replicates the standard effect of retrieval-induced forgetting. As was observed in experiment 1 and 2, once again no evidence of forgetting was found in any of the restudy conditions. Specifically, Rp- items were not recalled

differently than Nrp items in the no-context-change condition (Rp- items:  $M = .73$ ,  $SE = .02$ ; Nrp items:  $M = .71$ ,  $SE = .02$ ),  $t(73) = -1.31$ ,  $p = .19$ , the near-context-change condition (Rp- items:  $M = .72$ ,  $SE = .02$ ; Nrp items:  $M = .69$ ,  $SE = .02$ ),  $t(73) = -1.22$ ,  $p = .23$ , or the far-context-change condition (Rp- items:  $M = .73$ ,  $SE = .02$ ; Nrp items:  $M = .69$ ,  $SE = .02$ ),  $t(73) = -1.59$ ,  $p = .12$ .



*Figure 1.* Recall performance on the final test as a function of retrieval-practice status and experimental condition.

A 2 (Nrp vs. Rp-) X 3 (No-Context-Change vs. Near-Context-Change vs. Far-Context-Change) ANOVA examining the three restudy conditions failed to reveal a significant interaction,  $F(1, 220) = <.1$ ,  $MSE = .02$ ,  $p = .99$ , thus confirming once again that rates of forgetting did not differ significantly between the three restudy conditions.

Once again, we examined whether retrieval practice elicited a greater forgetting effect than restudy without context change. A 2 (Nrp vs. Rp-) X 2 (Retrieval Practice vs. No-Context-Change Restudy) ANOVA revealed a significant interaction such that the forgetting effect was significantly larger in the retrieval-practice condition than in the no-context-change restudy condition,  $F(1, 146) = 8.84$ ,  $MSE = .02$ ,  $p = .01$ . These results replicate the typical finding of retrieval-specificity and strength-independence that retrieval practice causes more forgetting than restudy practice.

Next, we examined whether retrieval practice caused significantly more forgetting than restudy even when restudy was accompanied by a context-change manipulation between study and restudy. For this analysis, we combined the near- and far-context-change conditions in each experiment to create overall context-change conditions. The 2 (Nrp vs. Rp-) X 2 (Retrieval Practice vs. Context-Change Restudy) ANOVA revealed a significant interaction, such that the forgetting effect observed in the retrieval-practice condition was significantly larger than that observed in the context-change condition  $F(1, 220) = 12.55$ ,  $MSE = .02$ ,  $p > .01$ . Thus, once again, contrary to the predictions of the context account, restudy with context change did not lead to as much forgetting as retrieval practice. Note that the interaction was also significant when we compared the retrieval-practice condition directly with the far-context-change condition  $F(1, 146) = 10.50$ ,  $MSE = .02$ ,  $p < .01$ ).

## General Discussion

The context account clearly predicts that forgetting should have emerged in the context-change restudy conditions, and possibly to a greater extent in the far condition than the near condition. Across three experiments and a total of 776 subjects, however, significant forgetting was only observed in the retrieval-practice condition. These results are difficult to reconcile with the core tenants of the context account of retrieval-induced forgetting. If it was the change in context induced by retrieval practice that was responsible for Rp- items becoming less recallable than Nrp items in the retrieval-practice condition, then such an effect should have also been observed in the restudy condition when a change in context was induced via experimental manipulation.

These results are consistent, however, with predictions of the inhibitory account of retrieval-induced forgetting (i.e., strength independence and retrieval specificity). That is, one line of evidence that has provided compelling support for the inhibitory account is that retrieval-induced forgetting is often only observed when information is actively retrieved from memory in the face of competition from related contextually-inappropriate information (Anderson, 2003; Murayama et al., 2014; Storm & Levy, 2012). Restudy practice would not be expected to produce forgetting, even if preceded by a contextual shift, because there would have been no need to inhibit the non-practiced items from the restudied categories. The present results thus reaffirm evidence of strength independence and retrieval specificity, and suggest that such effects cannot be explained, at least completely, by the context-account of retrieval-induced forgetting.

It is somewhat unclear why our results differ so strikingly from those of Jonker and colleagues. That is, why did Jonker et al. observe a significant forgetting effect following

restudy accompanied by mental-context change, whereas we did not? One possibility is that their finding reflected a false positive. Indeed, they observed a small to medium effect size ( $d = .40$ ) with a sample of only 30 participants. In comparison, collapsing across all of the restudy-plus-context change conditions of the three experiments reported here, our sample consisted of 388 participants. Even when we combined across all of these participants, however, we still failed to observe any evidence of forgetting (Rp- items:  $M = .69$ ,  $SE = .01$ ; Nrp items:  $M = .68$ ,  $SE = .01$ ),  $t(387) = -1.165$ ,  $p = .25$ ,  $d = .05$ . A power analysis based on the effect size observed by Jonker and colleagues suggests that a sample of this size should have been more than sufficient to observe an effect (power = .98). Thus, despite having considerably more power and participants than Jonker and colleagues, and even when we followed their exact procedure down to the smallest detail, we failed to observe a significant effect of forgetting in any of the restudy conditions.

Although the present results may seem surprising in light of Jonker and colleagues' results, they are consistent with other recent work that has examined the role of context in retrieval-induced forgetting. For example, Miguez, Mash, Polack, and Miller (2014) followed the standard retrieval-practice paradigm, but placed participants in one physical context (A or B) for study and the other for retrieval practice. Then, participants were either tested in the study context (ABA) or retrieval practice context (ABB) at test. Context A was a small office with white test booklets, a female experimenter, and instructions that were delivered via audio recordings and played through headphones. Context B was a spacious classroom with a male experimenter, orange test booklets, and instructions that were spoken aloud to participants. Presumably, the contextual-cuing account predicts that retrieval-induced forgetting should have

been observed in the ABB condition, but not in the ABA condition. To the contrary, however, significant retrieval-induced forgetting was observed in both conditions.

In addition to this recent failure to replicate the findings reported by Jonker and colleagues, much of the data present in the extant literature is at odds with the predictions made by the contextual-cuing account. For example, when a forget instruction is interpolated between study and retrieval-practice, retrieval-induced forgetting is not observed (Storm, Bjork, & Bjork, 2007). Forget instructions have been shown to reliably induce a change in mental context (Sahakyan and Kelley, 2002), and thus the contextual-cuing account should predict substantial retrieval-induced forgetting; the results however, suggest otherwise. Similarly, retrieval-induced forgetting has been found to be reduced or eliminated when a negative mood or stress is induced prior to retrieval practice (e.g., Bäuml & Kuhbander, 2007; Koessler, Engler, Riether, & Kissler, 2009). Both of these manipulations should have led to significant changes in internal context, yet no retrieval-induced forgetting was observed. Moreover, retrieval-induced forgetting has also been shown to be eliminated when participants perform retrieval practice under divided attention (Román, Soriano, Gómez-Ariza, & Bajo, 2009). The contextual-cuing account contends that retrieval practice causes forgetting, whereas restudy does not, because the more difficult retrieval task leads to a shift in context. Presumably, combining the retrieval-practice task with a concurrent updating task should have, if anything, enhanced the shift in context, yet once again no forgetting was observed. Taken together, these and many other findings, combined with results of the current study, suggest that inserting a mental context change between study and restudy is not sufficient to produce retrieval-induced forgetting.



## CHAPTER 3

### **Reinstatement of the Study Context Fails to Eliminate Retrieval-Induced Forgetting**

If asked to describe the relationship between remembering and forgetting, most people would assume that they are opposing processes. That is, to remember is to avoid forgetting. However, in reality, the connection between remembering and forgetting is decidedly more complex than that. For instance, it is often necessary to decrease the accessibility of old, or irrelevant information if it interferes with the successful retrieval of newer, relevant information. Hence, forgetting can serve as an updating mechanism that keeps important information accessible, while selecting against related, extraneous information. One very illustrative example of such forgetting is the phenomenon of retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994).

In experiments investigating such retrieval-induced forgetting (RIF), participants study a series of category-exemplar pairs drawn from a number of different categories (e.g., *fruit\_orange, trees\_dogwood, drinks\_vodka...*). In the subsequent retrieval practice phase, participants retrieve half of the exemplars from half of the categories in response to cues such as *fruit: or \_\_\_*, and are then tested on all of the items from each of the studied categories. Not surprisingly, items that receive retrieval practice (Rp+ items) are recalled better at test than nonpracticed items from the same categories (Rp- items). Interestingly however, relative to control items from unpracticed categories (Nrp items), recall for Rp- items is impaired.

One of the most prominent theories put forth to explain the causal mechanism that underlies RIF is the *inhibitory account*. In this framework, inhibition is recruited during the retrieval practice phase in an effort to decrease the accessibility of related, nontarget items and in turn facilitate the successful retrieval of target items. While there is a lot of evidence in support

of the inhibitory account (Murayama et al., 2014; Storm, Bjork, & Bjork, 2007; Storm et al, 2006; Storm et al., 2009), some have argued that RIF could also occur in the absence of inhibition (Raaijmakers & Jakab, 2013; Verde, 2012).<sup>2</sup>

Recently, Jonker, MacLeod, & Seli (2013) proposed a noninhibitory theory that emphasizes the role of context. In this framework, the study and retrieval-practice phases are represented as two disparate contexts. While the study context includes all of the studied items – that is, the Rp+, Rp-, and Nrp items – the practice context only contains the Rp+ items. Critically, while the Nrp or baseline items are only present in the study context, the Rp- cues are associated with both the study context and the retrieval-practice context. Thus, at test, participants may search the retrieval practice context first which then makes it more difficult to recall items from the study context. The Nrp cues, however, are only associated with the study context, and are therefore very effective at reinstating the initial study context.

Jonker and colleagues (2013) conducted a series of experiments designed to test the core tenants of their theory. In one experiment, participants studied several category-exemplar pairs in the initial learning phase, and then were asked to study a subset of those pairs again before the final test. Typically extra-study practice fails to elicit forgetting of related, nontarget pairs (Anderson, Bjork, & Bjork, 2000; Bauml, 2002; Jonker, MacLeod, and Seli, 2013, Experiment 1) however Jonker et al. attributed the absence of such forgetting to the fact that study proceeded by more study does not produce a discriminable change in context in the way that study proceeded by retrieval practice does. The crux behind this critical difference is that presumably, the initial study phase and the restudy phase are represented as one large context. In contrast,

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<sup>2</sup>*Chapter 3 is a version of the following article:* Buchli, D.R., Storm, B.C., & Bjork, R.A. (in prep). Reinstatement of the study context fails to eliminate retrieval-induced forgetting.

study and retrieval practice are represented as two discriminable contexts due to the fact that the task demands of study and retrieval practice are fundamentally different. Hence the shift from study to retrieval practice induces a change in context, while restudy does not. Jonker et al. predicted that implementing a context shift between study and restudy would allow the study and restudy phases to become represented as two separate contexts, thus making non-practiced items associated with restudied categories vulnerable to forgetting. This is exactly what the authors found. After inserting a mental context change between study and restudy (i.e., asking participants to imagine their parents' house and draw a diagram of the layout), restudy practice caused non-practiced items from practiced categories to suffer significant forgetting.

Jonker et al. also determined that forgetting following extra study that was preceded by a mental context change could be eliminated, provided that the initial study context was reinstated before the final test. The authors asked participants a series of questions that were designed to encourage them to think back to the initial phase of the experiment. For instance, "What did you notice when you first entered the room for the experiment?" They also provided audio of the Star Wars theme song during at the beginning of the experiment to create a kind of distinct anchor that differentiated the first phase of the experiment from the restudy phase. Because participants were now able to effectively reinstate the study context at test when attempting to retrieve Rp- items, no forgetting occurred.

Jonker et al. (2013) replicated this finding when they employed the standard retrieval practice paradigm as well. After participants had studied a series of category-exemplar pairs and practiced retrieving half of the exemplars from half of the categories, they were tested on all the items in the typical fashion. Critically however, during study and retrieval practice, each category-exemplar pair or category-plus-two-letter-stem cue was presented alongside videos that

illustrated ordinary contexts that most people would be familiar with, such as the first-person perspective of walking downstairs or a panoramic view of a kitchen. In the initial study phase, every exemplar in each category was paired with the same unique video. Then, during retrieval practice, the practiced cues were paired with a new video. At test, one of the two videos was provided along with the category-plus-letter-stem cues. The authors predicted that participants who received the retrieval-practice video would erroneously search the retrieval-practice context for related, nontarget, Rp- items. In contrast, participants who received the study video would correctly search the study context for the Rp- items, and thus show no evidence of forgetting. As predicted, retrieval-induced forgetting was observed in the former condition where the retrieval-practice context was reinstated, but not in the latter condition where the study context was reinstated.

**Experiment 1A: Does RIF persist when participants are explicitly told not to recall Rp+ items (category-cued recall test)?**

**Rational of study**

An important assumption of the contextual-cuing account is that if only the practice context is reinstated at final test, RIF will occur because participants are unable to access Rp- items. In contrast, if the study context is reinstated at test, because all items are available, RIF should be eliminated. To test this critical assumption, subjects were encouraged to reinstate the study context regardless of whether a given item was practiced or unpracticed. Specifically, they were instructed to recall only Nrp and Rp- items on the final category-cued recall test. That is, after study and retrieval-practice, subjects were shown a category (e.g., *fruit*) and told only to recall members of that category that had not been practiced in the preceding phase. Thus, by

requiring subjects to exclude Rp+ items during the final test, I hoped to prevent them from reinstating the retrieval-practice context instead of the study context.

## **Method**

**Participants & Design.** Sixty-nine students from the University of California, Los Angeles participated in this experiment for course credit. Retrieval practice status (Rp+, Rp-, and Nrp) was manipulated within-subjects.

**Procedure.** During the study phase, participants were presented with 48 category-exemplar pairs (6 categories, 8 exemplars). Each item was presented for 5 seconds. In the subsequent retrieval practice phase, participants generated half of the exemplars from half of the categories in response to category-plus-two-letter stem cues. Each cue was presented for 10 seconds. After a 5 minute distractor task, participants were given a category-cued recall test on all of the studied items, with the following instruction: *“you must avoid recalling the category members you have already recalled in the last phase, and focus on recalling the category members that you studied, but have not yet recalled.”* Each category and letter-stem-cue was presented for 6 seconds.

## **Results & Discussion**

Data from the final category-cued recall test was analyzed using a paired samples t-test (see Figure 1). Participants recalled significantly more Nrp items ( $M = 43$ ,  $SE = .03$ ) than Rp- items ( $M=30$ ,  $SE = .03$ ),  $t(68) = 4.53$ ,  $p=.01$ . Thus, despite explicit instructions not to recall items from the retrieval practice phase, participants still demonstrated a significant RIF effect. This finding appears to contradict predictions of the context account, namely that RIF should not persist when the study context is reinstated. However, further analysis revealed an average recall rate of 24% for Rp+ items, thus participants erroneously recalled items from the retrieval

practice phase, suggesting that some participants may have mistakenly reinstated the retrieval practice context instead of the study context at test. To mitigate this issue and force participants to output only Rp- items, in experiment 1B a category-plus-one-letter stem cued recall test was employed. All other aspects of the experiment were identical.

**Experiment 1B: Does RIF persist when participants are explicitly told not to recall Rp+ items (category-plus-letter-stem cued recall test)?**

**Results & Discussion**

Data from the final test was again analyzed using a paired samples t-test (see Figure 1). Even when output order and item type was controlled, participants still recalled significantly more Nrp items ( $M = 45$ ,  $SE = .03$ ) than Rp- items ( $M=38$ ,  $SE = .04$ ),  $t(22) = 2.43$ ,  $p=.02$ . Thus, across two experiments, significant RIF was observed despite the fact that participants were strongly encouraged to reinstate the study context. These results are difficult to reconcile with the contextual-cuing account, and suggest that there are instances when cuing subjects to think back to the initial learning context does not eliminate forgetting.

**Experiments 2-4: Does RIF persist when participants are given discriminative cues directing them to reinstate the appropriate context?**

**Rational of study**

Cuing participants to search the study context by explicitly telling them not to output practiced items failed to eliminate forgetting on both a category cued recall test and a category-plus-one-letter- stem cued recall test. However, Jonker and colleagues could argue that participants still implicitly or automatically reinstated the study context despite test instructions.

However, explicitly cuing participants with both the category, a letter-stem cue AND the appropriate context in which to search could prevent reinstatement of the wrong context. The contextual-cuing account predicts that cuing subjects with the category and a discriminating contextual cue should eliminate forgetting. Other theories, specifically the inhibitory account on the other hand, predicts that regardless of contextual cues given at test, inhibition will be recruited to suppress competing exemplars during retrieval practice, causing retrieval-induced forgetting.

## **Method**

**Participants & Design.** Thirty-two students from the University of California, Los Angeles participated in this experiment for course credit. Retrieval practice status (Rp+, Rp-, and Nrp) was manipulated within-subjects.

**Procedure.** Once again, during the study phase, participants were presented with 48 category-exemplar pairs (6 categories, 8 exemplars), each presented for 5 seconds. In the subsequent retrieval practice phase, participants generated half of the exemplars from half of the categories in response to category-plus-two-letter stem cues (fruit—or). Each cue was presented for 10 seconds. After a 5-minute distractor task, participants were given a category-plus-one-letter stem cued recall test on all of the studied items, each cue appearing for 6 seconds. They were also shown a graphic indicating in which phase they last encountered the item. Before the final test phase began, participants were given the following instructions:

*“You will now be tested on all of the items that you learned. This time you will be given a category and the first letter of each item. Each category and letter clue will appear inside a box that says either LEARNING PHASE or PRACTICE PHASE . Words in the learning phase were only presented in the initial phase of the experiment. Words in the practice phase were presented*

*initially and also generated with category and letter clues during the practice phase. As you try to recall each item, use the phase labels to think back to when you last saw it. Was it an item you tried retrieving in the practice phase? Or an item you studied at the beginning of the experiment and have not retrieved before? Try to mentally travel back in time to when you last saw each item -- and use that memory cue, along with the category and letter cues provided, to recall the item”*

## **Results & Discussion**

Data from the final category-cued recall test was analyzed using a paired samples t-test (see Figure 2). Participants recalled significantly more Nrp items ( $M = 55$ ,  $SE = .03$ ) than Rp-items ( $M=48$ ,  $SE = .03$ ),  $t(31) = 2.046$ ,  $p=.05$ . Thus, RIF persisted even when participants were (a) instructed not to recall items from the retrieval-practice phase and (b) given cues to reinstate the appropriate context at final test. This pattern of results contradicts predictions of the contextual-cuing account and challenges many of its core assumptions. However, it is possible that participants failed to reinstate the study context despite prompting with the appropriate cue. Perhaps (a) making the study and retrieval-practice phases more discriminable, (b) providing an anchor to further separate the study phase from the retrieval practice phase, and (c) using specific questions to prompt retrieval of the appropriate context would allow participants to successfully reinstate the correct context. To that end, in experiment 4, the transition from the study phase to the retrieval practice phase was demarcated by a change in background and font color on the computer screen. Items in the study phase appeared on a blue background with yellow font. Items in the retrieval practice phase were presented on a purple background with green font. To provide a distinct anchor signifying the beginning of the study phase, the Star Wars theme song



was played during the initial instructions. To help students reinstate the appropriate context, specific questions were asked after each learning or practice phase cue (e.g., what happened at the beginning of the experiment?). It should be noted once again that both of these manipulations were employed by Jonker and colleagues (Experiment 2b).

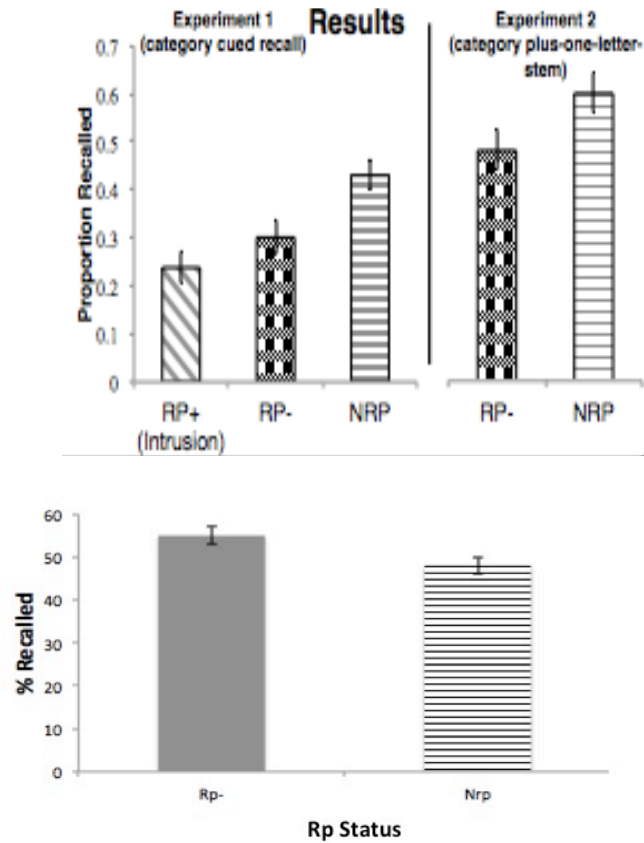


Figure 2. Proportion of Nrp and Rp- items recalled on the final category cued and category-plus-one-letter-stem cued recall test.

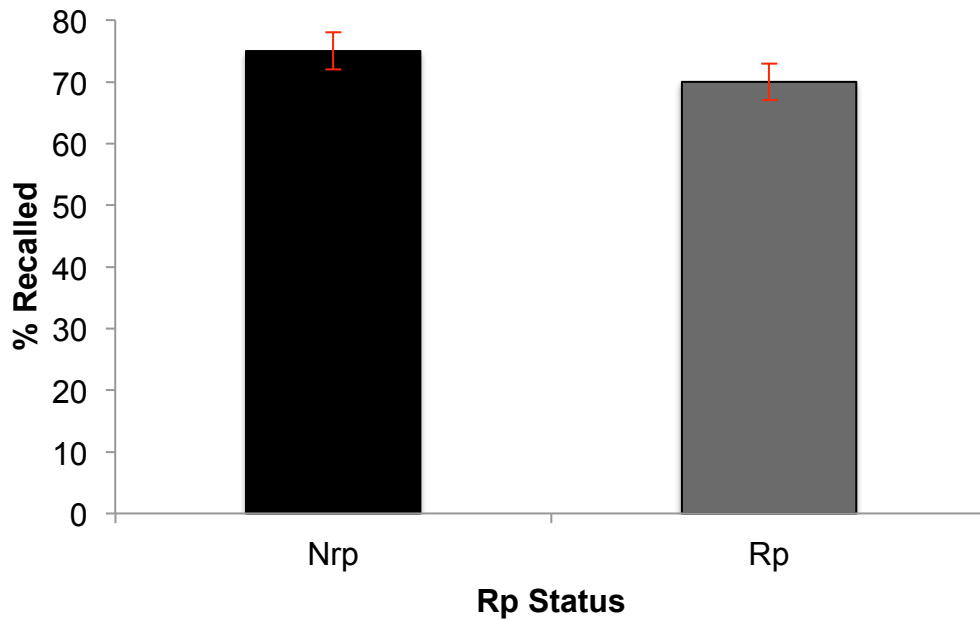
## Method

**Participants & design.** Sixty students from the University of California, Los Angeles participated in this experiment for course credit. Retrieval practice status (Rp+, Rp-, and Nrp) was manipulated within-subjects.

**Procedure.** Once again, during the study phase, participants were presented with 48 category-exemplar pairs (6 categories, 8 exemplars), each presented for 5 seconds. In the subsequent retrieval practice phase, participants generated half of the exemplars from half of the categories in response to category-plus-two-letter stem cues (fruit—or). Each cue was presented for 10 seconds. After a 5-minute distractor task, participants were given a category-plus-one-letter stem cued recall test on all of the studied items, each cue appearing for 6 seconds. Before each item on the test, a reinstatement cue appeared in which participants were given a label (either LEARNING PHASE or PRACTICE PHASE), and a series of questions prompting the retrieval of the appropriate context. Participants were given as much time as they needed to answer each question, before proceeding on to the next item.

## Results and Discussion

Data from the final category-cued recall test was analyzed using a paired samples t-test (see Figure 3). Participants recalled significantly more Nrp items ( $M = 75$ ,  $SE = .02$ ) than Rp- items ( $M = 70$ ,  $SE = .02$ ),  $t(59) = 2.262$ ,  $p < .05$ . Thus, RIF persisted even when strict measures were taken to enhance discriminability between contexts, and facilitate successful reinstatement of the appropriate contexts. Once again, these results are difficult to explain, given that a core tenant of the contextual-cuing account is that retrieval of the appropriate context at test should eliminate RIF.



*Figure 3.* Proportion of Nrp and Rp- items recalled on the final category-plus-one-letter-stem cued recall test.

In one last-ditch effort to provide sufficient contextual support for reinstatement, experiment 4 incorporated videos along with category-plus-letter stem and phase cues to orient participants to the appropriate context. During the study phase, category exemplar pairs were presented underneath brief video segments depicting common, every day contexts that most participants would be familiar with (e.g., a panoramic view of a kitchen, walking down the stairs, getting on to an elevator, etc.). Every member of each category shared the same unique video. During the retrieval practice phase, a new video appeared for each category that was practiced. Finally, at test, participants were given a category-plus-letter stem cue, a phase cue, and the appropriate video. That is, practiced items were cued with the video shown during retrieval practice, and related unpracticed items were cued with the initial study video, as were baseline

items. The context account would predict that providing discriminative cues at test that allow participants to reinstate the appropriate context should eliminate forgetting.

## **Method**

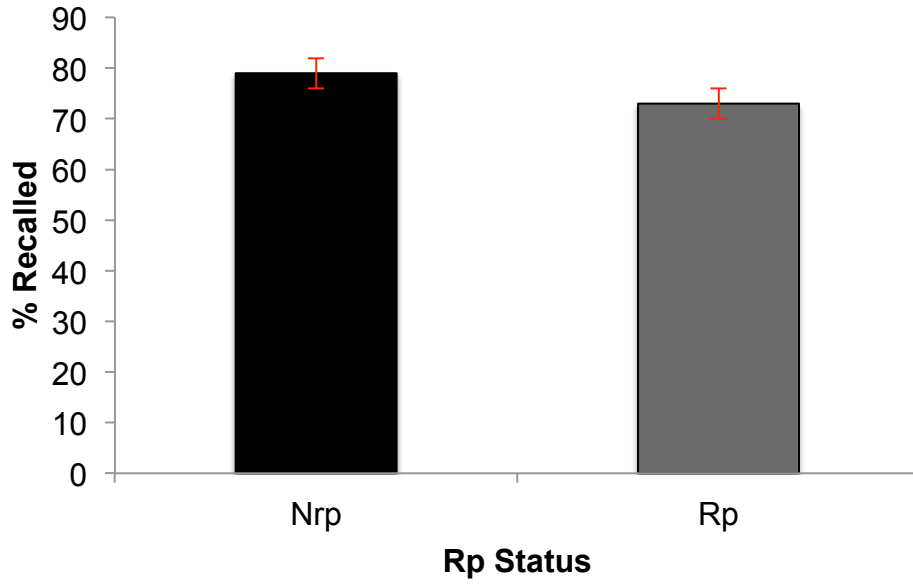
**Participants & Design.** Sixty students from the University of California, Los Angeles participated in this experiment for course credit. Retrieval practice status (Rp+, Rp-, and Nrp) was manipulated within-subjects.

**Procedure.** During the study phase, participants were presented with 48 category-exemplar pairs (6 categories, 8 exemplars), each presented for 5 seconds. Underneath each item, a short video appeared depicting various environmental contexts. In the subsequent retrieval practice phase, participants generated half of the exemplars from half of the categories in response to category-plus-two-letter stem cues (fruit—*or*). Each cue was presented for 10 seconds. Once again, videos appeared, but the video associated with each category was new. After a 5-minute distractor task, participants were given a category-plus-one-letter stem cued recall test on all of the studied items, each cue appearing for 6 seconds. In addition to the cue participants were given a label (either LEARNING PHASE or PRACTICE PHASE), and the appropriate video that appeared previously in either the study or retrieval practice phase. Rp+ items were shown with the video that appeared during retrieval practice, while Rp- and Nrp items appeared with the video shown during the initial study phase.

## **Results and Discussion**

Data from the final category-cued recall test was analyzed using a paired samples t-test (see Figure 4). Participants recalled significantly more Nrp items ( $M = 79$ ,  $SE = .03$ ) than Rp- items ( $M = 72$ ,  $SE = .02$ ),  $t(59) = 2.311$ ,  $p < .05$ . Thus, RIF persisted even when substantial contextual support was offered to help participants reinstate the appropriate context. This

suggests that reinstatement of the appropriate context is not always sufficient to protect against retrieval-induced forgetting.



*Figure 4.* Proportion of Nrp and Rp- items recalled on the final category-plus-one-letter-stem cued recall test.

## General Discussion

Jonker, MacLeod and Seli (2013) proposed an alternative to the inhibitory account of retrieval-induced forgetting in which impairment of related, unpracticed exemplars is thought to be a product of inappropriate contextual-cuing at the time of test. That is, the study and retrieval practice phases are represented as two disparate contexts. While baseline items appropriately cue retrieval of the study context, and practiced items appropriately cue the retrieval practice context, because related, unpracticed items are associated with both the study context and the retrieval practice context, participants often accidentally retrieve the stronger and more recent retrieval practice context.

Critically, Jonker and colleagues contend that if the study context is reinstated during the final test, and thus participants are able to search the appropriate context for related, unpracticed items, then RIF will be eliminated. Furthermore, if discriminative cues are provided at the time of test that appropriately signal reinstatement of the appropriate context (study for baseline and related, unpracticed items and retrieval practice for practiced items), this should also protect participants from forgetting.

Across 4 experiments, each providing more elaborate discriminative cues and greater levels of contextual support than the last, significant RIF was observed. This suggests that reinstatement of the correct context at the time of test does not always eliminate forgetting. It remains unclear why the results reported above contradict those reported by Jonker et al., although it should be noted that there have been other failures to eliminate retrieval-induced forgetting when context reinstatement is encouraged at test (Miguel et al., 2014). Further research is needed to determine the conditions under which inappropriate contextual cues do and do not eliminate forgetting.

## CHAPTER 5

### Concluding Remarks

#### Summary of Results

Remembering is often regarded as the antithesis of forgetting. That is, to remember is to avoid forgetting. Forgetting is further assumed to reflect an abject failure of memory that should be prevented if at all possible. Ample research strongly suggests however, that both of these conclusions are incorrect. Forgetting is actually quite beneficial for memory, in that selective reductions in the accessibility of outdated or irrelevant information facilitate the successful retrieval of that which is relevant. This is the way in which numerous researchers have understood retrieval-induced forgetting, the phenomenon by which selective retrieval of target information disrupts or impairs memory for related, nontarget information (Anderson, Bjork, and Bjork, 1994). Chapter 1 provided a brief review of this theory and others, purported to explain retrieval-induced forgetting.

Recently however, Jonker, MacLeod, and Seli (2013) proposed an alternative account, in which the impairment of related, outdated information is subscribed to a discernable shift in context between learning and retrieval, and the incorrect cuing of the appropriate context at test. While participants correctly cue the study context for baseline items and the retrieval-practice context for practiced items, because practiced category cues are shared between practiced items, and unpracticed, related items, subjects incorrectly reinstate the stronger, more recent practice context.

There are several essential tenants of the contextual-cuing account that were assumed to be correct based on the results of experiments conducted by Jonker and colleagues. They are described in detail below:

*Retrieval-induced forgetting will occur when:*

- 1) *There are two distinct contexts (e.g., study & retrieval practice, or study & restudy preceded by a mental context shift).*
- 2) *The [retrieval] practice context is active during the final test for practiced categories.*

*Retrieval-induced forgetting will not occur when:*

- 1) *There is no context shift between the study phase and the practice phase.*
- 2) *When the test cues reinstate the study context rather than the practice context.*

Chapter 2 addressed the contention that retrieval-induced forgetting persists between study and restudy, provided there is a mental context shift manipulation inserted between the two phases. Across three experiments, with a combined power of .98, restudy preceded by a change in mental context failed to produce a significant effect of forgetting.

Chapter 3 tested the critical assumption that reinstatement of the study context eliminates forgetting. Multiple experiments revealed that retrieval-induced forgetting persisted, even when participants were explicitly instructed to reinstate the appropriate context, and given appropriate contextual support.

## **Conclusion**

The results reported above, in conjunction with ample evidence from the extant literature, strongly suggests that the tenants of the contextual-cuing account are by no means infallible or consistent. This is not to say that context has no direct influence whatsoever on retrieval-induced forgetting, but rather that context may not always operate in the manner in which Jonker and colleagues prescribed. In addition, the results explained above seem to provide additional



support for the updating hypothesis – particularly the properties of retrieval specificity and strength independence (Anderson, Bjork, & Bjork, 2000; Bauml, 2002; Storm et al., 2006; 2009; Murayama et al., 2014).

### **Future Directions**

Given the lack of evidence in support of the contextual-cuing account and the growing body of work showing that many of its core findings are not replicable, the theory must either be amended or dismissed entirely. At a minimum, it must be accepted that inappropriate contextual-cuing alone cannot explain the phenomenon of retrieval-induced forgetting. Inhibitory processes that act to update memory and facilitate the retrieval of target information must also be considered if a unified theory of retrieval-induced forgetting is ever to be developed.

Future research should endeavor to further delineate the conditions under which context does and does not produce forgetting, and whether or not context is the sole causal mechanism, or whether it acts in conjunction with other inhibitory and noninhibitory processes. Special attention should also be paid to how researchers might develop a domain general mechanism by which related information becomes impaired, either as a goal-directed process or an incidental one that is triggered by features of the external environment, or internal state. In either case, seeing similar effects in domains outside of memory, and in more applied settings (see Storm et al., 2015; Storm & Levy, 2012) would help to expand the literature and move towards a more global understanding of human cognition.

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