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This dissertation is dedicated to Lauren Virginia Blackwell.

You are my inspiration, my motivation, and my love.

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Abstract

Memory updating, defined as the replacement of outdated information with new information, is be achieved by both increasing the likelihood of remembering the new information and reducing proactive interference caused by the outdated information. Intentional forgetting provides the means to limit the likelihood of sampling outdated information in the future and consequently its ability to interfere with the learning of new information. Intentional forgetting can occur by selectively rehearsing the correct information or alternatively, suppressing the error representation. The present study conducts an investigation of these processes and their role during an error correction task, which serves as an application of the memory updating process. For this task, participants attempt to forget an *erroneous* stimulus-response association and immediately update their memory with the *correct* association, comprised of the same stimulus paired with a new response. Experiments examine dynamics of retrieval and recognition, boundary conditions for intentional forgetting, and the stored memory representations of the new and outdated information to determine the key mechanisms of an online updating process. Findings reveal this process to include components of both selective rehearsal and suppression, which presents a problem for current theories of intentional forgetting. We conclude by proposing an alternative explanation and outline key goals for continued research in memory updating.

Online Memory Updating: Investigating Directed Forgetting

The Importance of Updating Memory

Forgetting is a cornerstone of human memory and learning; forgetting erroneous or outdated information is a crucial part of learning. Consider a young student of cognitive psychology who attempts to learn the basic definition of secondary memory. Initially, he might think secondary memory describes the aspect of memory related to active maintenance and manipulation until he looks back at his course readings and notes and realizes that secondary memory actually describes the aspect of memory related to long-term storage and retention. His initial mistake has been corrected, but how does committing this error relate to memory for the correction? Often in the course of learning, whether in an academic or training context, learners will inevitably make mistakes that require corrective feedback, and this feedback must then be used to update the erroneous information. Individuals might also want to forget and replace outdated or irrelevant information. Cognitive researchers have discovered potential benefits of making and then correcting mistakes, but the mechanism for this process and the conditions under which it acts are still being explored. Exploring the mechanisms underlying such memory updating in the course of learning are the focus of the present research.

Cognitive psychologists, trainers, and educators alike, have all begun to embrace the benefits of an *errorful* rather than *errorless* approach to learning, which include the view that testing constitutes a potent learning event (Roediger & Karpicke, 2006), as well as the recent finding that errors caused by pretesting—testing over material before it is studied—boosts recollection of a subsequently presented correct response relative to conditions in which the correction is read and there is no opportunity to err (Kornell, Hays, & Bjork, 2009) for both young and old adults (Cyr & Anderson, 2012). Testing and pretesting along with spaced study (Glenberg, 1979) and spaced tests (Carrier & Pashler, 1992), contextual interference during the learning process (Bjork, 1994), and generation of information (Slamecka & Graf, 1978) can all be considered part of the *desirable difficulties* framework. This framework suggests particular methods that initially slow the process of learning and increase the potential for errors during learning, but ultimately promote long-term retention and transfer of learned information (Bjork, 1994; Schmidt & Bjork, 1992).

Research on desirable difficulties and error correction argues against an earlier perspective—that errors be avoided at all costs because once committed, they have a higher chance of impeding learning (Guthrie, 1952; Skinner, 1968). As an explanation for desirable difficulties, Bjork and Bjork (1992) have applied the *new theory of disuse*, which claims that items in memory have both retrieval strength and storage strength. Storage strength measures how well information is learned, and retrieval strength determines the likelihood of retrieving that information at a particular time. In both cases, the strengths are hypothesized to accumulate in inverse proportion to then current strength, exhibiting diminishing returns. Storage strength is hypothesized to accumulate over time and practice by building upon associations with related knowledge; while it can increase, it is never reduced. Retrieval strength is much more variable with increases based on subsequent study and test, as well as situational factors such as recency of study, and decreases in relation to the retrieval strengths of other information in memory.

Bjork and Bjork (2011) have argued that methods constituting desirable difficulties disrupt the retrieval strength of the to-be-learned item, interfering with the ability to bring information into conscious awareness. Information that is successfully retrieved in spite of this challenge efficiently increases in storage strength by minimizing diminishing returns, thereby enhancing learning and retarding forgetting to a greater extent than restudy. Currently, researchers attribute increases in storage strength following retrieval practice to a greater degree of transfer-appropriate processing, increased elaboration of the memory trace, and/or the creation of additional retrieval routes for access to the memory trace (Roediger & Karpicke, 2006). New theory of disuse suggests that retrieval interference—via competition, context changes, or otherwise—if overcome, could eventually result in larger learning gains.

Error correction research suggests that interference from errors, if they are left uncorrected, tends to perseverate (Cunningham & Anderson, 1968; Finn & Metcalfe, 2010; Lansdale & How, 1996; Lhyle & Kulhavy, 1987; Pashler, Rohrer, Cepeda, & Carpenter, 2007). Error correction research, which typically compares memory for a correct item occurring with or without a previously encoded error, supports an account of the benefits of correcting errors as due to increases in elaborative encoding of the contextual and semantic elements of the correct item that support its future retrieval (Butterfield & Metcalfe, 2001; Cyr & Anderson, 2012; Kornell et al., 2009; Richland, Kornell, & Kao, 2009). Furthermore, learning will benefit when feedback facilitates this elaborative encoding, for example by directing generation of the correct item (Finn & Metcalfe, 2010; Lhyle & Kulhavy, 1987), or by making the correct item seem familiar and increasing attentional resources devoted to processing the correct item (Butterfield

& Mangels, 2003; Butterfield & Metcalfe, 2001; Butterfield & Metcalfe, 2006; Fazio & Marsh, 2009; Kulhavy & Anderson, 1970).

However, the focus of both desirable difficulties and error correction explanations rests on memory for the correct information rather than the erroneous information. The outcome for erroneous information is an important consideration because such information can influence—interfere with or facilitate—the retrieval of correct information (Landon & Kimball, 2012a). For example, the cue-overload principle states that when multiple targets are associated to a stimulus cue, the diagnosticity and distinctiveness of that cue decrease, and targets compete for retrieval in response to the cue (Nairne, 2002; Watkins & Watkins, 1975). Similarly, basic interference theory would suggest that erroneous information competes with memory for the correct item and should therefore be forgotten (Baddeley & Wilson, 1994; Johnson, 1994). According to the new theory of disuse, the competition between error and correct item and its resultant adverse impact on the retrieval strength of the correct item will give rise to increased learning gains, assuming that the competition can be overcome (Bjork & Bjork, 1992).

However, Soraci (1999) and others (Cyr & Anderson, 2012; Kornell et al. 2009) have suggested erroneous information might serve as a direct cue within the relevant semantic network to facilitate future retrieval of the correct information (but see Landon & Kimball, 2012a). Thus, to date, researchers have suggested both inhibitory and facilitative effects of erroneous information on memory for corrective information. It is possible that the role of errors in the learning process could depend on the type and circumstances of their encoding (Grimaldi & Karpicke, 2012; Landon & Kimball, 2012a), as most research indicating a facilitative role for errors occurs when errors are generated rather than read (Soraci et al., 1994; but see Hays, Kornell, & Bjork, in press). The present research investigated the role played by interference from erroneous information in the process of updating memory with corrective information. Interference caused by the initial learning of erroneous information could be managed by motivated attempts to forget such information to reduce interference. This research investigates how intentional forgetting would be achieved in the context of such online updating.

Interference Theory

At a time when interference theory, the leading theory of forgetting in memory literature, was in its adolescence—and in an almost constant state of flux—much of its theoretical growth and progression involved the use of the *A*-*B*, *A*-*D* paradigm, in which two different responses (*B* and *D*) are learned in association with the same stimulus (*A*), and later, when the stimulus recurs, the two responses compete for retrieval. For example, consider unrelated paired associates with stimulus (*A*), "metal," initial stimulus-response pair (*A*-*B*), "metal - toast," second stimulus-response (*A*-*D*), "metal - elbow," and a separate second stimulus pair (*C*-*D*), "flag - elbow." The basic findings of the *A*-*B*, *A*-*D* paradigm using lists of word pairs indicates that learning a second list (*A*-*D*), which pairs new responses with previously learned stimuli, causes proactive and retroactive interference for the D and B responses, respectively, compared to learning non-overlapping stimuli and responses (*A*-*B*, *C*-*D*) (McGeoch, 1942; Osgood, 1949; as discussed in Crowder, 1976).

Several theories were proposed to explain *A*-*B*, *A*-*D* paradigm findings. One of the first theories to explain these findings considered verbal learning to operate in the same way as classical conditioning. According to the unlearning theory, strengthening *A-D* associations in the learning process causes an absolute reduction in memory for formerly associated *A-B* pairs, but despite this reduction, without continued reinforcement of the new *A-D* associations, former *A-B* associations could be spontaneously recovered and then interfere with corrections (Melton & Irwin, 1940; Underwood, 1948). However, continued research into unlearning theory indicated that *A-B* associations could be recovered at high rates in predictable fashion on recognition tests, which could not be explained by either spontaneous recovery or re-learning (Postman & Stark, 1969; as discussed in Anderson & Neely, 1996; Crowder, 1976).

The response-set suppression theory instead posited that learning the second list of *A-D* associations initiated a suppression mechanism, which acted list-wide to weaken the accessibility of all *A-B* memory traces. But the effectiveness of the suppression mechanism was proposed to dissipate overtime and under specific testing procedures such as multiple-choice testing and recognition, and this feature of the theory more accurately predicted the recovery of *A-B* associations compared to unlearning theory (Postman & Stark, 1969; as discussed in Crowder, 1976). The response-set suppression mechanism was also hypothesized to act within the *A-B*, *C-D* procedure to account for the small but significant retroactive interference observed in situations when stimulus terms were not shared (Postman & Stark, 1969). However, since the suppression mechanism was proposed to act list-wide, the theory could not explain the finding that a mixed second list, comprising *A-D* and *C-E* items, only impaired recall of the *A-B* pairs for which a corresponding *A-D* pair had been studied (Delprato, 1971; as discussed in, Anderson & Neely, 1996). Postman and Underwood (1973), attempted to salvage the theory by proposing the potential for stimulus-specific response suppression

Another alternative account, the associative interference theory suggests that *A-B* and *A-D* associations are learned relatively independent of one another, but during retrieval, associations sharing the same stimulus term will compete for conscious recollection. By this account, the likelihood of retrieval is viewed as being distinct from the learning episode. Impairment of the *A-B* response pair is most clearly evident on an immediate test when participants are given *A* and asked to recall the *B* response (this impairment is further exacerbated if the *A-D* response pair is provided as a retrieval cue) (Postman, Stark, & Fraser, 1968). As time elapses between study and test, though, the mechanism for inhibition was found to weaken, causing the relative memory strength of *A-B* associations to rebound and facilitate retrieval (Postman et al., 1968; Postman & Stark, 1969; Weaver, Rose, & Campbell, 1971; as discussed in Anderson, 2003).

Finally, as an extension to the stimulus sampling theory (Estes, 1950), the stimulus-encoding theory suggests that each time the stimulus term is encountered, for both *A-B* and *A-D* events, the learner encodes a set of component features—the stimulus-response association, context of presentation, and other various associations to both the stimulus and response—that are sampled from the wider set of such features then available. These sets can contain overlapping or different individual features at each encoding, with the A-B and A-D encodings likely to contain different features to the extent that B and D are dissimilar. Retrieval probability is then dictated by the degree of similarity between the sets of features encoded during each study event (A-B and/or A-D) and the set of features available and sampled at test. The degree of similarity will vary based on the initial level of associative learning and differences in the availability of particular features across time and interpolated tasks since encoding (Martin, 1971).

With evidence seemingly supporting and refuting each theory and a lack of continued interest in the paradigm, a consensus was never reached (Wheeler, 1995), which might indicate an inability for any parsimonious explanation to account for the myriad findings within this paradigm (Crowder, 1976). Despite the absence of a single parsimonious theory, literature to date would support the general notion that learning one stimulus-response relationship would complicate—rather than facilitate—the learning of another stimulus-response relationship when that stimulus is shared.

This paradigm contributed much to the progression of interference theory and served as an important precursor to further research with forgetting, but as Crowder (1976) characterized it, “this research owes to an analogy with real life more than to the supposition that the laboratory situation itself is representative; seldom are two incompatible habits successively acquired in the same stimulus situation” (p 246). In other words, real-world *A-B* and subsequent *A-D* learning situations do not often present themselves. Today, with technology at our fingertips and a rapid pace of information flow, we often have to make some stimulus-response association that would soon require updating—examples include: gas price fluctuation, stock value, national debt, and particularly, as previously discussed, when errors are encoded during the learning process.

Interference and Directed Forgetting

With regards to errorful learning, the production and subsequent correction of errors will likely involve a motivation to forget particular information (errors) and remember other information (corrections)—a cognitive process which maps onto another interference and forgetting memory paradigm: directed forgetting, also referred to as goal-directed forgetting and intentional forgetting. Directed forgetting represents a specific type of intentional forgetting, which Johnson (1994) defined as a motivated attempt to limit the future expression of specific memory content. Whereas the *A*-*B*, *A*-*D* paradigm produces unintentional forgetting of initially learned *A*-*B* stimulus-response pairings via proactive interference caused by learning *A*-*D* pairings, directed forgetting describes the conscious and purposeful limiting of access to previously learned information following a specific forget instruction. Still, the theoretical conclusions drawn from the *A*-*B*, *A*-*D* paradigm have informed research on directed forgetting. Directed forgetting has been researched through two basic methods: item-method and list-method.

In the standard item-method directed forgetting paradigm, after studying each item, participants receive an instruction to remember or forget that item with the expectation that they will only be tested on the items that they are instructed to remember. However, participants are later tested on all previously presented items, regardless of the instruction to remember or forget. Results indicate that memory for to-be-remembered (TBR) items is significantly better than for to-be-forgotten (TBF) items (Roediger & Crowder, 1972; Woodward & Bjork, 1971). These findings of impairment, defined as the empirical decrement in recall of TBF items, hold regardless of the testing format, whether the task is to recall or recognize studied associates, and because recall tests item retrieval and recognition tests item identification, it would appear that TBF items in this case lack a strong or even complete memory representation (as discussed in Johnson, 1994; Davis & Okada, 1971; Wetzel & Hunt, 1977).

For this reason, researchers have interpreted the locus of such differences as occurring at encoding and storage in secondary memory, such that items are only maintained in memory for a short time via shallow rehearsal processing until participants receive the instruction to forget or remember, and thereafter only TBR items are processed more deeply and elaborately (Basden, Basden, & Gargano, 1993; Woodward & Bjork, 1971; Woodward, Bjork, & Jongeward, 1973). For over two decades this reigning explanation of item-method forgetting as attributable to differential rehearsal has gone relatively unchallenged. In fact, some researchers stopped using item-method paradigm altogether to investigate directed forgetting phenomena because of the assertion that information temporarily maintained in primary memory is not actually *learned*, which is a basic prerequisite for forgetting (Johnson, 1994). For this reason, much of the more recent directed forgetting research instead has used list-method directed forgetting.

In the standard list-method directed forgetting paradigm, participants are divided into separate groups, and both are told that they will be learning word lists for a later test. After learning the first list, researchers instruct one group—the *remember group*—that they should remember all items from both the first list and the subsequent second list, while the other group—the *forget group*—is told to forget items from the first list and focus exclusively on the items comprising the subsequent second list. However, at test, participants are instructed to recall items from both lists, regardless of the instruction to remember or forget. Results indicate that, relative to the remember group, the forget group exhibited significantly lower recall rates of items from the first list but significantly higher recall rates of items from the second list, which have been termed the *costs* and *benefits* of list-method directed forgetting, respectively (Geiselman, Bjork, & Fishman, 1983). However, these findings are not evident on tests of recognition, for which forget and remember groups exhibit similar performance (e.g., Basden et al., 1993; Geiselman, Bjork, & Fishman, 1983); this would suggest that, unlike with item-method directed forgetting, here the TBF items are learned and stored, but access to their memory traces is impaired, barring restoration of access through presentation during recognition testing (Bjork, Bjork, & Anderson, 1998).

There are currently two main competing explanations of typical list-method directed forgetting findings: the single-factor, suppression account, and the dual-factor, context and strategy change account. Initial support for a suppression of list-method directed forgetting came from investigations of the effects of the global instruction to forget. Using the standard list-method paradigm, Geiselman et al. (1983) required participants to either make a judgment about a word or learn the word for a later memory test with the two tasks alternating from item to item within each list. The forget group, relative to the remember group, recalled fewer items from the first list, regardless of encoding task or the need for rehearsal during the encoding task. Such an impairment demonstrated that the effect of the forget instruction operated for the entire list—it was not specific to to-be-learned words within the list. These findings supported an inhibitory account with a mechanism operating on the entire initial learning episode to suppress or block the retrieval of all items preceding the global forget instruction (E.L. Bjork & Bjork, 1996; R. A. Bjork, 1989; Golding & MacLeod, 1998).

Interestingly, we can draw comparisons of this suppression account of directed forgetting to the response-set suppression account proposed to explain interference findings from the *A*-*B*, *A*-*D* paradigm (Anderson, 2003). Both accounts suggest that the inhibition acts list-wide for a particular episode to decrease proactive interference for information learned later, such that a single mechanism can explain both the costs and benefits of directed forgetting, respectively. Additionally, the inhibitory mechanism has been interpreted as impairing conscious access to the original learning episode without altering the semantic representation of TBF information in directed forgetting (Bjork, Bjork, & Anderson, 1998) or initially learned information in the *A*-*B*, *A*-*D* paradigm (Postman & Stark, 1969). With sufficient retrieval cues, TBF information and *A*-*B* associations experience a release from inhibition, and the information can be accessed. For this reason, tests of recognition where the item is re-presented show that TBF List 1 items are unimpaired compared to TBR List 1 items (e.g., Block, 1971; Geiselman et al., 1983; but see Benjamin, 2006).

Unfortunately, the suppression account of directed forgetting often appears in conflict with suppression accounts of other forms of forgetting. Specifically, in the retrieval-induced forgetting paradigm, practice in retrieving category exemplars impairs memory for other unpracticed exemplars in the same category relative to exemplars in unpracticed categories. Researchers have suggested that the retrieval practice causes suppression of the overall memory representation for competing, unpracticed exemplars (Anderson, 2003; Anderson, Bjork, Bjork, 1994). By this account, competition via overt retrieval is a requisite for the enactment of the suppression mechanism, which then causes an absolute weakening of the memory trace of the suppressed item. Whereas list-method directed-forgetting suppression purportedly affects only the future retrieval of an item and can be overcome with the appropriate cues, retrieval-induced suppression purportedly decreases the likelihood of future retrieval by directly weakening the representation in memory such that impairment has been observed on recognition and implicit tests of memory (for review, see Anderson, 2003).

A suppression mechanism has also been proposed to explain the findings of the think/no-think paradigm. In this paradigm, participants are cued to actively avoid thinking about a particular item, and as the frequency of such cuing increases, subsequent retrievability decreases, which is attributed to executively controlled, targeted suppression (Anderson, 2003; Anderson & Green, 2001). By this account, competition is no longer requisite for the enactment of suppression; rather, it is simply caused by the desire to limit the future accessibility of an unwanted item representation in memory. Executively controlled suppression accounts (e.g., think/no-think), much like retrieval-induced suppression accounts, differ from list-method directed forgetting suppression by suggesting that the representation of the item in memory suffers from absolute weakening rather than a relative weakening that would leave the semantic representation of the TBF items intact in memory.

Bjork and colleagues have attempted to distinguish suppression in directed forgetting from that in retrieval-induced forgetting (see Bjork, Bjork, & Anderson, 1998), but they seem to be unable to clearly explicate the difference beyond those inherent to the methodology and empirical findings. That is, beyond differences in the experimental methods associated with directed forgetting and retrieval-induced forgetting, and beyond the empirical findings that seem to suggest differences in item accessibility between the two types of suppression, it remains unclear exactly how the suppression mechanism in list-method directed forgetting operates. If it operates by competition, much like retrieval-induced forgetting, why would it only affect retrieval and not recognition? Why would retrieval-induced suppression weaken both absolute and relative strength of a representation in memory, while list-method directed forgetting suppression weakens relative strength?

However, the greatest challenge to the suppression account of list-method directed forgetting (LMDF)—and in fact to any single-factor account—is presented by recent findings showing that some manipulations can dissociate directed forgetting costs from benefits (Benjamin, 2006; Sahakyan & Delaney, 2003; Sahakyan & Kelley, 2002). If LMDF benefits were observed in the absence of costs, and the costs were observed in the absence of benefits, such dissociations could not be reconciled with a single-factor account, which would assume costs and benefits co-occur. Sahakyan and colleagues hypothesized that the instruction to forget initiates two separate processes rather than one, and these processes operate independently of each other to produce either the observed DF costs or the benefits.

Sahakyan and Kelley (2002) provided evidence of costs dissociated from benefits when a task given to a remember group between lists induced participants to change their internal contexts and consequently caused a decrement in first list recall comparable to the forget condition. Sahakyan and Delaney (2003) were able to dissociate benefits from costs when participants in a remember group were explicitly instructed to alter their strategy for learning the second list from a shallow encoding strategy to a deep encoding strategy and demonstrated rates of recall for second list items that were similar to the forget condition. Based on this evidence, and the somewhat questionable inference that similar effects have similar causes, Sahakyan and Delaney (2003) postulated a dual-factor account of list-method directed forgetting: costs were attributed to a change in internal context caused by the forget instruction and corresponding context mismatch at test, and benefits were attributed to an adoption of a more efficient study strategy for the second list, similarly prompted by the forget instruction.

Other forgetting researchers have embraced the idea of the dual-factor account to explain list-method directed forgetting, agreeing that first-list costs reflect a retrieval problem and second-list benefits reflect an encoding difference, but the specific mechanisms responsible for the costs are currently under debate. While Sahakyan and colleagues have proposed context change and strategy change mechanisms for costs and benefits, respectively, Bäuml and colleagues have proposed a retrieval inhibition mechanism as responsible for costs evident in List 1 recall, and proposed that List 2 benefits are caused by a resetting of encoding processes, as evidenced by primacy effects in List 2 recall (Pastötter & Bäuml, 2010). As research continues to benefit from converging evidence in the literature, dual-factor accounts currently stand as the leading accounts for list-method directed forgetting effects.

Online Updating of Memory

Though research with interference and directed forgetting has led to important and significant discoveries relevant for human learning, the leading explanations for interference and directed forgetting do not appear to inform the type of online memory updating that is applicable in errorful learning circumstances: Because the *A-B*, *A-D* paradigm and list-method directed forgetting have exclusively used lists of items, findings using these paradigms have limited relevance for situations in which a single error is processed and then immediately corrected. In such situations, item-method directed forgetting would seem most applicable, but the selective rehearsal account for such forgetting is based on maintenance in primary memory rather than actual initial learning involving storage in long-term memory. As such, this account would suggest that errors are only maintained for a short time in primary memory until corrected, at which time rehearsal and processing of errors effectively ends. Any decrement in memory for item-level errors would be attributed to shallow maintenance rehearsal rather than any specific or purposeful forgetting of learned information.

However, the interference perseveration hypothesis of Kulhavy & Anderson (1972), the spacing hypothesis (as discussed in Smith & Kimball, 2010), and much of the error correction research suggests that errors will be observed to exert proactive interference until such time as the corrective feedback is sufficiently strengthened and learned. This indicates that the memory for errors does not passively decay, but instead that its representation and related associations can actually remain intact. If outdated information, such as errors, is not just maintained in working memory for a short period of time as suggested by the selective rehearsal account, but actually stored in memory, then there would be a motivation to limit future sampling of outdated information. In this situation, intentional forgetting would appear a practical solution to error interference in an errorful learning context given that 1) an immediate forget instruction occurs between the presentation of the learned error and the presentation of the to-be-remembered correct information (R.A. Bjork, 1970; Roediger & Tulving, 1979), and 2) new learning occurs immediately after the forget instruction with an intent to forget previous information and remember new information (Gelfand & Bjork, described in R.A. Bjork, 1989). The elucidation of such a mechanism would contribute to our knowledge of the memory updating process upon receiving immediate and corrective feedback. Yet, as previously mentioned, current theories on goal-directed forgetting would suggest that the reduction of interference via some inhibitory mechanism would not be observed at the item level, but rather such would be explained by selective rehearsal instead.

A handful of studies have investigated intentional forgetting of stimulus-response associations at the item or sub-list level. Such studies used a particular forgetting paradigm, which preceded and led to the development of the standard item- and list method-paradigms discussed above. In this paradigm, developed by R.A. Bjork (as described in Bjork, LaBerge, & Legrande, 1968), subjects were typically presented with lists of varying length (e.g., 4-8 items) comprising stimulus-response pairs—a unique nonsense syllable as a stimulus and a common unrelated word as a response. Subjects would study part of a list of sequential pairs, which was then followed by a cue to forget. The cue meant that subjects could forget all previously presented stimulus-response pairs from the first part of the list and would only need to remember the subsequently presented stimulus-response pairs in the list. Lists of zero to-be-forgotten (TBF) items served as control conditions. A single-item cued-recall test immediately followed the conclusion of each list: Subjects were supplied with a stimulus item from the to-be-remembered (TBR) part of the list and asked to recall the correctly paired response. Results from this paradigm appeared to detail the role of intentional forgetting on proactive interference in primary memory because of the short length of lists and immediate testing procedures (Bjork, LaBerge, & Legrande, 1968; Block, 1971).

Bjork et al. (1968) used this initial forgetting and interference paradigm (among other comparisons) to compare recall for a TBR item that appeared 1) following an initial TBR item, 2) following an initial TBF item, or 3) as the only item. They found that the instruction to forget an initial item yielded memory for the subsequent TBR item similar to that for a single TBR item, and significantly improved recall relative to the second of two TBR items. Bjork et al. never assessed recall of the first of the two items. The authors favored a selective rehearsal explanation, explaining the advantage as caused by ending maintenance of the TBF item, which completely released proactive interference and enabled elaboration of the TBR item.

R.A. Bjork (1970) further tested the selective rehearsal account and found evidence inconsistent with its assumptions. Bjork manipulated the time at which forget or remember instructions occurred in lists comprising two sets of two sequentially presented stimulus-response pairs. A forget or remember instruction was given after learning the first two stimulus-response pairs and then again following the second two pairs, thus creating four conditions: forget both sets of pairs (FF), forget the first two pairs and remember the second two pairs (FR), remember the first two pairs and forget the second two pairs (RF), and remember both sets of pairs (RR). Subjects were tested on one of the TBR items following each list. Again, memory for TBF items was not assessed—the FF condition served only to prevent participants from anticipating a remember instruction in the FR condition.

Bjork (1970) found that when the order of instructions was reversed from the standard updating condition—that is, when the remember instruction occurred before (RF) rather than after the forget instruction (FR)—memory for the TBR pair was significantly impaired for the RF condition relative to the standard FR updating condition. According to the selective rehearsal account, memory maintenance afforded to TBF items should not have been affected by the reversal of instructions and the account thus predicted comparable rates of TBR recall across the two conditions. Yet, when the forget instruction occurred first, memory for the TBR item benefitted more. Bjork concluded that selective rehearsal of TBR items could not solely explain these findings.

Unlike Bjork (1970), Reitman, Tanner, Bjork, and Higman (1973) tested memory for TBF items, not just TBR items. Using the same paradigm as in Bjork (1970), Reitman et al. instructed participants that they might be tested on one of the TBF items, but that these tests would be infrequent and should not cause them to change their strategy to remember only TBR items. TBF items did not appear to interfere with memory for TBR items—that is, TBR items following TBF items appeared to benefit from a release from proactive interference. Recall of TBF items indicated impaired accessibility relative to TBR items across item positions.

Interestingly, the patterns of recall results for forget and remember items observed by Reitman et al. (1973) were similar to those later labeled as list-method intentional forgetting costs and benefits—decreased memory for TBF items relative to TBR items in the same position, and increased memory for TBR items following TBF items relative to TBR items following other TBR items. Taken together, this research provided preliminary evidence of intentional forgetting occurring at the item level.

Unfortunately, two major factors led to abandonment of this paradigm. First, it was limited in scope to the observation of intentional forgetting in primary memory rather than secondary memory because memory was usually assessed immediately after the presentation of a short list of items. Second, there appeared to be no clear way to test memory for forget items often enough without contaminating processes in later list-learning trials. Following these studies, researchers turned instead to the item and list methods described earlier. Consequently, long-term memory for TBF item-level stimulus-response information was not empirically investigated, and theoretical explanations for these findings were never fully explored.

As a precursor to investigating this issue, Landon and Kimball (2012b) recently researched the degree to which, at the item level, initially learned and intentionally forgotten information remains in memory relative to initially learned and intentionally remembered information. Landon and Kimball used a design modeled after a typical timeline observed with trial-and-error learning in pretesting manipulations. Stimulus-response word pairs were presented then signaled as correct or incorrect following each pair, and were told that memory testing would only involve correct pairs. Some stimulus words were presented only once, with the response word signaled as correct (R condition). Other stimulus words appeared twice in succession, with the second word pair signaled as correct, and the first word pair signaled as either correct or incorrect—corresponding to an instruction to remember or forget the first response word (RR and FR conditions, respectively). These conditions were manipulated factorially with the type of encoding task for target responses, which was either a simple read task or a word-stem completion generation task. In order to control for item effects, response words were strong associates that participants were highly likely to generate.

At test, participants were cued to recall all responses studied in relation to a previously studied stimulus word, regardless of the correct vs. incorrect label (i.e., regardless of TBF or TBR instruction) (Experiment 2, Landon & Kimball, 2012b). Recall rates for the first-learned TBF association were significantly lower compared to those of the first-learned TBR association of the RR condition and the only TBR association of the R condition. Recall rates for the second-learned TBR association of the FR condition were significantly higher than those of the TBR association of the RR condition but numerically lower than those of the R condition. Interestingly, comparisons of the RR condition to the R condition indicated significant proactive interference acting in the RR condition to decrease recall of the second-TBR association, but did not reflect retroactive interference, as rates of the R condition and first-learned TBR association were not significantly different.[1] Beyond an overall advantage for generative encoding, there were no other effects or interactions caused by the encoding task manipulation.

In order to test whether the observed costs and benefits were due to selective rehearsal—the common explanation for differences resulting from item-specific forget instructions—Landon & Kimball (2012b, Experiment 3) replicated the experiment using a yes/no recognition test for response words. Findings demonstrated significant directed forgetting benefits for memory of remember items that followed an instruction

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[1] One explanation for the lack of retroactive interference would be that the first-learned TBR association in the RR condition benefitted from continued rehearsal, which would result in a stronger item representation or association with the stimulus word.

to forget, but findings failed to reveal any significant differences between recognition rates of initially presented TBF or TBR associates. These results indicated, similar to list-method directed forgetting research, unimpaired access to TBF information for recognition testing (e.g., Basden et al., 1993). Such access supported the idea that TBF associate pairs were learned and stored in memory and became accessible when the item representation was re-presented during recognition testing. This would suggest that, contrary to the selective rehearsal account, TBF items were not weakly encoded, and participants did not simply maintain the TBF items until they received the forget instruction.

However, Benjamin (2006) has noted that the absence of costs and the presence of benefits on a recognition test would present a challenge for any suppression account of directed forgetting as well. According to Benjamin (2006), if recognition testing releases the forget item from suppression, and suppression drives both the costs and benefits of directed forgetting, then recognition testing should demonstrate the absence of both costs and benefits. Benjamin further argued that retrieval-based recognition tests provide more accurate assessments of memory contents than familiarity-based tests because they are less influenced by memory valence. The recognition test employed in Experiment 3 of Landon and Kimball (2012) would be considered a familiarity-based task because item identification could be completed without regard to the context of learning—based on familiarity of the response word alone. Benjamin claimed that differences between the ability to discriminate TBF from TBR items in the item- and list-methods of directed forgetting, rather than differences related to memory processes such as rehearsal or suppression, can account for previously observed familiarity-based recognition discrepancies (e.g., Basden et al., 1993).

As Benjamin (2006) explained, the immediacy of the TBF or TBR instruction typical for item-method tasks facilitates the discrimination of items in memory, so that rehearsal and elaboration can end relatively soon after an instruction to forget. However, discrimination is much more difficult for list-method tasks because the global instruction to forget occurs after a period of learning multiple TBF items. As a result, participants are more likely to unintentionally continue remembering TBF information. With familiarity-based recognition testing, participants can base their judgments on perceived valence of an item, which would be much higher for TBF items in the list-method and thereby mask any real learning costs. To address this issue and effectively differentiate between items that might share similar levels of familiarity, Benjamin recommends employing retrieval-based recognition tests, which require using pattern-completion mechanisms to evoke memory for the specific context of the learning episode.

In an attempt to employ a retrieval-based recognition test, Landon and Kimball (2012b) assessed memory in Experiment 4 with a yes/no recognition experiment where previously studied stimulus items were paired with either previously studied target associates or new associates. Now, familiarity served as a poor proxy for recognition decisions because all test trials appeared somewhat familiar and included features such as stimulus cues and similar semantic relations that were involved in prior learning. As a result, participants would need to retrieve more details about the specific context of the study episode—details of the specific studied stimulus-response association. It is possible that this change simply shifted the criterion of familiarity such that all trials appear more familiar, and so participants could have continued to rely upon relative valence of items rather than engaging retrieval processes to make their decisions. In this case, recognition would be similar to those previously found in Experiment 3. To the contrary, findings of Experiment 4 indicated the emergence of directed forgetting costs and benefits similar to those observed on the cued-recall test in Experiment 2, which would implicate the use of retrieval processes for this recognition task.

Taken together, the experiments in Landon and Kimball (2012b) provide novel evidence of directed forgetting at a local level that cannot be readily explained by selective rehearsal. The pattern of directed forgetting benefits in the absence of costs on a familiarity-based recognition test (Experiment 3) reflected previously established list-method directed forgetting patterns (Benjamin, 2006; Sahakyan, Waldum, Benjamin, & Bickett, 2009). Also, the pattern of directed forgetting benefits and costs on a retrieval-based recognition test (Experiment 4) reflected the pattern previously predicted by Benjamin (2006) and observed by Sahakyan et al. (2009) with list-method directed forgetting. Selective rehearsal would have predicted that TBF associations would be weakly encoded relative to the elaborated TBR associations in FR and RR conditions, which would have been reflected by large costs for TBF items on both the familiarity-based recognition tests and retrieval-based recognition test. Directed forgetting benefits would have been predicted on the retrieval-based recognition test to the degree that selective rehearsal in the FR condition differentially improves memory of the TBR responses relative to the shared rehearsal of two TBR responses in the RR condition. Since findings with recognition map onto those established with list-method, this could suggest that either the list-method theoretical mechanisms serve as more appropriate explanations for this online updating paradigm, or alternatively, that item-method mechanisms, such as selective rehearsal, might not be solely responsible for the demonstrated patterns. Unfortunately, results from this study could not conclusively support either suppression accounts or selective rehearsal.

Still, some explanations for the findings in Landon and Kimball (2012b) seem much less viable. The current dual-factor theory of context change and strategy evaluation would not seem to be suited to explain this type of forgetting because both factors require mechanisms which depend on a single, discernible change: a global instruction to remember or forget an entire list rather than a single item. Item-specific instructions to forget would imply constantly changing contexts and encoding strategies, which would negate mental context match or mismatch at test and suggest that encoding strategies oscillate between poor and improved following every forget trial—mechanisms that are clearly inapplicable. Similarly, any retrieval inhibition mechanism, as a single-factor or part of a dual factor account, that is proposed to operate on an entire list could not explain these findings either (e.g., Bjork & Bjork, 1996; Geiselman et al., 1983; Pöstetter and Bäuml, 2010).

Though intentional forgetting accounts have been established based on lists rather than individual items, Anderson et al. (1994) and Anderson and Neely (1996) suggest an alternative inhibitory account with a mechanism for stimulus-specific response suppression described as the response competition theory of interference. The response competition theory of interference was introduced with retrieval-induced forgetting research discussed above. It states that when multiple responses are related to a particular stimulus term, the accessibility of one response can suffer due to competition from the other response impeding its relative memory strength, though the absolute item strength of the disadvantaged response and the strength of its association to the stimulus are left unimpaired. This competition can be overcome if one competing response is suppressed, resulting in an overall or absolute weakening of the response representation in memory (M. C. Anderson, 2003; Postman & Underwood, 1973)—a position initially proposed as an amendment to the response-set suppression theory of the *A-B*, *A-D* paradigm. Such an inhibitory mechanism appears consistent with the findings of Landon and Kimball (2012b), but this mechanism was developed and researched almost exclusively with retrieval-induced forgetting—a type of unintentional forgetting resulting from retrieval practice. It has not been investigated with respect to any type of goal-directed forgetting, particularly on an item-by-item basis.

Overview of the Present Research

With the following experiments, we were interested in testing whether and in what way suppression might serve as a mechanism for goal-directed forgetting at an item-specific level. In order to learn more about the cognitive processes and mechanisms related to directed forgetting, the present series of experiments expanded upon the design and procedures used by Landon and Kimball (2012b), which were distinct from those used in standard item and list methods of directed forgetting. By using these new methods, we could critically examine the theories associated with directed forgetting to determine their operations beyond the methodologies used when they were developed, which have limited them (Benjamin, 2006). Our goal was to identify general mechanisms responsible for memory updating.

The present experiments expanded on the results of Landon and Kimball

(2012b) by examining that paradigm in relation to key studies that have helped to develop interference and directed forgetting theories. We used such studies to explore important theoretical claims made by various inhibition accounts. Experiments 1A and 1B sought to explore aspects of interference as they relate to response competition in the presence vs. absence of a forget instruction. Experiment 2 investigated potentially relevant boundary conditions for the findings of Landon and Kimball (2012b), and provided further empirical evidence to differentiate between a selective rehearsal account and other inhibition accounts currently used to explain forgetting. Lastly, Experiment 3 had the advantage of not only testing the viability of the selective rehearsal account, but more importantly, it sought to examine the mechanism of suppression that we suspected might underlie the updating process.

Similar to the design of Landon and Kimball (2012b), the present experiments employed a single-remember control condition (R) to assess memory uncontaminated by specific competition. Here also, the dual-remember condition (RR) served as the standard control condition to examine response competition in the absence of an instruction to forget. Finally, the memory updating condition (FR) resembled a process typical of errorful learning, in which directed forgetting could be used to alter response competition between a TBF item (error) and a subsequent TBR item (correction).

Comparing the single-remember condition (R) to the dual-remember condition (RR) provided a measure of interference caused by encoding the stimulus with one versus two, responses. Comparing the single-remember condition (R) to the second item in the updating memory condition (FR) provided a measure of the effects on a TBR item attributable to an instruction to forget an earlier response associated with the stimulus term. Finally, the comparison of the dual-remember condition (RR) and memory updating condition (FR) measured directed forgetting by providing an examination of the potential costs and benefits associated with the forget instruction at the item level.

Experiment 1A

In the course of exploring interference theory, Postman et al. (1968) set up an experiment to test the response-set suppression theory developed with the *A-B*, *A-D* paradigm. The experiment implemented the standard design with three different methods for recall testing to assess memory for *A-B* pairs: Participants were provided with the stimulus term and told to only recall the first learned response, provided with the stimulus term and told to recall both learned responses in the order in which they were learned, or provided with both the stimulus and second response term and told to recall only the first learned response. On the immediate recall test, researchers were only interested in recall of the first learned response, and suppression was found to be highest and cued recall lowest in the third condition because cuing with the *A-D* pair was interpreted as perpetuating the suppression initiated during the second list learning process.

A similar effect has also been found with part-set cuing methods, where re-presenting a selection of items from a previously studied set is found to impair recall of other items from the set (Roediger, Stellon, & Tulving, 1977). For categorized lists, category names used as part-set cues appeared to facilitate rather than impair memory for category exemplars (see Nickerson, 1984, for a review), but impairment was maintained if both category names and category exemplars were used as cues for remaining exemplars (Mueller & Watkins, 1977; Watkins, 1975). Current theoretical explanations for part-set cuing findings would suggest that presenting the stimulus term with one of the responses would cause inhibition of the alternative association via sampling bias (Raaijmakers & Shiffrin, 1981), blocking (Roediger, 1973; Rundus, 1973), disruption of a retrieval strategy (Basden & Basden, 1995; Basden, Basden, & Galloway, 1977), and/or covert retrieval of cues and consequent suppression of alternatives (Anderson et al., 1994; Bäuml & Aslan, 2004).

Experiment 1A was modeled after Postman et al. (1968) to determine the effect of cuing recall of the first association, either a TBF or TBR association, when the test cue included the stimulus word with versus without the second response, a TBR item. Such a manipulation would determine whether or not recall of an initially learned stimulus-response association was affected when the competing stimulus-response pair was re-presented, and how such an effect would be impacted by an instruction to forget.

Based on findings of Postman et al. (1968)—the maintenance of inhibition caused by learning the second stimulus-response pairs when cuing with those pairs at test—and research with the part-set cuing effect, recall of the first-learned TBR association in the dual-remember condition (RR) should be impaired with the stimulus-response cuing method compared to the stimulus-only cuing method (Mueller & Watkins, 1977). However, it is possible that participants attempt to learn the two responses and the shared stimulus by attempting to integrate all three items in memory, in which case the stimulus-response cuing method would benefit recall (Anderson & McCulloch, 1999; Goodmon & Anderson, 2011).

For the memory updating condition (FR), if the initially encoded TBF association already suffers impairment based on a suppression mechanism resulting from learning the second stimulus-response pair, then cuing with that pair should maintain such impairment relative to stimulus-only cuing. Furthermore, inhibition due to suppression could combine with inhibition caused by part-set cuing to create a greater impairment of the TBF association with stimulus-response cuing. This pattern of results would reflect additive effects of the forget instruction and part-set cuing. When considered together with the part-set cuing effects predicted for the RR condition, two main effects of learning condition and cuing method would occur with the lowest rates of recall observed in the FR condition for the TBF item cued with the second-learned TBR association. The exception to this predication relates to the specific theory of part-set cuing suppression: If TBF items were already subject to suppression caused by the instruction to forget, then any further suppression enacted from part-set cuing methods would be negated because of either a decreased need to further suppress a weakened memory trace, or a shared mechanism for suppression.

According to error-correction research, there might be a potential for facilitative effects with the FR condition, such that cuing with the TBR stimulus-response association would lead to increased rates of recall of the TBF association. However, evidence potentially supporting such integration has only been observed when errors were generated prior to processing the correct item (Gimaldi & Karpicke, 2012; Kornell et al., 2009; Soraci et al. 1994). Furthermore, the same accounts have suggested only one direction for such facilitation: the error (TBF association) serving as a cue or alternative retrieval route to the correction (TBR association). With the absence of error generation in the present experiment and the TBR association being the retrieval cue for the stimulus-response cuing method, facilitation of memory for TBF associations in the updating memory condition does not seem theoretically plausible.

As a final, alternative prediction based on selective rehearsal, participants could use maintenance rehearsal to process TBF and TBR associations of the FR condition until they receive an instruction to remember or forget. Upon receiving the instruction, participants told to forget the association would end rehearsal, whereas participants told to remember the association would engage in elaboration of the association representation. During recall, memory strength alone would predict retrieval outcomes, and so TBF associations would be recalled at lower rates than TBR associations. This pattern would be predicted for both cuing methods because weakly encoded TBF associations would not compete with the TBR association, much like the scenario discussed above with offsetting inhibitory mechanisms. If we assume that selective rehearsal acts for the RR condition as well, both TBR associations would have been elaborated, and during recall, they would be predicted to compete. With the stimulus-response cuing method, this should produce part-set cuing effects in the RR condition. When considered together, a sub-additive interaction would occur between learning conditions and cuing methods such that the stimulus-response cuing method would only decrease rates of recall in the RR condition.

Method

Participants

Participants were 56 undergraduate students participating for course credit in introductory psychology courses at the University of Oklahoma. Data from four participants were excluded for failure to follow instructions.

Design

The within-subjects design included seven conditions comprising a 2 (associate learning condition: RR, vs. FR) X 2 (response learning position: first vs. second), and 2 (first-learned response test cuing: stimulus-only vs. stimulus with second response) factorial design with an additional single-remember (R) control condition.

Materials

Stimuli consisted of 384 words divided into semantically distinct word sets, drawn from the University of South Florida word association norms (Nelson, McEvoy, & Schrieber, 1998). Each set comprised one stimulus word and three of its semantic associates as responses, for a total of 96 stimulus words and 288 responses. The word sets were those used in Landon and Kimball (2012b) and were selected to avoid associations to words in other sets. A separate set of basic algebraic math problems served as stimuli for the distractor task. All aspects of the study were completed on a computer using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

Procedure

The experiment consisted of a study phase and cued-recall test phase separated by a two-minute distractor task. Participants received detailed instructions, which involved task practice and example slides, prior to the start each experimental phase. Part of the study phase instructions involved differentiating “correct” from “error” stimulus-response pairs: participants were told they would only be tested on correct pairs, and thus, they were instructed specifically to focus on remembering pairs labeled as correct and not pairs labeled as errors. During the study phase, a stimulus word in capital letters and a randomly determined response word in lowercase letters were presented together as a pair for 5500ms, and participants were tasked with noticing the semantic association between the stimulus and response words and then retyping the response word in full in a blank space, onscreen. After each presentation of a stimulus-response association, participants received a feedback slide lasting 1500ms with a picture of either a green check mark to indicate a correct to-be-remembered pair or a red “x” to indicate an erroneous to-be-forgotten pair, which served as a remember or forget trial, respectively (see Figure 1).

All study trials began with a blank screen presented for 500ms; the number and types of study trials were determined by experimental condition assignment. The updating memory condition (FR) comprised two trials: a forget trial presenting a particular stimulus-response pair immediately followed by a remember trial presenting the same stimulus now paired with a different response. The dual-remember condition (RR) comprised two trials as well: a remember trial presenting a particular stimulus-response pair immediately followed by another remember trial presenting the same stimulus now paired with a different response. The single-remember condition (R) comprised only one remember trial. In addition to the three conditions of interest, we used two types of catch trial sets to prevent participants from anticipating remember instructions. By only using the conditions of interest in the study, participants could have determined that the second of two trials would always be a remember trial. In order to prevent participants from anticipating the instruction to remember the second association in the FR condition, updating catch trial sets comprised two forget trials prior to the final remember trial, exposing participants to all three responses from the stimulus set. In order to prevent participants from anticipating the instruction to remember the second associate in the RR condition, remember catch trial sets comprised a remember trial followed by a forget trial. Catch trials were not analyzed.

Stimulus sets were randomly assigned anew to conditions for each participant. Stimulus assignment sought to emphasize comparisons of interest while controlling for possible response biases by roughly equating set assignment across conditions of interest: 22 stimulus sets assigned to the single-remember condition (23% of all sets), 22 assigned to the dual-remember condition (23% of all sets), 26 assigned to the updating memory condition (27% of all sets). Catch-trial sets were required to represent at least half of the stimulus-response assignments to their corresponding condition of interest: 12 stimulus sets assigned to the remember catch trial sets and 14 assigned to the updating catch-trial sets. In total, about 58.33% of trials began as a remember trial and 41.67% of trials began as a forget trial.

After the distractor task, participants took a cued-recall memory test comprising a total of 50 randomly ordered and randomly sampled, studied stimulus sets. For each of the FR, RR, and R conditions, stimulus words from 10 studied sets were re-presented onscreen, and participants were asked to recall as many studied response terms as possible, regardless of the instruction to remember or forget. For the FR and RR conditions, second-learned TBR stimulus-response pairs from another 10 studied sets were re-presented onscreen, and participants were asked to recall as many of the first-learned response terms as possible, regardless of the instruction to remember or forget. Only 10 sets from each condition for each cuing method were tested to avoid any possible response biases attributable to an uneven distribution of test items across conditions. The cued recall phase was self-paced and participants were not forced to respond.

Results

Analyses focused first on directed forgetting effects and then examined comparisons to the R control condition, which replicated the patterns of recall in Landon and Kimball (2012b). Finally, critical comparisons examined the recall of the first-learned association with regards to cuing method and study condition. Pairwise simple effect comparisons detailed the relationships between learning conditions.

Recall rate analysis began with an examination of standard directed forgetting effects in the stimulus-only cuing condition. There was a typical directed forgetting pattern, as evidenced by a significant interaction of memory instructions and response position, $F(1,51) = 28.98$, $p < .001$, $\omega^2 = .119$, $\eta^2 = .124$. The recall rate for the first-learned response (Figure 2) was higher in the RR condition ($M = .525$, $SD = .281$) than the FR condition ($M = .325$, $SD = .235$) reflecting directed forgetting costs, $F(1,51) = 24.33$, $p < .001$, $\omega^2 = .183$, $\eta^2 = .323$, whereas the rate for the second-learned response (Figure 3) was higher in the FR condition ($M = .504$, $SD = .245$) than the RR condition ($M = .373$, $SD = .238$) reflecting directed forgetting benefits, $F(1,51) = 15.06$, $p < .001$, $\omega^2 = .119$, $\eta^2 = .229$.

Simple effect comparisons between the R control condition ($M = .506$, $SD = .234$) and the RR condition indicated that the recall rate in the R condition was higher than that of the second-learned TBR response, $F(1,51) = 19.18$, $p < .001$, $\omega^2 = .149$, $\eta^2 = .273$, reflecting proactive interference, but did not differ from that of the first-learned TBR response, $F < 1$, $p > .455$, which suggested the absence of retroactive interference in the RR condition. Comparisons of the R condition to the FR condition indicated that the recall rate in the R condition was higher than that for the TBF response, $F(1,51) = 24.75$, $p < .001$, $\omega^2 = .186$, $\eta^2 = .327$, reflecting an impairment completely attributable to the forget instruction due to the absence of retroactive interference, but did not differ from that of the TBR response, $F < 1$, $p > .90$, reflecting a complete release from proactive interference in the FR condition.

The primary analysis of interest compared rates of recall of the first-learned responses (see Figure 2) for each of the two test-cuing methods in the FR and the RR condition. Two-way ANOVA results revealed a significant interaction, $F(1,51) = 4.65$, $p = .036$, $\omega^2 = .017$, $\eta^2 = .023$, with the stimulus-response cuing significantly impairing recall only in the RR condition, $F(1,51) = 7.37$, $p = .009$, $\omega^2 = .058$, $\eta^2 = .126$, and not in the FR condition, $F < 1$, $p > .485$. As with stimulus-only cuing, there were significant directed forgetting costs for the stimulus-response cuing method in that the recall rate for the first-learned response was higher in the RR condition than the FR condition, $F(1,51) = 7.05$, $p = .011$, $\omega^2 = .055$, $\eta^2 = .121$.

Discussion

The main purpose of Experiment 1A was to test the presence of retrieval inhibition acting on the TBF response in the memory updating condition (FR). Such inhibition was hypothesized to increase with use of the TBR stimulus-response cue as compared to the stimulus cue alone (Postman et al., 1968; Roediger et al., 1977). However, no such increase was observed for the first-learned TBF response in the FR condition; instead, the TBR stimulus-response cue only impaired recall of the first-learned TBR response in the RR condition. The absence of an effect of cuing method in the FR condition would suggest that recall of the first stimulus-response association (TBF) was not subject to any additional competition when cued with the TBR association. This finding can be readily explained by the selective rehearsal theory—curtailment of TBF rehearsal weakened the memory trace of the TBF response and the absence of co-rehearsal of first- and second-learned responses reduced the likelihood of interference, which altogether resulted in the recall of the TBF response being solely determined by its weakened memory trace, regardless of cuing method.

Yet results here would not completely exclude suppression explanations. Results show robust costs resulting from the forget instruction. Even when the first-learned TBR response was presumably subject to part-set cuing effects, recall was still higher than that of the TBF responses. If TBF associations were already subject to suppression, inhibition caused by part-set cuing might not additively increase the impairment (cf. Bäuml & Samenieh, 2012); rather it might be negated if some other suppression mechanism had already been enacted during study. Such a relationship would thus apply for all suppression accounts presently discussed: list-method directed forgetting suppression, retrieval-induced suppression, or executively controlled suppression. In all cases, if suppression decreased memory strength during study, the consequent adverse impact might be observed, but not compounded, at retrieval.

Despite the use of small and interrelated stimulus sets where *A-B*, *A-D* associate pairings occurred in immediate sequence, there was no evidence of facilitation for either the FR or RR conditions. The lack of facilitation and indeed the part-set cuing in the RR condition appear analogous to part-set cuing inhibition caused by category exemplars or a combination of exemplars and category names acting to cue the remaining exemplars

(Mueller & Watkins, 1977; Watkins, 1975; but see, Reardon, Polzella, & Brown, 1975). One explanation for part-set cuing observed with the RR condition would be the strategy disruption theory. In this case, cuing with the second-learned association might have disrupted a retrieval strategy generated by the learner based on serial learning order at encoding (Basden & Basden, 1995; Basden, Basden, & Stephens (2002).

Alternatively, the suppression theory states that retrieval guided by part-set cues initiates a process of inhibition whereby part-set cues are covertly retrieved, requiring the suppression of interfering non-cue items (Anderson et al., 1994; Bäuml & Aslan, 2004). Revisions to the theory further suggest that such suppression can be offset by a combination of interitem associations and transfer-appropriate organization of cues (Bäuml and Aslan, 2006), and, with regards to the FR condition, the theory suggests that if non-cue items already suffer impaired accessibility (via intentional or context-dependent forgetting), part-set cues will not inhibit, and in certain cases, they will facilitate recall (Bäuml & Samenieh 2010; Bäuml & Samenieh, 2012). This account, titled the three-factor account of part-set cuing, much like the theory of strategy disruption, can explain the present findings with the RR condition based on a transfer-inappropriate organization of cues, and it might explain the null findings for the FR condition with the assumption that the TBF responses already suffered impaired accessibility and would therefore not be further inhibited by part-set cues.

In sum, Experiment 1A findings support selective rehearsal as the most parsimonious explanation for the updating process. Though suppression interpretations of the findings cannot yet be excluded, they make the same empirical predictions as the selective rehearsal account, while positing an additional, direct suppression mechanism that appears to originate during study and would not additively combine with part-set cuing effects. Results from the present experiment alone cannot support or deny the existence of such a suppression mechanism. Such an assessment required a more direct test of the suppression mechanism. One way to test the existence of suppression would be to determine if the re-presentation of the purportedly suppressed TBF association would release it from suppression (Bjork & Bjork, 1996; Bjork et al., 1998; Geiselman et al., 1983). Experiment 1B sought to investigate conditions under which suppression might be released by reversing the cuing procedures—cuing with the first-learned TBF or TBR stimulus-response association. This has the added advantage of testing the part-set cuing effect in the dual-remember condition when the cue fit a retrieval strategy based on the serial order of the learning process.

Experiment 1B

The purpose of Experiment 1B was to further test inhibition accounts used to explain the benefits of errorful learning by again manipulating cuing methods during recall. In this experiment, the first learned stimulus-response pair, labeled either TBF or TBR in the respective updating (FR) and dual-remember conditions (RR), was used as a cue for the retrieval of the second TBR stimulus-response pair.

For the FR condition, a selective rehearsal account would predict that TBF cuing would not affect recall rates of the TBR response. Similar to predictions for TBF retrieval in Experiment 1A, retrieval of the TBR response should be dictated by its memory strength alone. While the TBF response would only be weakly encoded in memory, the TBR response would be elaborately encoded in memory. Without the co-rehearsal of the two responses, there would be a lower likelihood of interference. Thus, the strengthened memory of the TBR response would demonstrate similar recall rates between the two cuing methods, which should be equivalent to those of the single-remember baseline condition based on the absence of proactive interference.

Alternative predictions for the memory updating condition based on a suppression account could be drawn from previous directed forgetting research. E.L. Bjork and R.A. Bjork (1996) manipulated the task intervening between study of the two lists and testing: no task (immediate recall); a recognition test with TBF items as distractors; and a recognition test without TBF items as distractors. Unlike in the other two conditions, when TBF items were used as distractors in the interpolated recognition task, directed forgetting benefits were eliminated (i.e., proactive interference was reinstated). In contrast to other types of interpolated tasks—in particular, indirect memory tests that included TBF items—researchers found that only when the interpolated task explicitly referred back to the TBF learning episode were directed forgetting effects eliminated (E.L. Bjork & Bjork, 1996; E.L. Bjork et al., 1998). Based on such findings with directed forgetting research, re-presenting the initial TBF stimulus-response as a retrieval cue in Experiment 2 could similarly be predicted to reinstate some or all of the proactive interference observed in the dual-remember condition (Bjork et al., 1998), thereby impairing recall of the second-learned TBR response.

Additionally, the re-presentation of the TBF stimulus-response pair might facilitate or impair the retrieval of the TBR association based on part-set cuing theories (Anderson et al., 1994; Basden & Basden, 1995; Bäuml & Aslan, 2012; Raaijmakers & Shiffrin, 1981; Roediger, 1973; Rundus, 1973). Though part set-cuing effects were only observed for the RR condition and not the FR condition when recall was cued with the second-learned association in Experiment 1A, cuing with the first-learned association might alter the dynamics of retrieval.

The sampling bias explanation of part-set cuing, based on the search of associative memory (SAM), claims that cues initiate a search of memory for the remaining targets, and this search will end if sampling continues to result in failures, as dictated by a stopping rule. Sampling is assumed to occur with replacement of the sampled item back into memory, and cues are hypothesized to be frequently sampled—re-sampled cues constitute failures, which cause the search to end with infrequent sampling of non-cue items (Raaijmakers & Shiffrin, 1981). Based on the associative sampling bias theory, increased sampling of the TBF association should result in increased rates of failure and earlier attainment of the stopping rule, which would interfere with retrieval of the TBR association.

The theory of blocking claims that part-set cues benefit from increased memory strength relative to un-presented non-cue items, and the relative increase in memory strength reduces the likelihood of retrieving the non-cue items (Rundus, 1973). Based on the blocking theory, cuing with the TBF association would increase its associated memory strength and decrease that of the alternative TBR association. With regards to the theories of associative sampling bias and blocking, recall of the second-learned TBR associations in the FR condition would be subject to reinstated proactive interference and/or part-set cuing inhibition caused by the TBF association cues. Findings from Experiment 1A can be extended to suggest that these effects would not be additive.

The part-set cuing theories of strategy disruption and the three-factor account would make alternative predictions because cuing the second-learned association with the first-learned association might fit well with learner retrieval strategies. With regards to both theories, if serial position of the TBF association was used as part of a retrieval strategy to later recall the TBR association, then part-set cuing with the TBF item might be predicted to facilitate recall. However, an added dimension based on the forget instruction complicates such a straightforward prediction. To this end, strategy disruption theory remains largely silent, as the motivation to forget has not been discussed in relation to learner retrieval strategies.

The three-factor theory states that cuing with TBF items reinstates the context of learning related to the inhibition, which would then facilitate recall of other inhibited items, but this feature of the theory was based on intra-list cuing conditions—cuing the remaining items from the TBF list using TBF items as cues (Bäuml & Samenieh 2010; Bäuml & Samenieh, 2012). If we assume that TBF and TBR information generally do not share the same learning context—intentions and strategies should differ considerably[2]—then cuing with previously inhibited information should activate the context surrounding inhibition, rather than the context that would facilitate recall of the TBR information. Thus, we would predict competing influences of facilitative transfer-appropriate cuing organization based on the serial order of learning within cue set learning conditions but conflicting reinstatement of the learning context associated with the TBF association cues, which were subject to the forget instruction. It was possible

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[2] Differences in context of learning, circumstances of processing at study, does not map onto the mental context change account of Sahakyan and Kelley (2002), which requires a global instruction to forget and a match of retrieval context to the context of study.

that such competing influences would cancel.

For the dual-remember condition, cuing with the first-learned TBR association involves somewhat similar but simpler predictions. Part-set cuing theories of associative sampling bias, blocking, and the single-factor retrieval competition would predict a part-set cuing impairment similar to that exhibited in Experiment 1A because the impairments are based on the sampling or strength of the part-set cues alone. Alternatively, cuing with the first-learned TBR association could alter the impact of part-set cues to not impair or facilitate the retrieval of the second-learned TBR association if the cuing supports the retrieval strategies of learners developed during study—retrieval strategies based on serial processing of associations within cue sets. In this case, cuing with the first-learned TBR association would lead to the retrieval, rather than inhibition, of the second-learned association. As previously mentioned, only two theories of part-set cuing would make this prediction: the theory of strategy-disruption and the three-factor theory of part-set cuing.

Method

The experimental methods for Experiment 1B remained the same as Experiment 1A with the following exceptions: There were 58 new participants drawn from the same subject pool; data from six participants were excluded for failure to follow instructions; and for the updating and dual-remember conditions, first—not second—learned stimulus-response pairs were presented as recall cues for the second-learned association for half of the tested stimulus sets.

Results

Analysis began with an examination of standard directed forgetting effects in the stimulus-only cuing condition, which paralleled those in Experiment 1A. Again, there was a typical directed forgetting pattern, as evidenced by a significant interaction of memory instructions and response position, $F(1,51) = 30.85$, $p < .001$, $\omega^2 = .125$, $\eta^2 = .131$. The recall rate for the first-learned response (Figure 4) was higher in the RR condition ($M = .467$, $SD = .193$) than the FR condition ($M = .294$, $SD = .187$), reflecting directed forgetting costs, $F(1,51) = 28.97$, $p < .001$, $\omega^2 = .212$, $\eta^2 = .362$, whereas the rate for the second-learned response (Figure 5) was higher in the FR condition ($M = .456$, $SD = .198$) than the RR condition ($M = .387$, $SD = .189$), reflecting directed forgetting benefits, $F(1,51) = 5.45$, $p = .024$, $\omega^2 = .041$, $\eta^2 = .097$.

Also as in Experiment 1A, simple effect comparisons between the R control condition ($M = .471$, $SD = .228$) and the RR condition indicated that the recall rate in the R condition was higher than that of the second learned TBR response, $F(1,51) = 8.37$, $p = .006$, $\omega^2 = .066$, $\eta^2 = .141$, reflecting proactive interference, but did not differ from that of the first-learned TBR response, $F < .1$, $p > .90$, which suggested the absence of retroactive interference in the RR condition. Comparisons with the FR condition also paralleled those for Experiment 1A, indicating that the recall rate in the R condition was higher than that of the TBF response, $F(1,51) = 18.99$, $p < .001$, $\omega^2 = .147$, $\eta^2 = .271$, attributable solely to the forget instruction due to an absence of retroactive interference, but did not differ from that of the TBR response, $F < 0.24$, $p > .63$, which demonstrated a complete release from proactive interference in the FR condition resulting from the forget instruction.

The primary analysis of interest compared rates of recall of the second-learned responses (see Figure 5) for each of the two recall methods in the FR and the RR condition. Two-way ANOVA results indicated a main effect of the forget instruction such that it facilitated memory for the TBR response in the FR condition, collapsing across cuing methods, $F(1,51) = 10.73$, $p = .002$, $.045 < \omega^2 < .086$, $\eta^2 = .077$, but no main effect of cuing methods, $F < 0.1$, $p > .9$, and—in contrast to Experiment 1A—no interaction, $F < 0.16$, $p > .69$, with similar recall rates for cuing methods in both RR and FR conditions, *F*s < 0.1, *p*s > .75. Reaffirming previous findings of directed forgetting benefits with the stimulus-only cuing methods, recall rates for the second-learned response were higher in the FR condition than the RR condition for the stimulus-response cuing method, $F(1,51) = 7.23$, $p = .009$, $\omega^2 = .057$, $\eta^2 = .124$.

Discussion

Similar to the findings of Experiment 1A, recall patterns in Experiment 1B for the FR condition were not affected by cuing methods. Across both cuing methods, the complete release from proactive interference in the FR condition was maintained, which would suggest that retrieval of the TBR response was independent of the TBF association and lend further support for a selective rehearsal explanation of memory updating—weakly encoded TBF items and the absence of co-rehearsal of TBF and TBR items in the FR condition mitigated interference associated with retrieving elaborately encoded TBR associations. Unlike in Experiment 1A, part-set cuing effects were also absent from the RR condition, and such an absence would be best explained by the strategy disruption theory and three-factor account of part-set cuing.

For suppression theories, the claim that suppression can be released with appropriate cuing methods (e.g., contextual factors related to episode of learning, or the re-presentation of the suppressed item itself) remains a core aspect of suppression accounts. Such a release has been used to explain the failure to obtain differences in recognition testing between TBF and TBR items with list-method directed forgetting (Geiselman et al., 1983; but see Benjamin, 2006), and was predicted here based on the findings of Bjork and colleagues (Bjork & Bjork, 1996; Bjork et al., 1998).

However, Anderson (2003) claims that with retrieval-induced or executively controlled suppression, the re-presentation of a suppressed item would not necessarily release it from its inhibited state. Anderson, much like Benjamin (2006), suggested that any lack of differences on tests that re-present the suppressed item could be attributed to non-diagnostic testing caused by reliance upon familiarity. However, here, we failed to obtain differences on a retrieval test that required reliance on recollection rather than familiarity. Clearly, suppression accounts would not be able to explain the findings here without the assumption that re-presentation did not release the TBF association from suppression. If this were true, the observed absence of a retrieval detriment for the TBR association would no longer exclude suppression accounts. Such accounts would suggest that the suppression mechanism was enacted by the forget instruction during study, and caused a lasting decrease in the memory strength of the TBF association, a decrease strongly resistant to dynamics of retrieval at test.

If suppression were retained as a potential explanation for FR results, part-set cuing theories have difficulty explaining FR results observed here. Without evidence for impairment caused by the part-set cues, the associative sampling bias and blocking theories are not viable. Though there would be potential for the strategy disruption theory or three-factor account of part-set cuing to explain the absence of impairment, it would remain unclear how the forget instruction affected the manipulation.

In Experiment 1A, equivalent recall rates of the TBF association for both cuing methods could be explained with the assumption that inhibitory effects from both suppression and part-set cuing offset one another; this claim was supported by evidence of inhibitory effects resulting from the instruction to forget and from part-set cuing in the FR and RR conditions, respectively. No such explanation can account for findings with the second-learned TBR response in the present experiment. While the forget instruction clearly facilitated retrieval of the TBR response in the FR condition, the part-set cuing manipulation did not facilitate recall in the RR condition. Thus, a similar claim of sub-additive effects of facilitation would be unsubstantiated.

For the RR condition, the absence of impairment with the stimulus-response cuing method would argue against part-set cuing theories of associative sampling bias, blocking, and the single-factor retrieval competition. However, the remaining strategy disruption and three-factor suppression theories would predict that presentation of the first-learned TBR association would not impair and would even facilitate recall of the second-learned TBR association because of the interitem semantic associations and because the cuing matched the serial order of study (Basden & Basden, 1995; Bäuml & Samenieh 2010). One caveat here would be that the present experiments did not include a control condition in which cues were completely absent from recall. Such a control, which would require free recall of responses, would completely assess the degree of facilitation produced by either the stimulus-only or stimulus-response cues. Any facilitation relative to a free recall control observed for both stimulus-only and stimulus-response cuing conditions would provide further evidence supporting strategy disruption and the three-factor theory of suppression. This would also suggest that the facilitation provided by part-set cues might have been obscured by facilitation in the FR condition caused by suppressing the competing TBF response.

Ultimately, an in-depth examination of part-set cuing theories is beyond the scope of the current project. We discuss part-set cuing here only to clarify the potential mechanisms influencing recall in the updating conditions. Given the caveat above, strategy disruption or the three-factor suppression seem to best account for the presence and absence of part-set cuing in Experiment 1A and 1B, respectively. This influences our understanding of the updating process by demonstrating that the part-set cuing mechanisms did not impact retrieval of either the outdated TBF information or the new TBR information. It remains to be determined whether the lack of effect was caused by reliance upon memory strength associated with selective rehearsal or due to overlapping suppressing and facilitative mechanisms predicted by the suppression account.

In sum, considering Experiments 1A and 1B together, we see that cuing in the FR condition with either the TBR or TBF association did not facilitate recall relative to presenting the stimulus word alone, contrary to predictions based on error correction research suggesting a facilitative role for outdated information (Kornell et al., 2009; Soraci et al., 1999). The selective rehearsal account can explain findings from both experiments, but with a flexible interpretation of suppression theory, suppression accounts might yet be viable. If we retain suppression accounts, findings here succeeded in delimiting important features for their future investigation: suppression originated at study, and did not interact with cuing manipulations at retrieval.

Experiment 2

Findings from Experiments 1A and B supported the selective rehearsal account of updating memory, but further research was needed to determine the viability of suppression accounts as alternative explanations. Experiment 2 tested such explanations and explored potential boundary conditions for directed forgetting effects in memory updating. A common assumption with intentional forgetting is that it would be more difficult to achieve if the TBF information relates to TBR information (Johnson, 1994). Here we manipulated the relatedness of words within cue sets to determine how the updating process would be impacted when stimulus and response do or do not share semantic features. Also, we added another associative learning condition to determine how the typical ordering of the updating memory process—learn, forget, replace—might influence forgetting and learning. With these manipulations, we could further test key assumptions of selective rehearsal and suppression accounts.

The present design was based on Golding, Long, and MacLeod (1994), which explored the effect of instruction order on directed forgetting and examined effects of semantic relations between TBR and TBF items. They used an item-method manipulation, and presented items sequentially in pairs such that first-learned item and second-learned item comprised a pair, which was either related or not. Related pairs comprised individual nouns that often co-occurred together in English language (e.g., ice and cream, seat and belt, cheese and cake); unrelated pairs comprised the same nouns that were then quasi-randomly paired such that no two related items appeared in sequence. Pair relatedness was manipulated first between subjects (Experiment 1) and then within subjects (Experiment 2). An instruction to forget or remember followed each item, producing a within-subjects factorial manipulation of instructions for pairs (i.e., RR, RF, FR, FF). Free recall and recognition tests were administered to measure memory for individual TBR and TBF items for each instruction condition as well as memory for completed pairs of items for each instruction condition—recall or recognition of both items comprising a pair.

Results for both free recall and recognition indicated a main effect of item relatedness, for both within and between-subject manipulations, with higher rates for related pairs than unrelated pairs and main effects of the directed forgetting manipulation with lower rates for TBF words and higher rates for TBR words. However, when pairs were related, participants recalled and recognized TBF words and completed word pairs from the *reversed-updating* condition (RF) at higher rates than other conditions involving a forget instruction (FR, FF); this reduced the costs typically associated with TBF items. When pairs were unrelated, no such differences were observed, with rates of TBF and TBR items in the RF condition appearing similar to those in the FR condition and to those TBF items in the FF condition. The authors concluded that maintenance rehearsal of TBF items and elaboration of TBR items resulted in the standard directed forgetting costs and benefits, regardless of test type, but went on to claim semantic relatedness as a limiting factor for item-method directed forgetting effects—a limitation evidenced by the RF condition and attributed to unintentional continued rehearsal of a TBF item prior to presentation of the next item due to the semantic relationship to the preceding elaborately rehearsed TBR item.

In list-method research, between-list semantic associations have also insulated TBF items in the first list from forgetting (Conway, Harries, Noyes, Racsma’ny, & Frankish, 2000, Experiment 6; Takahashi & Itsukushima, 2009). Conway, et al. (2000) suggested that the degree of inhibition caused by an instruction to forget depends on the level of competition in memory between TBF and TBR lists. Lists that are unrelated or weakly related would be encoded in memory as competitors, necessitating and facilitating inhibition, whereas lists that are closely related would be integrated, in which case access to the TBF list would be maintained as a byproduct of maintaining access to the related TBR list.

Thus, semantic relations between TBF and TBR items have been found to reduce both item- and list-method directed forgetting in recall, and to reduce item-method directed forgetting in recognition as well. Two exceptions to this general pattern include Woodward and Bjork (1971) and Horton and Petruk (1980), which found directed forgetting effects in free recall relatively unaffected by semantic relations between TBF and TBR category exemplars appearing in short lists or individually. Beyond the studies previously mentioned, no known research has investigated the effect of semantic relations between TBF and TBR items for either list-method or item-method directed forgetting. This absence has likely resulted from the assumption that a forget instruction would not successfully disrupt such pre-established semantic links, and that such links would promote integration of TBF with TBR information (see Anderson & McCulloch, 1999; Goodmon & Anderson, 2011; Johnson, 1994).

In fact, this assumption has roots in studies using semantically related stimuli in the *A-B, A-D* paradigm that demonstrated a facilitative effect of memory for *B* and *D* responses (see Crowder, 1976). However, McGeoch and colleagues found contradictory evidence suggesting that as similarity increased, so did interference (McGeoch & McGeoch, 1937; as discussed in Crowder, 1976). As a result, Osgood (1949) presented his *transfer and retroaction surface theory*, which predicted relative rates of facilitation and interference when either or both the stimulus and response terms in the *A-B, A-D* paradigm vary from being identical to completely unrelated.[3] His theory predicts that when responses share the same stimulus term and are semantically related, memory for both responses should be facilitated. Though Osgood's theory was limited to findings with the *A-B, A-D* paradigm and not directed forgetting, the corollary would be that when items or lists compete for conscious recollection, semantic relations between such items or lists would reduce competition and increase the likelihood for facilitation. Thus, Osgood's theory supports the prediction that directed forgetting would be difficult to achieve (i.e., costs and benefits would be reduced) when the TBF and TBR items or lists are related to each other, particularly in the present case when such items share the same stimulus term.

Still, since a degree of directed forgetting was observed in Landon and Kimball (2012) as well as in Golding et al. (1994) and Conway et al. (Experiment 5, 2000), directed forgetting with semantically related TBF and TBR words might still be observed, although the effectiveness of the instruction and the size of the directed

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[3] One important critique of Osgood's transfer and retroaction surface theory is that it does not speak to varying degrees of semantic relations occurring *between* stimulus and response, but rather focuses on semantic relatedness of the stimulus terms and response terms, independent of one another.

forgetting effects might be reduced. However, an intriguing question arises from Golding et al. (1994), which saw reduced directed forgetting effects in the reverse updating condition (RF) for related item pairs. Although Golding et al. explained this reduction as resulting from an inability to stop rehearsal of the TBF item due to its relation to the TBR item, Osgood's theory would suggest that the same difficulty should occur in the standard memory updating condition (FR).

One possible explanation would suggest that the order of forget and remember instructions has intrinsic importance and relates to the mechanism of inhibition, that in order to observe successful forgetting, the original learning needs to be replaced by new learning. Replacement learning occurs in the standard directed-forgetting sequence of learning an item or list, being told to forget that item or list, and then replacing the former with a new item or list to remember. This would not exclude the possibility for differential rehearsal of forget and remember items, but it would suggest the presence of a mechanism above and beyond that of selective rehearsal that depends specifically on replacement learning. This replacement explanation relates to other boundary conditions discussed with the list method in the directed forgetting literature (cf. E.L. Bjork, et al., 1998): that the forget instruction has to be explicit (Weiner & Reed, 1969), that an unfilled interval or a separate task following the forget instruction is not sufficient to observe forgetting (E.L. Bjork & Bjork, 1996), that the second list must be adequately encoded as a competitor (Conway, et al., 2000; Gelfand & Bjork, 1985; as described in R.A. Bjork, 1989), and that delaying the forget instruction until after the study of replacement learning reduces the effectiveness of the forget instruction (R.A. Bjork, 1970; Epstein, Massaro, & Wilder, 1972; Roediger & Tulving, 1979).

If the learn-forget-replace sequence affects the occurrence or absence of directed forgetting effects, it might help define the circumstances in which the theoretical mechanism/s responsible for directed forgetting would operate. This sequence is central to list-method directed forgetting procedures but with item-method directed forgetting, TBF and TBR instructions occur intermittently, creating a string of forget and remember trials that are not connected in any formal sequence. Golding et al. (1994) departed from typical item-method procedures in this respect by creating a structure for replacement with the related condition pairs—such a structure was not present for the unrelated condition pairs, which demonstrated similar rates of recall and recognition for TBF and TBR items.

Perhaps current directed forgetting theories differentiated by standard item- or list- methods capture this distinction. Other researchers have previously placed importance on the need to replace TBF information (Bjork, 1970; Bjork, 1989), but such accounts suggest that replacement facilitates the competition between items or lists, which initiates an ill-defined process of suppression. Our research here has thus far revealed patterns of recall in Experiments 1A and 1B most readily accounted for by selective rehearsal, but it has not yet excluded such suppression as a possible explanation.

In the present experiment, in which a shared stimulus was associated with a TBF response and a replacement TBR response in typical or reversed order (FR and RF, respectively), we were able to test the importance of the learn-forget-replace order in directed forgetting. If retrieval and recognition of TBR and TBF responses are determined completely by the elaborative rehearsal afforded to them as predicted by the selective rehearsal account, there should not be differences between TBR and TBF items in the FR and RF conditions (Bjork, 1970). Golding et al. (1994) proposed that rehearsal of the TBF item continued despite the instruction to forget because of its relation to the TBR item. By this prediction, directed forgetting costs in the RF condition should be substantially reduced with related cue sets, but other patterns of directed forgetting should be similar between the RF and FR conditions. In the absence of such a reduction, the selective rehearsal account would have difficulty reconciling any differences in directed forgetting patterns between RF and FR conditions without proposing some additional mechanism.

Similarly, if this sequence were found to be important to goal-directed forgetting, explanations involving a suppression mechanism would need to account for this sequence. Specifically, the suppression mechanism proposed to explain retrieval-induced forgetting has been described as cue-independent, resulting from a motivation to reduce competition among items in memory (Anderson, 2003). With the reverse-updating condition (RF), competition would still be present, and so the need to suppress the TBF item should not change. Similarly, the suppression mechanism proposed as an explanation for findings with the think/no-think paradigm has been described as the result solely of a motivation to limit the future retrieval of unwanted items; with directed forgetting, the motivation to forget TBF items should not differ based on the order of instructions. If any difference in forgetting were found between the typical FR and reversed RF sequences, this difference would not be explained by these theories of suppression.

Thus, in Experiment 2, we expanded our design to include a reverse updating condition (RF) in order to explore how such a departure from the standard learn-forget-replace sequence would impact the directed forgetting process. Also, similar to Golding, et al. (1994), we manipulated the relatedness of stimulus set information to determine how semantic relations might modulate the ability to forget, but contrary to Golding et al., relatedness here was manipulated by the presence or absence of semantic relations between the stimulus and response terms. Effects of sequence order and semantic relatedness were assessed with stimulus-cued recall and yes/no stimulus-response recognition tests.

Selective rehearsal and suppression theories make similar predictions for cued recall tests, but make distinct predictions for recognition tests. Selective rehearsal has traditionally been associated with a pattern of results revealing directed forgetting costs in the absence of benefits (Golding et al., 1994), which is explained by differences between TBF and TBR representation strengths in memory resulting from selective elaboration of the TBR items. Suppression theories have been associated with a pattern of results revealing the absence of costs and the presence of benefits (Benjamin, 2006; Sahakyan, et al., 2009). The absence of costs has previously been explained as either a release from suppression that occurs with the re-presentation of the suppressed item (Bjork & Bjork, 1996) or by familiarity-based recognition testing that fails to appropriately discriminate (Anderson, 2003; Benjamin, 2006).[4] The presence of benefits

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[4] We have addressed this claim by employing a recognition test that requires retrieval of the specific learning context of study in order to make memory decisions (Landon & Kimball, 2012b).

has been attributed to a decrease in proactive interference caused by the forget instruction (Benjamin, 2006; Sahakyan, et al., 2009).

Method

Participants

Participants were 198 undergraduate students at the University of Oklahoma participating for course credit in introductory psychology courses or volunteering for gift certificates, of which 8 participants opted to exclude their data from analyses. Of the 190 participants who agreed to include their data, 93 were assigned to the unrelated stimuli condition, such that 46 received a final recall test and 47 received a final recognition test. The remaining 97 participants were assigned to the related stimuli condition, such that 47 received a final recall test and 50 received a final recognition test.

Design

The current experiment was modeled after the within-subjects design of Experiments 1A and 1B with the addition of the RF learning condition and the between-subjects manipulation of both stimuli relatedness and test type. Thus, the present experiment consisted of a 3 (associate learning condition: RR, FR, and RF) X 2 (response learning position: first vs. second) and the single-remember (R) control, X 2 (Stimuli relatedness: related vs. unrelated) X 2 (Memory testing: cued-recall vs. recognition) mixed factorial design.

Materials

Related stimulus sets consisted of the same pairs as those used in Experiments 1A and B, but for the recognition experiment, we added one associate to each set in order to have an appropriate number of foils. Related stimulus sets now comprised 96 stimulus cues with 384 response associates. Our approach to stimuli relatedness differed from that of Golding et al. (1994). We used two stimulus-response associations as different paired items, as opposed to single items presented as part of a single pair, and we defined semantic relatedness as stimulus-response forward association strength, such that both the TBF and TBR responses were related to a stimulus item, but relations between the targets were not systematically directional. Additionally, different responses with different association strengths were randomly assigned to forget and remember conditions. Unrelated stimulus sets were similarly drawn from the University of South Florida word association norms (Nelson et al., 1998) and were selected to minimize intra- and inter-set associations, with preference given to the former. Each unrelated stimulus set similarly comprised one stimulus word and four unrelated words as responses, for a total word count equivalent to that of the related stimulus sets.

Procedure

All aspects of the study phase procedure remained the same with the following exception: The reverse updating condition (RF) served as a condition of interest and as such, stimulus assignment was altered to emphasize comparisons of interest (see Figure 6). The following set assignment attempted to equate the number of cue sets assigned across conditions of interest and minimize the possibility of response bias: 18 stimulus sets assigned to single-remember condition (≈19% of all sets), 20 assigned to the dual-remember condition (≈21% of all sets), 22 assigned to the updating memory condition (≈23% of all sets), 20 assigned to reverse updating memory condition (≈21% of all sets). The updating catch trial set (described below) consisted of 16 assigned sets. In total, about 60% of trials began as a remember trial and 40% of trials began as a forget trial.

For the cued-recall test phase, all aspects remained the same as in the stimulus-response cuing method of Experiments 1A and 1B with the following exception: The cued-recall memory test comprised a total of 60 randomly ordered and randomly sampled, studied stimulus sets with 15 stimulus words drawn from each of the four conditions of interest (i.e., single-remember, dual-remember, reverse updating, and updating memory).

For the recognition test phase, we used a procedure similar to that of Landon and Kimball (2012b, Experiment 4). Test pairs comprised of previously studied stimulus items paired with either previously studied responses or new responses, which served as foil pairs. For the related and unrelated stimuli conditions, foils were drawn from the sampled cue sets and comprised unpresented associates or unrelated words, respectively. Test stimuli consisted of a total of 60 randomly sampled, studied stimulus sets with 15 stimulus words drawn from conditions of interest and 15 corresponding foil response/s presented at a random interval. Thus, the recognition test comprised a total of 210 test item pairs: 15 remember items with 15 corresponding foil pairings from the single-remember condition; 15 remember and 15 remember/forget item with 30 corresponding foil pairings from each of the dual-remember, updating memory, and reverse updating conditions. We again equated the number of items tested to avoid any possible response biases attributable to an uneven distribution of test items across conditions. Participants were told to identify all previously studied stimulus-response pairs, regardless of the instruction to remember or forget.

Results

Cued Recall Test Results

Conditions Comparable to Conditions in Experiments 1A and 1B

Analysis here began with an examination of standard directed forgetting effects and simple effect control comparisons with related and unrelated stimuli for the three learning conditions (R, RR, and FR) examined in Experiments 1A and 1B. In the comparisons of FR to RR conditions, there were typical directed forgetting patterns similar to those found in Experiments 1A and 1B with stimulus-only cued recall, evidenced by a significant interaction of memory instruction and response position for related stimuli, $F(1,46) = 42.23$, $p < .001$, $\omega^2 = .18$, $\eta^2 = .19$, and for unrelated stimuli, $F(1,45) = 23.42$, $p < .001$, $\omega^2 = .109$, $\eta^2 = .115$. The recall rate for the first-learned response (Figure 7) was higher in the RR condition (related: $M = .454$, $SD = .227$; unrelated: $M = .157$, $SD = .148$) than the FR condition (related: $M = .250$, $SD = .185$; unrelated: $M = .071$, $SD = .076$) reflecting directed forgetting costs for related stimuli, $F(1,46) = 32.69$, $p < .001$, $.144 < \omega^2 < .252$, $\eta^2 = .262$, and for unrelated stimuli, $F(1,45) = 21.65$, $p < .001$, $.101 < \omega^2 < .183$, $\eta^2 = .194$. The rate for the second-learned response (Figure 8) was higher in the FR condition (related: $M = .485$, $SD = .242$; unrelated: $M = .143$, $SD = .132$) than the RR condition (related: $M = .357$, $SD = .215$; unrelated: M=0.1, $SD = .106$) reflecting directed forgetting benefits for related stimuli, $F(1,46) = 20.56$, $p < .001$, $.094 < \omega^2 < .172$, $\eta^2 = .183$, and for unrelated stimuli, $F(1,45) = 6.45$, $p = .015$, $.029 < \omega^2 < .056$, $\eta^2 = .067$.

Simple effect comparisons between the R control condition (related: $M = .512$, $SD = .207$; unrelated: $M = .132$, $SD = .127$) and the RR condition indicated that the recall rate in the R condition was higher than that of the second-learned TBR response of the RR condition for related stimuli, $F(1,46) = 33.98$, $p < .001$, $.149 < \omega^2 < .260$, $\eta^2 = .270$, and for unrelated stimuli, $F(1,45) = 4.41$, $p = .042$, $.018 < \omega^2 < .036$, $\eta^2 = .047$, reflecting proactive interference. The recall rate in the R condition was higher than that of the first-learned TBR response of the RR condition for related stimuli, $F(1,46) = 4.88$, $p = .032$, $.02 < \omega^2 < .04$, $\eta^2 = .05$, but did not differ significantly for unrelated stimuli, $F(1,45) = 1.66$, $p = .205$, $.004 < \omega^2 < .007$, $\eta^2 = .018$, which suggested that retroactive interference occurred with related but not unrelated stimuli. Similar patterns of proactive interference in the absence of retroactive interference for the RR condition were observed previously in Experiments 1A and 1B.

Also, as found in previous experiments, comparisons between the R condition and the FR condition indicated that the recall rate in the R condition was higher than that of the TBF response for related stimuli, $F(1,46) = 54.84$, $p < .001$, $.223 < \omega^2 < .364$, $\eta^2 = .373$, and unrelated stimuli, $F(1,45) = 10.54$, $p = .002$, $.049 < \omega^2 < .094$, $\eta^2 = .11$, reflecting an impairment attributable to the forget instruction, but did not differ from that of the TBR response for related stimuli, $F(1,46) = 1.07$, $p = .31$, $0 < \omega^2 < .001$, $\eta^2 = .011$, or for unrelated stimuli, $F < 0.44$, $p > .51$, reflecting a complete release from proactive interference in the FR condition.

Reverse-updating Patterns of Directed Forgetting

Again, analyses began with an examination of directed forgetting effects for the RF condition with both related and unrelated stimuli. There were significant interactions of memory instruction and response position for related stimuli, $F(1,46) = 9.62$, $p = .003$, $\omega^2 = .044$, $\eta^2 = .05$, and for unrelated stimuli, $F(1,45) = 8.68$, $p = .005$, $\omega^2 = .04$, η^2

= .046. The recall rate for the first-learned response (Figure 7) in the RR condition was not different from that of the RF condition (related: $M = .492$, $SD = .255$; unrelated: $M = .167$, $SD = .167$) reflecting an absence of directed forgetting benefits for related stimuli, $F(1,46) = 1.79$, $p = .188$, $.004 < \omega^2 < .008$, $\eta^2 = .019$, and for unrelated stimuli, $F < 0.36$, $p > .55$. The rate for the second-learned response (Figure 8) was lower in the RF condition (related: $M = .252$, $SD = .175$; unrelated: $M = .042$, $SD = .063$) than the RR condition reflecting directed forgetting costs for related stimuli, $F(1,46) = 12.42$, $p < .001$, $.057 < \omega^2 < .108$, $\eta^2 = .119$, and for unrelated stimuli, $F(1,45) = 6.45$, $p < .001$, $.029 < \omega^2 < .056$, $\eta^2 = .067$.

Comparisons between the R condition and the RF condition indicated that the recall rate in the R condition was higher than that of the second-learned TBF response of the RF condition for related stimuli, $F(1,46) = 62.26$, $p < .001$, $.246 < \omega^2 < .394$, $\eta^2 = .319$, and for unrelated stimuli, $F(1, 45) = 25.33$, $p < .001$, $.117 < \omega^2 < .209$, $\eta^2 = .170$, reflecting a combination of proactive interference and the forget instruction. But, the recall rate in the R condition did not differ from that of the first-learned TBR response of the RF condition for related stimuli, $F < 0.78$, $p > .383$, which suggested the absence of retroactive interference and/or a benefit resulting from an instruction to forget. For unrelated stimuli the TBR response of the RF condition exhibited a higher recall rate than the R condition that approached significance, $F(1,45) = 3.98$, $p = .052$, $.016 < \omega^2 < .031$, which appeared to indicate some benefit of the forget instruction above and beyond an absence of retroactive interference.

Recognition Test Results

Recognition discriminability was measured by *d'* and bias, *C* (Stanislaw & Todorov, 1999), and recognition accuracy was measured by hits minus false alarms (Table 1). In recognition testing, relevant patterns differed slightly from those of the recall test, but patterns of accuracy and those of discriminability and bias were similar. Altogether, simple effect comparisons between the control condition, R, and other conditions of interest suggested decreased effects of proactive interference relative to the comparisons of cued recall rates. Analysis for recognition began with an examination of directed forgetting effects for both FR and then RF conditions with both related and unrelated stimuli, which was followed by simple effect comparisons to the single remember condition.

Updating Patterns of Directed Forgetting

There were directed forgetting patterns in discriminability as evidenced by a significant interaction of memory instruction and response position for related, $F(1,49) = 11.93$, $p < .01$, $\omega^2 = .052$, $\eta^2 = .057$, and unrelated stimuli, $F(1,46) = 5.87$, $p = .02$, $\omega^2 = .025$, $\eta^2 = .031$. Similar interactions were observed with bias for related, $F(1,49) = 14.76$, $p < .001$, $\omega^2 = .064$, $\eta^2 = .07$, and unrelated stimuli, $F(1,46) = 17.41$, $p < .001$, $\omega^2 = .08$, $\eta^2 = .086$, and with accuracy rates for related stimuli, $F(1,49) = 15.37$, $p < .001$, $\omega^2 = .067$, $\eta^2 = .073$, and for unrelated stimuli, $F(1,46) = 18.96$, $p < .001$, $\omega^2 = .087$, $\eta^2 = .093$.

Recognition discriminability for the first-learned response (Figure 9) was higher in the RR condition (related: $M = 1.83$, $SD = .84$; unrelated: $M = 1.51$, $SD = .81$) than in the FR condition (related: $M = 1.66$, $SD = .76$; unrelated: $M = 1.32$, $SD = .73$), reflecting costs associated with the forget instruction that approached significance for related stimuli, $F(1,49) = 3.73$, $p = .059$, $.013 < \omega^2 < .027$, $\eta^2 = .037$, and for unrelated stimuli, $F(1,46) = 3.63$, $p = .06$, $.014 < \omega^2 < .027$, $\eta^2 = .038$. The response bias of the RF condition appeared more liberal (related: *M* = -.12, *SD* = .35; unrelated: *M* = .22, *SD* = .81) than in FR condition (related: *M* = .16, *SD* = .31; unrelated: *M* = .4, *SD* = .41) for related, $F(1,49) = 39.81$, $p < .001$, $.16 < \omega^2 < .28$, $\eta^2 = .29$, and unrelated stimuli, $F(1,46) = 11.9$, $p < .01$, $.055 < \omega^2 < .104$, $\eta^2 = .115$. Similar directed forgetting costs were reflected by accuracy for the first-learned response (Figure 10), which was higher in the RR condition (related: *M* = .657, *SD* = .204; unrelated: *M* = .513, *SD* = .241) than the FR condition (related: *M* = .512, *SD* = .238; unrelated: *M* = .395, *SD* = .261) for related stimuli, $F(1,49) = 27.71$, $p < .001$, $.118 < \omega^2 < .211$, $\eta^2 = .22$, and for unrelated stimuli, $F(1,46) = 15.78$, $p < .001$, $.073 < \omega^2 < .136$, $\eta^2 = .146$.

The discriminability rate for the second-learned response (Figure 11) for the FR condition (related: *M* = 1.86, *SD* = .78; unrelated: *M* = 1.43, *SD* = .86) was greater than the RR condition (related: *M* = 1.6, *SD* = .81; unrelated: *M* = 1.3, *SD* = .73) for related stimuli, $F(1,49) = 7.2$, $p < .01$, $.03 < \omega^2 < .058$, $\eta^2 = .068$, but not unrelated stimuli $F(1,46) = 2.76$, $p = .1$, $.009 < \omega^2 < .018$, $\eta^2 = .029$. Bias rate for the FR condition (related: *M* = .01, *SD* = .34; unrelated: *M* = .21, *SD* = .41) was more liberal than the RR condition (related: *M* = .04, *SD* = .34; unrelated: *M* = .37, *SD* = .41) for unrelated stimuli, $F(1,46) = 8.62$, $p < .01$, $.039 < \omega^2 < .075$, $\eta^2 = .086$, but was not different for related stimuli, $F < 0.25$, $p > .6$. Interestingly, the accuracy rate for the second-learned response (Figure 12) for the FR condition (related: *M* = .596, *SD* = .233; unrelated: *M* = .510, *SD* = .269) and the RR condition (related: *M* = .574, *SD* = .219; unrelated: *M* =

.411, *SD* = .282) appeared to be influenced by this difference in bias as the accuracy rate was greater in the FR condition for unrelated stimuli, *F*(1,46) = 7.56, *p* = .009, .034 $< \omega^2 <$ .065, η^2 = .076, but was not different for related stimuli, *F* < 0.60, *p* > .443—demonstrating a reversal of the pattern of benefits observed with discriminability.

Reverse-updating Patterns of Directed Forgetting

Again, analyses began with an examination of standard directed forgetting effects with both related and unrelated stimuli. The interaction of memory instruction and response position on discriminability that would reveal directed forgetting patterns for the RR and RF comparison failed to reach significance for related, *F* < 0.65, *p* > .42, or unrelated stimuli, *F*(1,46) = 1.8, *p* = .19, ω^2 = .004, η^2 = .01. With response bias, RR and RF conditions also did not differ for related, *F* < 0.03, *p* > .86, or unrelated stimuli, *F*(1,46) = 1.52, *p* = .22, ω^2 = .003, η^2 = .008. The interaction of memory instruction and response position on accuracy rates for related stimuli was similarly not present, *F* < 0.01, *p* > .97, but approached significance for unrelated stimuli, *F*(1,46) = 3.49, *p* = .068, ω^2 = .013, η^2 = .019. The absence of interactions suggested that directed forgetting effects would not be evidenced on recognition tests for the RF condition.

Recognition discriminability for the first-learned response (Figure 9) in the RR condition was not different from that of the RF condition (related: *M* = 1.86, *SD* = .87; unrelated: *M* = 1.53, *SD* = .97) for related, *F* < 0.10, *p* > .75, or unrelated stimuli, *F* < 0.04, *p* > .84, reflecting an absence of directed forgetting benefits in recognition similar to that of cued recall. Differences in bias between the RR and RF condition (related: *M* =-.02, *SD* = .34; unrelated: *M* = .19, *SD* = .34) approached significance for related stimuli, *F*(1,49) = 3.41, *p* = .07, .012 $< \omega^2 <$ .024, η^2 = .034, indicating a slightly more liberal criterion for the RR condition, but did not differ for unrelated stimuli, $F < 0.46$, $p > .5$. This absence of directed forgetting benefits was also reflected by accuracy rate for the first-learned response (Figure 10), which did not differ between the RR condition and RF condition (related: $M = .62$, $SD = .23$; unrelated: $M = .54$, $SD = .28$) for related stimuli, $F(1,49) = 2.09$, $p = .155$, $.005 < \omega^2 < .011$, $\eta^2 = .021$, or for unrelated stimuli, $F < 0.76$, $p > .38$.

Recognition discriminability for the second-learned response (Figure 11) failed to indicate any costs associated with the forget instruction for the RF condition (related: $M = 1.5$, $SD = .78$; unrelated: $M = 1.14$, $SD = .92$) compared to the RR condition for related, $F < 0.77$, $p > .38$, and unrelated stimuli, $F(1,46) = 2.71$, $p = .106$, $.009 < \omega^2 < .018$, $\eta^2 = .029$. Bias followed a similar pattern as demonstrated with the first-learned response, indicating more liberal decisions in the RR condition compared to the RF condition (related: $M = .15$, $SD = .38$; unrelated: $M = .43$, $SD = .42$) for related, $F(1,46) = 4.05$, $p = .05$, $.016 < \omega^2 < .031$, $\eta^2 = .042$, but not unrelated stimuli, $F < 0.99$, $p > .33$. The accuracy rate for the second-learned response (Figure 12) was numerically lower in RF condition (related: $M = .536$, $SD = .227$; unrelated: $M = .354$, $SD = .272$) compared to that of the RR condition for related stimuli, $F(1,49) = 1.51$, $p = .225$, $.002 < \omega^2 < .005$, $\eta^2 = .015$, and for unrelated stimuli, $F(1,46) = 2.68$, $p = .109$, $.009 < \omega^2 < .018$, $\eta^2 = .028$.

Control Comparisons

Simple effect comparisons of discriminability with the R control condition (related: $M = 1.71$, $SD = .77$; unrelated: $M = 1.37$, $SD = .89$) to the second-learned TBR association from the RR condition indicated an absence of proactive interference, such that differences between the two were not significant for related, $F(1,49) = 1.27$, $p = .26$, $.001 < \omega^2 < .003$, $\eta^2 = .013$, or unrelated stimuli, $F < 0.62$, $p > .43$. Similarly, with response bias comparisons, the R control (related: $M = .06$, $SD = .32$; unrelated: $M = .32$, $SD = .33$) did not differ from the second-learned TBR response for related stimuli, $F < 0.23$, $p > .63$, or unrelated stimuli, $F(1,46) = 1.06$, $p = .31$, $0 < \omega^2 < .001$, $\eta^2 = .011$. The comparison of accuracy rates of the R control (related: $M = .613$, $SD = .209$; unrelated: $M = .452$, $SD = .289$) to that of the RR condition supported findings with discriminability and bias, demonstrating an absence of differences for related stimuli, $F(1,49) = 2.13$, $p = .151$, $.006 < \omega^2 < .011$, $\eta^2 = .021$, or for unrelated stimuli, $F(1,46) = 1.66$, $p = .205$, $.003 < \omega^2 < .007$, $\eta^2 = .018$.

Discriminability for the R control compared to the first-learned TBR response of the RR condition did not differ for related, $F(1,49) = 1.83$, $p = .18$, $.004 < \omega^2 < .008$, $\eta^2 = .018$, or unrelated stimuli, $F(1,46) = 1.99$, $p = .16$, $.005 < \omega^2 < .01$, $\eta^2 = .021$, which reflected an absence of retroactive interference. The comparisons of bias indicated a more conservative response bias for the R control condition relative to the first-learned TBR response for related, $F(1,49) = 15.91$, $p < .001$, $.069 < \omega^2 < .13$, $\eta^2 = .14$, and unrelated stimuli, $F(1,46) = 3.88$, $p = .05$, $.015 < \omega^2 < .03$, $\eta^2 = .04$. The more conservative response of the R condition likely resulted in an accuracy rate that was lower than that of the first-learned TBR response of the RR condition for related stimuli, $F(1,49) = 5.35$, $p = .025$, $.021 < \omega^2 < .042$, $\eta^2 = .052$, and for unrelated stimuli, $F(1,46) = 5.08$, $p = .029$, $.021 < \omega^2 < .042$, $\eta^2 = .052$.

Comparisons between the R condition and the RF condition indicated that the discriminability in the R condition was significantly greater than that of the second-learned TBF response of the RF condition for related stimuli, $F(1,49) = 4.6$, $p = .037$, $.018 < \omega^2 < .035$, $\eta^2 = .045$, but approached significance for unrelated stimuli, $F(1,46) = 3.75$, $p = .059$, $.014 < \omega^2 < .028$, $\eta^2 = .039$, which could be completely attributed to the instruction to forget since the RR and R condition comparison indicated an absence of proactive interference. Bias indicated that participants tended to be more conservative in identifying the TBF association of the RF condition, but this difference did not reach significance for either related stimuli, $F(1,49) = 2.09$, $p = .15$, $.005 < \omega^2 < .011$, $\eta^2 = .021$, or unrelated stimuli, $F(1,46) = 3.07$, $p = .09$, $.011 < \omega^2 < .022$, $\eta^2 = .032$. Similar to the comparison of discriminability, accuracy rate in the R condition was higher than the TBF response of the RF condition for related stimuli, $F(1,49) = 10.71$, $p = .002$, $.046 < \omega^2 < .089$, $\eta^2 = .099$, and for unrelated stimuli, $F(1,46) = 7.52$, $p = .009$, $.034 < \omega^2 < .065$, $\eta^2 = .076$.

The first-learned TBR response of the RF condition exhibited numerically greater discriminability relative to the R condition that did not reach significance for either related, $F(1,49) = 2.28$, $p = .14$, $.006 < \omega^2 < .013$, $\eta^2 = .023$, or unrelated stimuli, $F(1,46) = 2.98$, $p = .09$, $.01 < \omega^2 < .021$, $\eta^2 = .031$. Response bias for the TBR response appeared more liberal than that of the R control condition for unrelated, $F(1,46) = 7.87$, $p = .007$, $.035 < \omega^2 < .068$, $\eta^2 = .079$, but not related stimuli, $F(1,49) = 1.92$, $p = .17$, $.005 < \omega^2 < .009$, $\eta^2 = .019$. Much like the R control comparisons with the RR condition, this difference in bias might have caused the higher accuracy rate of the first-learned response in the RF condition for unrelated stimuli, $F(1,46) = 8.03$, $p = .007$, $.036 < \omega^2 < .069$, $\eta^2 = .08$, which was not evident with related stimuli, $F < 0.11$, $p > .755$.

Comparisons between the R condition and the FR condition indicated that the discriminability of the R condition was not greater than that of the TBF response for either related stimuli, $F < 0.23$, $p > .63$, or unrelated stimuli, $F < 0.36$, $p > .55$, which would suggest that forget instruction of the FR condition had less impact in recognition testing. Response bias for the TBF response was more conservative than that of the R condition for related stimuli $F(1,49) = 4.83$, $p = .03$, $.019 < \omega^2 < .037$, $\eta^2 = .047$, but not unrelated stimuli, $F(1,46) = 2.35$, $p = .13$, $.007 < \omega^2 < .014$, $\eta^2 = .025$. Again, this difference in bias seemed to impact accuracy rates, which were significantly higher in the R condition than that of the TBF response for related stimuli, $F(1,49) = 18.17$, $p < .001$, $.079 < \omega^2 < .146$, $\eta^2 = .156$, but only a numerical impairment for unrelated stimuli, $F(1,46) = 3.15$, $p = .083$, $.011 < \omega^2 < .022$, $\eta^2 = .033$.

For the TBR response of the FR condition, discriminability appeared to be greater than that of the R condition for related stimuli, $F(1,49) = 3.96$, $p = .052$, $.015 < \omega^2 < .029$, $\eta^2 = .039$, but not unrelated stimuli, $F < .5$, $p > .47$, which would indicated a complete release from proactive interferences and an additional benefit for related stimuli. The comparison of bias indicated the R condition to be relatively more conservative than that of the TBR response for unrelated stimuli, $F(1,46) = 4.77$, $p = .034$, $.02 < \omega^2 < .039$, $\eta^2 = .049$, but not related stimuli, $F(1,49) = 1.5$, $p = .23$, $.002 < \omega^2 < .005$, $\eta^2 = .015$. Once again, this difference in bias seemed to affect accuracy rates, which showed a numerically advantage for the TBR response of the FR condition with unrelated stimuli, $F(1,46) = 3.19$, $p = .081$, $.012 < \omega^2 < .023$, $\eta^2 = .034$, but did not differ for related stimuli, $F < 0.61$, $p > .44$.

Discussion

Unrelated and related stimuli produced relatively similar patterns of effects across all learning conditions for both recall and recognition tests. However, subtle differences in patterns of directed forgetting occurred between the FR and RF conditions, which reflected the contribution of the sequence of replacement. A selective rehearsal account of directed forgetting alone would not be able to account for these differences. Results for recall and recognition tests are discussed in turn.

Recall Discussion

Semantic relatedness did not hamper the directed forgetting effect, and contrary to predictions based on Golding et al. (1994), Conway et al. (2000), and Osgood (1949), related stimuli exhibited larger directed forgetting effect sizes than unrelated stimuli for updating memory comparisons to both the dual-remember and single remember controls. Unfortunately, unrelated stimuli recall rates were near floor, and so such an interpretation must be made with caution. Given the unexpected nature of this finding, several explanations should be considered.

From a methodological perspective, the stimuli used in this experiment did not explicitly control for relationships between TBF and TBR associations, but instead, stimuli construction focused on relationships with the shared stimulus word. This had the additional benefit of preventing the confounding of associations between representations and the order of their appearance (e.g., Golding et al., 1994). An alternative method for establishing relationships would have been to use category labels and exemplars such as those used by Conway et al., (2000). However, in Conway et al., directed forgetting results were only absent when the second 10-item TBR list contained five exemplars from the same category as a single exemplar in the first 10-item TBF list; one-to-one matching of category exemplars between lists exhibited reliable directed forgetting patterns. This would suggest that a great deal of semantic similarity must be present for the mediation of directed forgetting effects to be observed on tests of recall.

The most important findings from Experiment 2 centered on the dynamics of directed forgetting patterns demonstrated in cued recall by the FR and RF memory conditions (Table 2). The FR condition replicated previously established directed forgetting patterns with related stimuli (Experiment 1A and 1B) and extended them to unrelated stimuli. The FR condition comparisons exhibited significant costs and benefits relative to the RR condition, whereas the RF condition exhibited significant costs but failed to indicate any benefits. With regards to the comparisons to the R control condition, the FR condition indicated costs and a complete release from proactive interference resulting from the instruction to forget; the RF condition demonstrated slightly different effects, with large costs resulting from a combination of proactive interference and a forget instruction. The first-learned TBR association of the RF condition seemed to receive a release from retroactive interference and a possibly additional benefit from a forget instruction. However, as a similar benefit was found with the RR condition, this does not appear unique to the forget instruction in the RF condition.

Altogether, the RF condition demonstrated standard directed forgetting patterns, whereas the FR condition only demonstrated costs. The instruction to forget in the RF condition appeared to compound the proactive interference for the TBF association, but it did not confer any benefit on the recall of the TBR association. The differences in patterns of directed forgetting between the FR and RF condition revealed an important distinction between typical and atypical sequences of replacement, which would not be predicted by selective rehearsal or suppression accounts.

Recognition Discussion

Recognition accuracy rates demonstrated slightly different patterns of directed forgetting compared to recall (Table 3). Unrelated stimuli were again recognized at lower rates relative to related stimuli, but contrary to recall, recognition accuracy results showed some support for the claim that semantic relatedness modulates directed forgetting: For particular directed forgetting effect comparisons, unrelated stimuli exhibited directed forgetting effects that either approached or reached significance whereas related stimuli did not. However, discriminability rates did not support this claim (Table 4), and many of the differences in accuracy rates appeared attributable to differences in bias.

Critical comparisons again centered on directed forgetting effects for the FR and RF conditions. Relative to the RR condition, the FR condition exhibited costs for both related and unrelated stimuli, but only exhibited benefits with related stimuli. However, comparisons between the second-learned TBR responses in the RR condition to the R control revealed that with related stimuli, the RR condition did not exhibit proactive interference. This would suggest that the lack of consistent benefits for the FR condition might have been due to improved discriminability in the RR condition on the recognition test. The RF condition comparisons failed to indicate costs or benefits relative to the RR condition.

Control comparisons of recognition discriminability with the RR and RF conditions replicated patterns found on the recall test with the exception that proactive interference appeared to be absent. In this same vein, there did not appear to be differences between the TBF response of the FR condition and the R control. Thus, with recognition testing, we saw similar patterns as those demonstrated in recall but without evidence of proactive interference, which could be attributed to the re-presentation of stimulus-response associations during the recognition test.

Experiment 2 Summary

The RF condition appeared to be an incomplete or partial instantiation of a directed forgetting condition. Despite the forget instruction in the RF condition consistently impairing future retrieval and recognition of the TBF response, there were no consistent advantages conferred to the TBR association. Recall and recognition rates of TBR association were very similar to those of first-learned TBR association in the RR condition.

The finding that the RF condition did not produce standard directed forgetting effects on tests of recall or recognition presents a problem for the selective rehearsal and the retrieval-induced and executively controlled suppression accounts. According to selective rehearsal, the likelihood of recall or recognition should solely depend on the strength of the representation in memory rather than the order in which instructions to remember or forget occur. Similarly, for retrieval-induced and executively controlled suppression, proposed mechanisms include competition and executive control, neither of which have been proposed to change with the ordering of to-be-suppressed and suppressing information (i.e., forget or remember instructions). However, previous research in list-method directed forgetting has suggested that the ordering of instruction relates to the competition necessary for directed forgetting. Participants are hypothesized to encode the list of TBR items as a competitor to the list of TBF items, which is best achieved when the instruction to forget precedes the instruction to remember (Bjork, 1970). With the RF condition, the competitor can only be identified after both associates have been learned.

Experiment 2 results served as the first indication that the selective rehearsal account might not be able to account for findings with the online updating paradigm. Even when considering the FR condition in isolation, selective rehearsal would not predict the presence of both costs and benefits for the recognition test (Golding & MacLeod, 1998; Johnson, 1994). Moreover, the standard sequence of replacement appeared to be a boundary condition for directed forgetting and semantic relatedness did not appear to influence directed forgetting effects, findings which cannot be explained by selective rehearsal or the retrieval-induced or executively controlled suppression accounts. Altogether, Experiment 2 explored important boundary conditions that provided further information to guide critical analysis of current theoretical accounts of directed forgetting.

Experiment 3

Previous experiments in the present study focused exclusively on direct methods of testing memory. As discussed, findings from these methods have not been able to completely differentiate one theory of directed forgetting from another. While Experiments 1A and 1B provided support for the theory of selective rehearsal, Experiment 2 revealed important distinctions in patterns of directed forgetting effects produced by the updating and reverse-updating conditions, distinctions which would not be predicted by a theory based on memory strength alone. Results from previous experiments neither supported nor completely excluded theories of suppression, attesting to either inherent theoretical flaws (i.e., unfalsifiability), or limitations of prior methods of testing. On explicit tests of memory, such as recall or recognition, suppression and selective rehearsal have tended towards nuanced predictions, which further complicated interpretations.

Experiment 3 employed conceptual implicit testing methods to disambiguate previous findings in an attempt to make clear conclusions regarding suppression and selective rehearsal as theories for online memory updating. Explicit testing methods investigate theoretical mechanisms via direct access to memory representations, but implicit conceptual methods investigate theoretical mechanisms via indirect access to memory representations. With implicit testing, the levels of study item activation are assessed relative to the activation of unstudied items, such that larger, smaller, or similar levels of activation can be interpreted as positive, negative, or absent priming, respectively. Findings drawn from both explicit and implicit experimental methods can provide converging evidence to determine the viability of theories of intentional forgetting.

The noted distinction between familiarity- and retrieval-based recognition tests has a corollary with perceptually- and conceptually-based implicit tests because while the former in each case are influenced by exposure alone, the latter in each case are sensitive to the attributes specific to the study episode and functional representation of the tested items (Balota, 1994). When implicit testing methods appropriately tap the conceptual representation being suppressed—whether that be the semantic association between the stimulus and response, the response word itself, or both—results should demonstrate negative priming, but when implicit testing taps other aspects of the studied episode such as the phonological or lexical features of the response word, results would not serve as a diagnostic test of suppression as priming might simply be impacted by prior exposure (Anderson, 2003; Butler, Williams, Zacks, & Maki, 2001; Perfect, Moulin, Conway, & Perry, 2002).

For example, Basden et al. (1993) used both data-driven and conceptual implicit testing methods to assess memory for TBF and TBR items with the standard item-method directed forgetting procedure. For data-driven implicit testing, selective rehearsal predicted priming of both TBF and TBR items but not directed forgetting patterns because such tests are determined largely by prior exposure as opposed to levels-of-processing (Morris, Bransford, & Franks, 1977). For conceptual implicit testing, selective rehearsal predicted both priming and directed forgetting patterns because conceptual implicit tests are sensitive to variations in semantic representations (see also, Anderson, 2003; Perfect et al., 2002). As predicted, results from the data-driven implicit test (e.g., word fragment completion) indicated reliable priming for TBF and TBR items with an absence of directed forgetting effects (see also, Paller, 1990), but contrary to predictions, results from the conceptual implicit tests (e.g., word association) reflected an absence of both priming and directed forgetting effects.

Basden and Basden, (1996), altered the conceptual implicit task from a word-association task used in Basden et al. (1993) to a general knowledge task. With this change, the item-method manipulation produced reliable priming of both the TBF and TBR items with directed forgetting effects. Basden and Basden (1996) favored this outcome to the outcome from Basden et al., (1993) and claimed that floor effects had caused null levels of priming and prevented any dissociation of TBF from TBR items. Thus, selective rehearsal would appear to predict positive priming and directed forgetting effects on conceptual implicit tests, but previous research has lacked consistency.

With regards to list-method directed forgetting, Basden et al. (1993) and Basden and Basden (1996) predicted that list-method directed forgetting suppression would only be evident on explicit retrieval tests. For data-driven implicit tests, list-method directed forgetting predicted priming for both TBF and TBR items based on prior exposure alone, but no directed forgetting effects. For conceptual implicit tests, list-method directed forgetting suppression similarly predicted priming for both TBF and TBR items because semantic activation of TBF memory representations should remain unaffected by inhibitory mechanisms. Results showed that both data-driven and conceptual implicit tests demonstrated reliable priming of TBF and TBR items in the absence of directed forgetting effects.[5] Authors interpreted these findings as consistent with the list-method directed forgetting suppression account.

Predictions derived from these findings do not extend to the suppression mechanisms discussed with retrieval-induced forgetting and think/no-think procedures. For data-driven tests, retrieval-induced forgetting predicts an absence of priming of

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[5] Basden et al. (1993) and Basden and Basden (1996) confounded the forget instruction with temporal location by using the TBR list following the TBF list as the comparison group. It is unclear how temporal location might interact with the forget instruction on conceptual implicit tests. Unfortunately, this confound is not commonly recognized by other directed forgetting researchers (Bjork et al., 1998; MacLeod, 1998).

TBF items, but for conceptual implicit tests, the theory predicts negative priming of unpracticed exemplars from practiced categories (TBF) relative to a baseline established from unpracticed exemplars from unpracticed categories (Anderson, 2003). Here, the mechanism for suppression is understood as acting on unpracticed exemplars from practiced categories in order to facilitate retrieval of practiced items. Retrieval-induced suppression is motivated by the need to override exemplar competition during either overt or covert retrieval (Anderson & Bell, 2001; Anderson, Bjork, & Bjork, 2000; Storm, Bjork, Bjork, & Nestojko, 2006), and this process directly impairs the item representation itself, causing an overall weakening of the memory trace (Anderson, 2003). Furthermore, this should be observed independent of the specific episode of learning (Anderson & Spellman, 1995). Research appears mixed as to whether TBR items would appear primed. Perfect et al. (2002), used the retrieval-induced forgetting paradigm and observed positive priming for retrieved category exemplars on conceptual implicit tests. The executively controlled suppression of the think/no-think paradigm has been predicted to exhibit similar patterns of priming on data-driven and conceptual tests, again resulting from an absolute weakening of the TBF representation in memory, which is also cue independent but does not require competition to be achieved (Anderson, 2003; Anderson & Green, 2001).[6]

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[6] It is important to note that Anderson and Green (2001) only observed suppression after multiple attempts to suppress; a single attempt was not sufficient. Furthermore, Bulevich, Roediger, Balota, and Butler (2006) failed to replicate the findings of Anderson and Green.

Clearly, conceptual implicit testing methods can differentiate between selective rehearsal accounts and the various types of suppression accounts, while data-driven implicit testing methods would predict the same results for all potential accounts (Morris et al. 1977). Moreover, conceptual implicit tests might permit the identification of the type of suppression hypothesized for the present paradigm as list-method directed forgetting suppression predicts a pattern of test results different from the other retrieval-induced and executively controlled accounts.

In the present experiment, following the conceptual implicit test, participants were given an explicit cued recall test. We predicted recall patterns similar to those obtained on Experiment 2.

Method

Participants

Participants were 56 undergraduate students participating for course credit in introductory psychology courses at the University of Oklahoma, of which seven participants opted to exclude their data from analyses. An additional three participants were excluded for failure to follow instructions.

Design

The experiment consisted of a 4 (Memory condition: Dual-remember, updating memory, reverse updating memory, vs. single-remember) X 2 (Memory testing: Implicit test vs. recall) within-subjects factorial design. All other aspects of the study design remained the same.

Materials

In order to use a conceptual implicit test in which participants generated items based on semantic associations, we controlled for the relationship between the stimulus and response by using the unrelated stimuli introduced in Experiment 2. For the implicit test, an additional 384 words were matched as a semantic associate to each response from all 96 sets. These semantic associates served as test cues on the conceptual implicit test. We ensured that when provided with the test cues, there would be a moderate likelihood of generating the related cue-set response ($.081 < FSG < .19$; $M = 0.123$, $SD = .031$), target response output would not be impaired by alternative relations to highly associated items (competitor $FSG < .297$), and target response output would not compete with other responses comprising the unrelated stimuli.

Procedure

All aspects of the study phase procedure remained the same as those used in Experiment 2. For the conceptual implicit test phase, test trials included associate cues and required participants to make free associations. The free association task assured that the implicit test was conceptually based rather than data-driven. The implicit test phase comprised a total of 48 randomly ordered and randomly sampled, studied stimulus sets with six response words drawn from the single-remember condition, and 12 drawn from each of the other three conditions of interest, of which six were first-learned responses and six were second-learned responses. An additional 96 unpresented, unrelated responses were drawn from stimulus sets to serve as the baseline measure for the determination of priming effects. Thus, the conceptual implicit test consisted of 126 test trials.

Participants were led to believe that prior to the final memory test, they would be participating in a free-association task, which was unrelated to the study session. They were asked to generate an associate to the cue word onscreen. Participants could not proceed to the next cue without generating. There was no time limit imposed, but participants were encouraged to generate as quickly as possible by using the first word that came to mind when they read the cue. Anderson (2003) referenced this type of free association task as being sensitive to variations in the accessibility of learned semantic representations.

For the cued-recall test phase, all aspects remained the same as previous experiments with the following exception: The cued-recall memory test comprised a total of 40 stimulus sets with 10 stimulus words drawn from each of the four conditions of interest. Sampling of stimulus sets was random with the condition that no stimulus sets tested in the implicit test phase were tested in the cued-recall test phase.

Results

For the conceptual implicit test, comparisons focused specifically on determining the activation of studied responses relative to an unstudied baseline. For the cued recall test, comparisons were again modeled with the intention of investigating directed forgetting costs and benefits. Analyses were separated by memory test condition, and significance was established at $p < .05$. None of the multi-level comparisons that follow violated Mauchly's test of sphericity.

Implicit Test Results

Implicit test analyses, much like recognition and recall analyses of Experiment 2, began by making general comparisons among first-learned (Figure 13) and among second-learned association response rates (Figure 14) with rates of the single-remember control and the unstudied baseline displayed in both. Separate one-way, five-level analyses were conducted to compare among response rates. Neither first-learned, nor second-learned associations demonstrated significant differences across learning conditions and the unrelated baseline, $F(4,180) = 1.2$, $p = .313$, $\omega^2 = .003$, $\eta^2 = .021$, and $F(4,180) = 1.07$, $p = .375$, $\omega^2 = .001$, $\eta^2 = .019$, respectively. However, the comparison collapsing across all learning conditions to the unrelated baseline indicated a general effect of priming, $F(1,45) = 14.04$, $p < .001$, $\omega^2 = .124$, $\eta^2 = .135$.

Critical implicit test analyses compared each stimulus-response type within learning conditions to the unstudied baseline to determine rates of priming. Response rates of the R control condition ($M = .123$, $SD = .142$) indicated positive priming relative to the unrelated baseline condition ($M = .077$, $SD = .039$), $F(1,45) = 4.6$, $p = .038$, $\omega^2 = .038$, $\eta^2 = .049$. For first-learned associations (Figure 13), increased generation of TBF responses of the FR condition ($M = .109$, $SD = .123$) relative to the baseline condition approached significance, $F(1,45) = 3.57$, $p = .038$, $\omega^2 = .027$, $\eta^2 = .038$, but generation rates of first-learned TBR responses from both the RR ($M = .101$, $SD =.129$) and RF conditions ($M = .087$, $SD = .11$) failed to indicate significant differences, $F(1,45) = 1.73$, $p = .195$, $\omega^2 = .008$, $\eta^2 = .019$ and $F < 0.38$, $p > .543$, respectively.

For second-learned associations (Figure 14), generation rates of the TBR response of the FR condition ($M = .091$, $SD = .135$) did not differ from the baseline condition, $F < 0.48$, $p > .49$, but rates of the second-learned TBR responses of RR condition ($M = .112$, $SD = .132$) approached significant differences from the baseline,

$F(1,45) = 3.46$, $p = .069$, $\omega^2 = .026$, $\eta^2 = .037$, and rates of the TBF response from the RF condition ($M = .109$, $SD = .146$) demonstrated numerical differences from the baseline, $F(1,45) = 2.59$, $p = .114$, $\omega^2 = .017$, $\eta^2 = .028$.

As final comparisons, we collapsed across TBF response generation rates from FR and RF conditions and collapsed across TBR response generation rates from FR, RR, and RF conditions. We then compared the generalized TBF generation rates to those of the unrelated condition and found evidence of positive priming, $F(1,45) = 5.10$, $p = .029$, $\omega^2 = .043$, $\eta^2 = .054$. The comparison of the generalized TBR generation rates to those of the unrelated condition also indicated evidence for positive priming that approached significance, $F(1,45) = 4.02$, $p = .051$, $\omega^2 = .032$, $\eta^2 = .043$. The final comparison of generation rates between the generalized TBF and the generalized TBR responses failed to indicate any differences, $F < 0.35$, $p > .55$.

Exploratory analyses measured differences among conditions in response time. Response time provided a measure of retrieval fluency of responses. Similar one-way, five-level analyses failed to indicate any differences across generation response times for either first-learned (Figure 15) or second-learned responses (Figure 16) with the inclusion of the single-read and unstudied baseline. A two-way, three-level analysis examined response times within the three conditions involving two responses (FR, RR, RF), and while the main effects of learning condition and paired-associate learning order were both not significant (Fs $< .69$, ps $> .41$), the interaction was significant, $F(2,90) = 3.15$, $p = .047$, $\omega^2 = .017$, $\eta^2 = .024$. Separate one-way, three-level analyses examining differences in response time among the three learning conditions for the first and second learning positions failed to indicate any differences, $F < 2.11$, $p > .128$, and

F < 0.64, *p* > .528, respectively. Simple effect analyses examining reaction time differences within condition showed moderate differences between TBF and TBR items in the FR (TBF: *M* = 3214.23, *SD* = 961.86; TBR: *M* = 3408.13, *SD* = 1068.36) and RF conditions (TBF: *M* = 3278.34, *SD* = 789.63; TBR: *M* = 3485.28, *SD* = 1007.54), (*F*(1,45) = 3.05, *p* = .088, ω^2 = .022, η^2 = .033, and *F*(1,45) = 2.46, *p* = .124, ω^2 = .016, η^2 = .027, respectively), but failed to show any differences between the first- and second-learned TBR responses (First: *M* = 3472.24, *SD* = 1098.04; Second: *M* = 3485.28, *SD* = 1007.54) within the RR condition, *F* < 1.64, *p* > .206.

Recall Test Results

Recall test analyses began with an examination of standard directed forgetting effects with the FR condition. There were directed forgetting patterns as evidenced by a significant interaction of memory instruction and response position, *F*(1,45) = 13.51, *p* < .001, ω^2 = .064, η^2 = .07. The recall rate for the first-learned response (Figure 17) was higher in the RR condition (*M* = .141, *SD* = .186) than the FR condition (*M* = .039, *SD* = .093) reflecting directed forgetting costs, *F*(1,45) = 13.1, *p* < .001, ω^2 = .116, η^2 = .127. The rate for the second-learned response (Figure 18) was not significantly higher in the FR condition (*M* = .111, *SD* = .16) than the RR condition (*M* = .078, *SD* = .133) and failed to demonstrate forgetting benefits, *F*(1,45) = 2.75, *p* = .104, ω^2 = .019, η^2 = .03.

For the RF condition, the interaction of memory instruction and response position approached significance, *F*(1,45) = 3.13, *p* = .084, ω^2 = .011, η^2 = .017, providing some evidence of directed forgetting patterns. The recall rate for the first-learned response (Figure 17) in the RR condition was not different from that of the RF condition (*M* = .139, *SD* = .181), $F < 0.02$, $p > .90$, reflecting an absence of directed forgetting benefits. The rate for the second-learned response (Figure 18) was lower in the RF condition (*M* = .026, *SD* = .053) than the RR condition reflecting directed forgetting costs, $F(1,45) = 6.3$, $p = .016$, $\omega^2 = .054$, $\eta^2 = .065$.

Simple effect comparisons between the R control condition (*M* = .113, *SD* = .18) and the second-learned TBR association of RR condition indicated a difference in the recall rate that approached significance, $F(1,45) = 4.01$, $p = .051$, $\omega^2 = .032$, $\eta^2 = .043$, reflecting proactive interference. The recall rate in the R condition was not different from that of the first-learned TBR response of the RR condition for related stimuli, $F(1,45) = 2.08$, $p = .15$, $\omega^2 = .012$, $\eta^2 = .023$, which suggested the absence of retroactive interference.

Comparisons between the R condition and the RF condition indicated that the recall rate in the R condition was higher than that of the second-learned TBF response of the RF, $F(1,45) = 10.93$, $p < .01$, $\omega^2 = .097$, $\eta^2 = .108$, reflecting a combination of proactive interference and the forget instruction. But, the recall rate in the R condition did not differ from that of the first-learned TBR response of the RF condition, $F(1,45) = 2.11$, $p = .15$, $\omega^2 = .012$, $\eta^2 = .023$, which suggested the absence of retroactive interference and/or a benefit resulting from an instruction to forget.

Comparisons between the R condition and the FR condition indicated that the recall rate in the R condition was higher than that of the TBF response, $F(1,45) = 7.6$, $p < .01$, $\omega^2 = .067$, $\eta^2 = .078$, but did not differ from that of the TBR response, $F < .02$, $p > .90$, reflecting a complete release from proactive interference in the FR condition.

Discussion

Implicit Test Discussion

Positive priming with implicit testing methods appeared for the R control condition, but the other response types within learning conditions all exhibited similar rates of semantic generation, and none differed significantly from the unstudied baseline. There were a few notable exceptions to this pattern such as the TBF of the FR condition and the second-learned TBR of the RR condition, which both indicated positive priming that approached significance.

We did see positive priming when we compared the unrelated baseline to the combination of all studied response types, and furthermore, when we combined the specific TBF response types and specific TBR response types. However, conclusions must remain tentative since individual rates were low and failed to demonstrate significant differences. These findings do not indicate negative priming of responses within the FR, RR, and RF conditions. The exploratory analyses conducted on reaction times provided some support for claim that TBF responses were relatively accessible vs. inaccessible. An interaction occurred in the comparison across the FR, RR, and RF conditions and between reaction times of first-learned and second-learned responses. No simple effect comparisons were significant, but participants appeared to be generating target TBF responses slightly faster than the TBR responses.

Numerical indications of both priming and retrieval fluency would argue against predictions based on suppression accounts that predict TBF response representations to suffer an absolute reduction memory strength (e.g., retrieval-induced forgetting suppression, or executively controlled suppression). But, proponents of suppression might claim that our results were caused by transfer-inappropriate properties of the free association implicit test relative to the learning episode. If participants encoded the unrelated stimulus-response pairs as a unique association, then memory representations would consist mainly of episodic features of the association rather than general semantic representations of the individual words that comprise the association (Anderson, 2003). In this case, the suppressed items would have been the episodic representations, which were not measured by the conceptual implicit task employed here—it focused on semantic features of the individual responses rather than the composite association. However, to suggest that processes of suppression would only operate on the episodic representation of the association, which comprises individual semantic representations, would necessitate additional explanation for how those representations are disentangled and the proper ones selected to be suppressed. To address this alternative explanation would require an implicit test of the episodic strength of learned associations.

With regards to the other theoretical accounts, implicit testing results found here did not match findings predicted by selective rehearsal, that TBF and TBR responses would reflect positive priming and significant directed forgetting effects (Basden & Basden, 1996). Despite numerical trends towards positive priming, results also did not match findings predicted by list-method directed forgetting suppression, that TBF and TBR responses would reflect positive priming without directed forgetting effects (Basden & Basden, 1996; Basden et al., 1993). Present results on the implicit free association task appear similar to those obtained by Basden et al. (1993), which reported an absence of priming and directed forgetting effects for the item-method condition. They attributed their null results to floor effects caused by generally low levels of priming produced by the implicit task. Our results also indicated near-floor response generation rates, which might similarly be responsible for the null effects here.

Recall Discussion

Cued recall rates deviated slightly from those found with the unrelated stimuli condition in Experiment 2. First, we noted that recall rates of Experiment 3 were slightly lower than those of Experiment 2, and neither the R control condition nor the TBR association of the FR condition exhibited significantly higher recall rates compared to the second-learned TBR association of the RR condition. With these two exceptions, patterns appeared very similar to those obtained in Experiment 2.

The differences in recall rates between Experiment 2 and 3 could be attributed to the interpolated free association task causing either general interference or a reduced impact of the directed forgetting manipulation. The latter explanation would appear less credible since the R condition was similarly affected, and furthermore, the directed forgetting costs were still present. We hypothesize the more likely reason for lower recall rates would arise from the intervening event, the generation of semantic associations required by the implicit task. This would also explain the lower rates overall of learning conditions compared to those obtained in Experiment 2. Though the associations were different and involved a new set of cues, the processing involved with generating such associations and the related memory searches would have retroactively interfered via unlearning (Barnes & Underwood, 1948; Melton & von Lackum, 1941) competition (Postman et al., 1968) or changes in the episodic or mental context (e.g., Martin, 1971; Sahakyan & Kelley, 2002), thereby limiting future retrieval during the cued recall memory test.

As final alternative explanations, the observed decrease in recall rates could also be attributed to a methodological difference between experiments in the number of observations per participant, which caused a reduction in power (Experiment 2: 15 observations; Experiment 3: 10 observations), or floor effects limiting the expression of directed forgetting patterns. However, we noted that despite low rates, recall patterns were still exhibited, distinguishable, and generally replicated those of Experiment 2.

Experiment 3 Summary

Prior research has used implicit testing methods to support or refute predictions of suppression (Anderson, 2003; Butler et al., 2001; Perfect et al., 2002) as well as selective rehearsal (Basden & Basden, 1996; Basden et al., 1993). Here, the conceptual implicit testing method assessed the overall strength of forget and remember item representations in memory and found them to be relatively equivalent, trending towards positive priming, and for TBF representations to be slightly more accessible relative to TBR representations from the same condition.

General Discussion

The present study provided a detailed investigation into the roles of forgetting and interference in an online updating process. We have defined memory updating as the replacement of outdated, invalid, erroneous, or irrelevant information. One common application of this updating process would be the replacement of erroneous information with correct information during the learning process. In this situation, both error and correction relate to a particular stimulus or context, and as such can compete for conscious recollection (Nairne, 2002). Previous research established that encoding of the correction following an error can benefit from elaboration, increased association to the stimulus, greater processing of contextual elements related to the episode of learning, and increased attentional resources—all of which ultimately lead to future successful retrieval (Butterfield & Metcalfe, 2001; Butterfield & Metcalfe, 2006; Cyr & Anderson, 2012; Fazio & Marsh, 2009; Kulhavy & Anderson, 1970; Kornell et al., 2009; Pashler et al. 2007; Richland et al., 2009). However, this research has neglected to specify the fate of erroneous or outdated information, despite the fact that the accessibility and activation of such information impact the likelihood of successful learning (Grimaldi & Karpicke, 2012).

Intentional forgetting provides one way to decrease the likelihood of interference and future sampling of outdated or erroneous information (Golding & Macleod, 1998). As discussed here, theories of directed forgetting include selective rehearsal (Basden & Basden, 1993), list-method directed forgetting suppression (Bjork & Bjork, 1996), the two-factor account of context change and strategy evaluation (Sahakyan & Kelley, 2002; Sahakyan & Delaney, 2003; Sahakyan & Delaney, 2005), and the two-factor account of suppression and primacy (Pastötter & Bäuml, 2010). Two-factor accounts benefit from an ability to explain findings indicating dissociations of directed forgetting costs and benefits. Unfortunately for the all of these accounts, the mechanisms have only been identified and examined within specific directed forgetting methods.

The present research implemented an alternative method to specifically determine if processes involved with online updating, a procedure that does not fit neatly within item- or list-method directed forgetting, can be explained by intentional forgetting. By using a design apart from the item- or list-methods, we were also able to examine directed forgetting theories apart from the methods that have brought about and limited their development. We understand such research with memory updating as contributing to the resolution of the differences between item- and list-method directed forgetting and facilitating the development of a general theory of directed forgetting that would apply to many various forms of intentional forgetting, including those requisite for online memory updating.

Summary of Present Findings

The present series of experiments were designed to first examine how manipulations during retrieval impact the memory for outdated and new information (Experiments 1A and B), then explore boundary conditions for the updating process (Experiment 2), and finally, with implicit testing methods, determine the impact of the updating process on representation strength (Experiment 3). Collectively, this endeavored to detail the effects of updating on item and association representations during the stages of encoding, storage, and retrieval.

Experiments 1A suggested that the mechanism for intentional forgetting occurred during study because the re-presentation of the second-learned TBR association had no impact on retrieval of the TBF response. Experiment 1B showed that the re-presentation of the impaired TBF relationship similarly had no effect on the retrieval of the first-learned TBR association. Selective rehearsal, which hypothesized that retrieval of the TBF and TBR response was based on memory strength alone, best explained the absence of facilitative or part-set cuing effects. Though, an alternative account proposed that some mechanism for suppression might have occurred earlier in the learning episode and remained static during retrieval, despite the reintroduction of the suppressing or suppressed information. The list-method suppression account, however, predicted a release from suppression caused by the re-presentation of the suppressed item in Experiment 1B, which should have been observed by reinstated proactive interference. The absence of such a result suggested that this theory was not a viable explanation for the online updating process.

Experiment 2 then explored previously stated boundary conditions for directed forgetting—semantic relatedness and ordering of instructions—to determine their impact on the process of online updating. Semantic relatedness had little impact on recall, and in fact, larger directed forgetting effects were obtained with related stimuli. Experiment 2 also showed an important distinction between the FR and RF conditions. The RF condition exhibited directed forgetting costs without benefits for cued recall, but failed to exhibit any patterns of directed forgetting for recognition. This showed the sequence of replacement to be an integral aspect of the mechanism for successful updating, and without it, the instruction to forget was less effective. These two boundary conditions, semantic relatedness on recognition testing and the sequence of replacement, cannot be explained solely by selective rehearsal or theories suggesting some absolute suppression via retrieval-induced competition or executive control.

Experiment 3 complimented findings of explicit testing from Experiments 1-2 by using implicit testing to show that storage strengths of the studied TBR and TBF responses did not differ and generally appeared stronger than the unrelated baseline. The absence of positive priming in simple effect comparisons with the condition response types alluded to the importance of examining not only the individual response representations but also the episodic representations of the novel associations created during study (Racsmány & Conway, 2006). Still, there was no evidence to suggest that TBF response representations suffered from an absolute suppression that would limit their accessibility or semantic activation, which would be predicted by retrieval-induced and executively controlled suppression accounts. Also with Experiment 3, we saw an absence of directed forgetting benefits on the subsequent recall test, which otherwise replicated findings from Experiment 2. Together, findings indicated that online updating did not negatively impact the individual storage strengths of TBF representations, and that directed forgetting benefits of online updating could be affected by interference resulting from an interpolated task.

In sum, the present findings with online updating methods reflect many of the patterns known to directed forgetting and interference literature, but they also challenged current theories associated with those paradigms. Using a paradigm separate and apart from typical directed forgetting manipulations permitted clearer testing and specification of current theoretical mechanisms of directed forgetting without the confounding influence of typical experimental methods in which they were originally established. As a result, the findings conflict with various features of all theories discussed thus far.

Relevance of Present Research to Prior Literature

An explanation of online memory updating that relies on intentional forgetting and interference presupposes a relationship to the theoretical mechanisms associated with such paradigms. The present findings, which could not be explained by current theories of directed forgetting (for reviews see: Johnson, 1994; Macleod, 1998), coincide with recent developments in the directed forgetting paradigm that similarly support the notion that long-held theories and previous interpretation of empirical findings have been misinformed and require revision (e.g., Benjamin, 2006).

First, the work of Sahakyan and colleagues and Bäuml and colleagues indicate the rapid ascension of two-factor accounts within the directed forgetting research community. This theoretical change has been motivated by evidence of the dissociation of directed forgetting costs and benefits with the list method. By establishing that costs or benefits can occur in isolation, researchers have identified an important weakness of any single-factor theory, which by its very nature would not be able to account for separable occurrences. Unfortunately, as previously stated, such accounts have been developed exclusively with list-method directed forgetting manipulations, and their development based solely on a global instruction to forget. For this reason, these new two-factor theories do not translate to a manipulation such as the one here, which uses multiple local instructions to forget. Moreover, they do not attempt to unify various findings from other directed forgetting manipulations such as those using an item method.

For the context-change and strategy evaluation two-factor account (Sahakyan & Kelley, 2002; Sahakyan & Delaney, 2003), the idea that multiple local instructions to remember and forget would imply constantly changing contexts and constantly adjusted encoding strategies, and thus the explanations for costs and benefits would break down. For the retrieval inhibition and renewed primacy effects two-factor theory of Bäuml and colleagues (Pastötter & Bäuml, 2010), application of the theory at the local level would require the assumption that inhibition and primacy can act consistently with multiple lists of various lengths. Such a view seems possible (e.g., Watkins & Peynircioglu, 1983), and would apply to the present paradigm with the assumption that a list length of two items supports the necessary processing. But, the real crux of this theory would be the specification of the mechanism of retrieval inhibition. Bäuml, Hanslmayr, Pastötter, and Klimesch (2008) have suggested that this mechanism relates to a deactivation of retrieval routes to first list items resulting from the unbinding of such items from internal and episodic cues while the second list is being learned (Bäuml, Pastötter, & Hanslmayr, 2010). However, this theory has not yet to be applied beyond list method. For these reasons, the current two-factor theories appear ill equipped to explain current findings with memory updating and similarly unable to account for item-method directed forgetting.

Such an inability to explain item-method directed forgetting is not unique to two-factor theories as it has been the standard in the directed forgetting literature to treat the phenomena produced by item- and list- methods as being completely different. Researchers have even claimed that item-method phenomena do not reflect forgetting at all since selective rehearsal suggests that TBF items were never learned, only maintained at a shallow level of processing (Johnson, 1994). Justification for this claim and for keeping item- and list-methods separate has been based on differences observed with recognition testing. As Benjamin (2006) writes, “the absence of an effect of directed-forgetting instructions on recognition is the linchpin of the theoretical claim that retrieval inhibition and not selective rehearsal underlies [list-method directed forgetting effects]” (p. 831), because the re-presentation of inhibited items will release them from inhibition (Bjork & Bjork, 1996), or reinstate the episodic context of learning (Sahakyan et al., 2009). But, recent research has challenged this rationale by exposing the differential impact of familiarity-based recognition testing proposed to act on list- and item- methods (Benjamin, 2006; Hanczakowski, Pasek, and Zawadzka, 2012; Sahakyan et al., 2009).

Benjamin (2006) claimed that list-method does not permit the same ease of discrimination as item-method of TBF from TBR information because it requires participants to maintain a larger amount of information prior to receiving the forget instruction, which in turn leads to greater confusion of the two types of information. Familiarity-based recognition will produce the illusion of an absence of costs because the recent exposure and poor discrimination would lead TBF items to seem familiar relative to unstudied lures (see also, Anderson, 2003). In support of this claim, with appropriately retrieval-based recognition tests research indicated list-method costs and benefits with recognition testing (Hanczakowski et al., 2012; Sahakyan et al., 2009). Findings such as these indicate the blurring of previously held strict empirical boundaries that differentiated item- and list-method directed forgetting. What about the theoretical boundaries?

Recent findings with item-method directed forgetting would suggest that even the theoretical boundaries once thought to differentiate item- and list-methods have begun to appear less distinct. When placed under the microscope of neural imaging studies, Wylie, Fox, and Taylor (2007) found that item-method directed forgetting revealed processing patterns associated with an intentional forgetting process distinct from an unintentional and passive forgetting process typically theorized with the selective rehearsal account.

Wylie et al. (2007) compared neural activity during study associated with instruction and future behavioral outcomes: TBF items that were forgotten (intentional forgetting), TBF items that were remembered (unintentional remembering), TBR items that were forgotten (unintentional forgetting), and TBR items that were remembered (intentional remembering). If forgetting were simply a passive process (i.e., a result of the ending of maintenance rehearsal without further elaboration) then engagement of mechanisms associated with unintentional remembering should be greater than those of intentional forgetting, but in fact, there was greater activation for the latter condition in areas implicated in the successful stopping of overt behavior.

Additionally, intentional forgetting showed increased activation in specific regions (parahippocampal gyrus/hippocampus and superior frontal gyrus) relative to unintentional forgetting. Wylie et al. (2007) interpreted these findings as indications that unintentional forgetting reflects encoding errors, whereas intentional forgetting engages an active cognitive process to prevent words from being committed to long-term memory. By this account, mechanisms engaged during item-method directed forgetting manipulations require frontal activity for both the creation of memories and the prevention of such creation in much the same vein as has been reported for list-method directed forgetting (Hanslmayr et al. 2012).

The decreased emphasis on recognition findings together with the neurological basis for suppression acting locally in the item-method would indicate more commonalities between item- and list-method directed forgetting than previously thought. Moreover, we see an opportunity and necessity for the development of an intentional forgetting account that would explain findings of item- and list-methods as well as alternative methods such as those used here.

A New Two-factor Theory for Successful Updating

We propose here an account of intentional forgetting and online memory updating that would explain the present findings as well as findings from both list-method and item-method directed forgetting. The *rehearsal and association updating* comprises two main mechanisms: a mechanism for selective rehearsal and elaborative encoding as well as a controlled suppression mechanism. The two mechanisms tradeoff based on the external requirements of the learning episode. We discuss the account in relation to list-method and item-method manipulations, and finally with an application to the present findings.

In a list-method directed forgetting experiment, participants initially attempt to learn the first TBF list as they would a TBR list. When given the forget instruction, they end rehearsal and elaboration of the TBF list, altogether. However, the stopping of rehearsal by itself is not enough to successfully inhibit list items because up until receiving the instruction, rehearsal processes enabled the development of both interitem associations among list members and contextual associations within the learning episode (Martin, 1971). The provision of a new TBR list initiates a new round of rehearsal and elaboration focused on learning that TBR list. Now, participants are strengthening TBR list interitem associations and contextual associations with the learning episode; elaboration within the TBR list and between the TBR list and study episode benefit from the stopped rehearsal of TBF list content. In this situation there is no reason to 1) maintain relations between the TBF list and learning episode, and 2) create associations or attend to the pre-existing associations between TBF list content and TBR list content.

Freed up cognitive resources seek to reassign the previously created associations between the TBF list and the learning episode in order to benefit the associative connections of TBR list and learning episode. This would suggest that contextual cues can be both unique to the learning of the TBR list and reused from the previous learning of the TBF list. Contextual cue reassignment can occur via an unbinding process like the one discussed by Bäuml, Pastötter, and Hanslmayr, (2010), but we hypothesize that the internal and episodic cues are then bound again with the learning of the TBR list along with unique context cues and interitem binding. Artuso & Palladino, (2011) observed such an iterative process of content-context binding, dismantling, and rebinding within working-memory and suggested the process to be governed largely by attentional focus within a dynamic working memory system (Bledowski, Kaiser, & Rahm, 2010). We would extend this process to occur in association with secondary memory as well (Zhang, Verhaeghen, & Cerella, 2012), such that during the course of learning the TBR list, when contextual cues are sampled by an active working memory store, this sampling would in turn access previously learned contextual and episodic cues stored during the learning of the TBF list and reassigned them to the TBR list.

Thus, this process results in increasing the likelihood of context cues activating the TBR list items rather than the TBF list items, and decreases source memory related to learning of TBF list (e.g., Gottlob & Golding, 2007; Hanczakowski et al., 2012). Suppression here focuses specifically on severing connections of contextual and episodic cues to the TBF list, and when possible, reconnecting them to the TBR list in concert with the creation of new cues via selective rehearsal. The reassignment of contextual and episodic cues to the TBR list is assumed to be lasting rather than temporary. However, this process would leave the interitem binding within the TBF list intact. Altogether, this process would impair the access to TBF content via contextual episodic cues but leave TBF content representations relatively unaffected, which would align with predictions based on the list-method directed forgetting suppression (Bjork et al., 1998). For the RR condition, participants would instead be motivated to maintain contextual associations for both lists, as well as interitem associations within lists, and relations between two lists. The continued maintenance of contextual, interitem, and inter-list associations would facilitate elaboration of both lists but consequently, reduce overall cognitive resources available for such elaboration.

We propose that for item-method directed forgetting, binding and unbinding would still occur, but at a local level and reduced capacity. The reassignment of contextual associations would be deemphasized by the nature of the task; because items occur in rapid and random sequence with varying instructions, there would be less ability and less reason to capitalize off associations between TBR items and the context of learning. In this case, there is a tradeoff, such that participants adopt a strategy dominated by selective rehearsal, dropping TBF items quickly from working memory and focusing on rehearsal and elaboration of TBR items.

With the present experiment, though R, FR, RR, and RF conditions occurred in a rapid and random sequence, contextual associations were an important component of the learning episode. Specifically, the relationship with the stimulus word served as a shared episodic and semantic cue, and the consequent associations to the stimulus could have been subjected to the processes of reassignment, which would have permitted greater elaboration of the TBR association and inhibited the TBF association. In this case, the TBF response association with the stimulus word would be impaired, but the TBF response itself would remain somewhat accessible in memory based on the amount of elaboration devoted to it.

Applying the rehearsal and reassignment account to the present series of experiments, for Experiments 1A and B, the re-presentation of the TBR association in the FR condition would not cause any new reassignment of contextual and episodic associations. Retrieval of the TBF response would be based on item-specific memory strength and any remaining contextual associations that had not been impaired during study. Similarly, the re-presentation of the TBF association would not be hypothesized to reinstate previously reassigned contextual and episodic associations, and so those associations would still have served to facilitate the retrieval of the TBR response. For the RR condition, presenting the second-learned TBR association as a cue would have conflicted with the use of serial order of study as an episodic cue for the retrieval of the first-learned TBR association. Presenting the first-learned TBR association would not have conflicted with the use of such an episodic cue, and would have only facilitated retrieval of the second-learned TBR association if there had been a focus on inter-response associations—as opposed to the stimulus-response association. However, with the present task, the focus on the stimulus-response association would have been favored for all conditions given the inability to anticipate the frequent occurrence of an instruction to forget.

For Experiment 2, costs and benefits in the FR condition would again relate to the difference in memory strength and the ability to use contextual cues mentioned above. The absence of FR directed forgetting benefits on the recognition test with the related stimuli might have been caused by an increased ability in the RR condition to utilize the shared episodic or semantic cues for retrieval of the second-learned TBR response, resulting in higher recognition rates that offset directed forgetting costs as well as effects of proactive interference. For the RF condition, we hypothesize that the TBR association could never benefit from reassigned contextual cues because the instruction that would have motivated such actions came after the TBR association had been learned. However, costs would still remain as they would have been attributed to stopped rehearsal of the TBF item immediately following the forget instruction. Indeed, with the RF condition the benefits appeared completely absent from both recall and recognition tests, whereas costs were generally present.

Experiment 3 findings are more difficult to explain. However, it seems likely that the focus of our implicit conceptual test was on the semantic activation of the individual responses, rather than their associations, which resulted in a transfer-inappropriate testing of representation activation (as discussed in Anderson, 2003). Selective rehearsal would have been focused on the association with minimal item-specific semantic elaboration, which would have caused the low rates of priming for the responses that we found. Unlike alternative absolute suppression accounts, the present theory would not predict negative priming of the TBF association. It remains unclear how the interpolated task might have differentially affected recall for the TBR association in the FR condition. If this finding were not artifactual, further research would be necessary to determine how interpolated tasks might interfere with the reassignment of contextual cues in the FR condition.

As evidenced by Experiment 3 interpretation, such post-hoc explanations are limited, but they succeed in indicating the potential for a general theory of intentional forgetting such as the rehearsal and reassignment account. A substantive determination of the viability of this account will require further research and exploration. Specifically, it would require means of testing and differentiating the rehearsal process from the process of re-binding contextual associations. However, this rehearsal and reassignment account provides an initial step towards the goal of developing a unified theory of intentional forgetting.

Conclusion

With this series of experiments, we sought to determine how online memory updating could occur through successful intentional forgetting of outdated information. By doing so, we have identified key features and boundary conditions of intentional forgetting mechanisms that challenge current directed forgetting theories. We have also hypothesized an explanation, the rehearsal and association updating account, to address these challenges and inform the important components of memory updating. The rehearsal and association updating account discussed here has been developed based on the present series of experiments and current findings in directed forgetting literature. Further empirical research will be necessary to assess its validity and benefit as an explanation of intentional forgetting.

The advantage of the present design is that it provides a way to examine online memory updating, which we have operationalized as the learning and replacement of associate pairs that share the same stimulus word in immediate succession. Other forms of updating and tests of memory will need to be utilized to test the rehearsal and reassignment account. The tradeoff between selective rehearsal and contextual reassignment of this account serves as a crucial part of this hypothesis because it enables the explanation of intentional forgetting operating on a continuum, from item to the list levels. Future research will need to explore this tradeoff further and determine how it changes with changes in the nature of the memory task. Additionally, if attention allocation serves a requisite function for contextual reassignment (see also, Zacks, Radvansky, & Hasher, 1996), it will be important to examine how divided attention manipulations affect learning within this updating paradigm. Other future directions should explore an updating process with regards to complex stimuli (e.g., narratives, sentences, trivia questions, emotional stimuli), complex processing (e.g., generation), and various retention intervals to better represent common factors that might influence memory updating in the real world.

Online memory updating, as discussed here, appears to be largely attributable to selective rehearsal of the TBR information as well as the reassignment of important contextual and episodic relations. Using the analog to error correction, results here suggest successful correction of errors will incorporate not only elaboration of the correct response but also a clear connection between the correct response and the stimulus question that serves to alter the connection to the error. Such altering and subsequent reassignment of connections to the stimulus item might be achieved by greater coherence between the question and correct answer (e.g., Finn & Metcalfe, 2010), emotional valence related to learning the correction (e.g., Butterfield & Metcalfe, 2001), repetition of testing or feedback (e.g., Roediger & Karpicke, 2006), and intentional forgetting, as discussed here.

This aspect of updating memory also relates to other real world situations such as the instruction to disregard information in the courtroom. Johnson and Seifert (1994) examined the continued influence effect (CIE), when discredited information continues to impact understanding of an event despite an instruction to disregard, and they found that the CIE was observed when such discredited information plays a causal role in the event description and was decreased when negated and followed by a causal replacement. By providing feedback and replacement, participants were better able to curtail the CIE. Similar real-world analogs might be drawn such as the ability to alter attitudes or beliefs, how to minimize the loss of information, development of expert knowledge, etc.—such concepts would inevitably entail learning and forgetting of information characteristic of the updating process.

The updating process benefits from intentional forgetting because forgetting provides a way to address interference caused by maintaining irrelevant and competing information. Due to its relationship with human learning, memory updating has common use, and so, research detailing its dynamics will have both theoretical value of informing an important cognitive process as well as practical value by determining how this common cognitive process can be used to explain and benefit human behavior.

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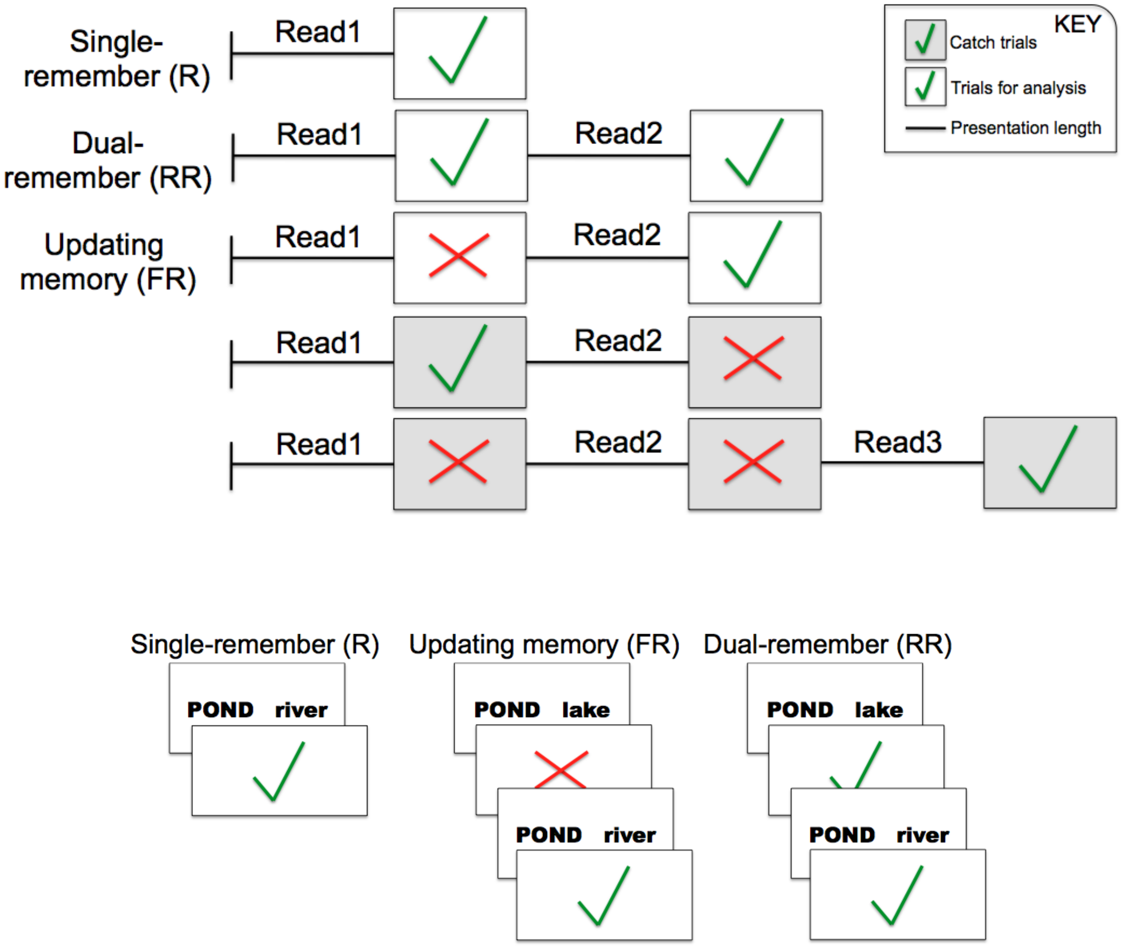


Figure 1. Research design for Experiments 1A-1B. The three conditions are listed above with catch-trial sets. An illustration of condition study trials is displayed below.

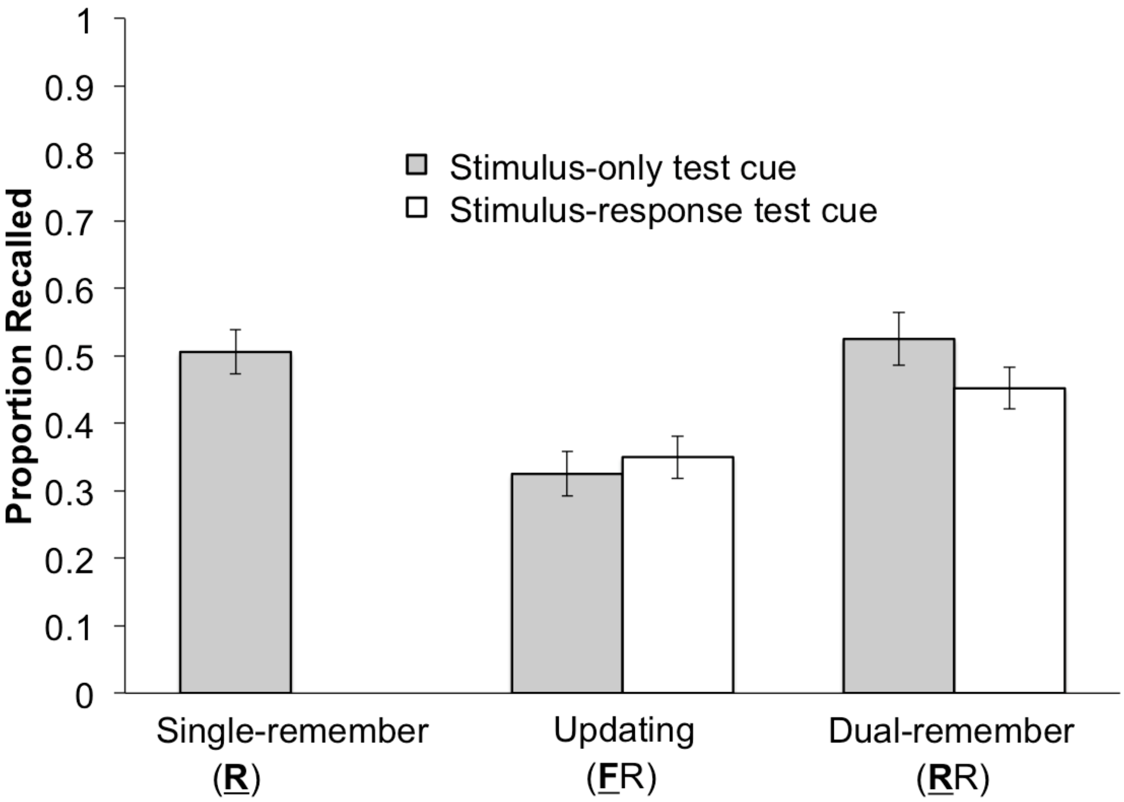


Figure 2. Proportion correct recall (and standard errors) for the first learned stimulus-response pair in Experiment 1A as a function of memory instruction and test cue. Means pertain to the item in each condition that is underlined and bolded below the condition label.

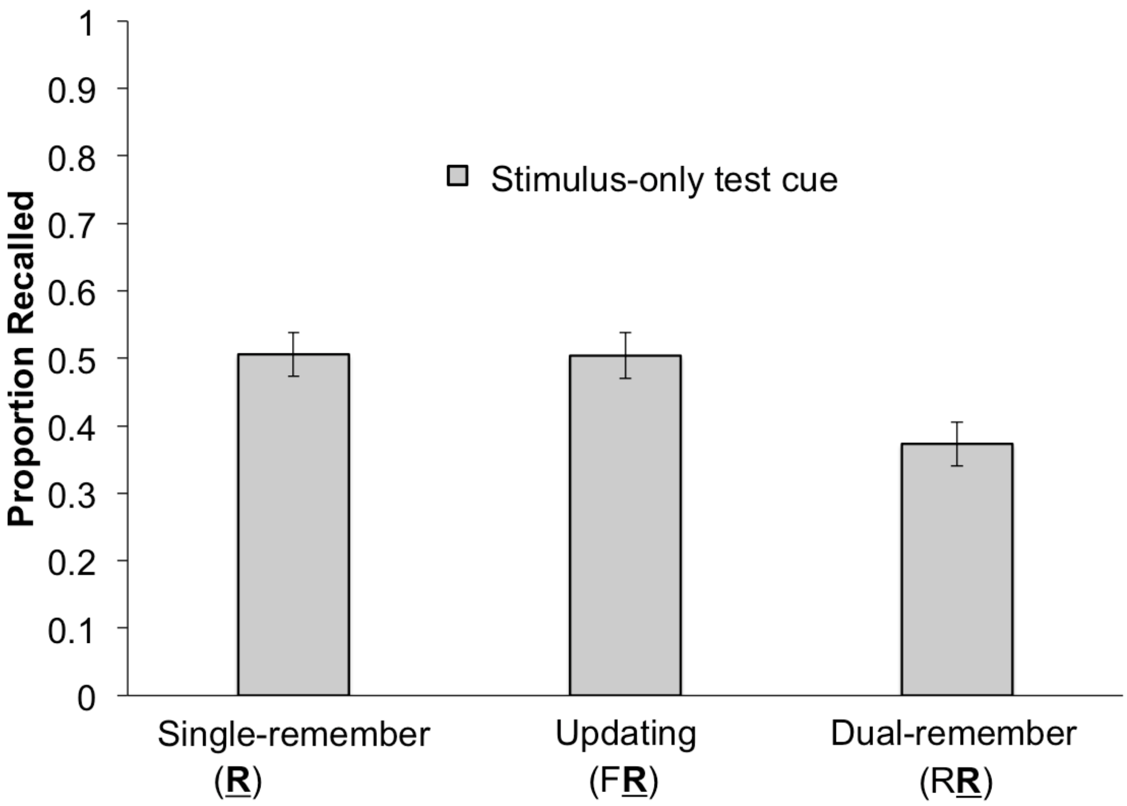


Figure 3. Proportion correct recall (and standard errors) for the second-learned stimulus-response pair in Experiment 1A as a function of memory instruction and test cue. Means pertain to the item in each condition that is underlined and bolded below the condition label.

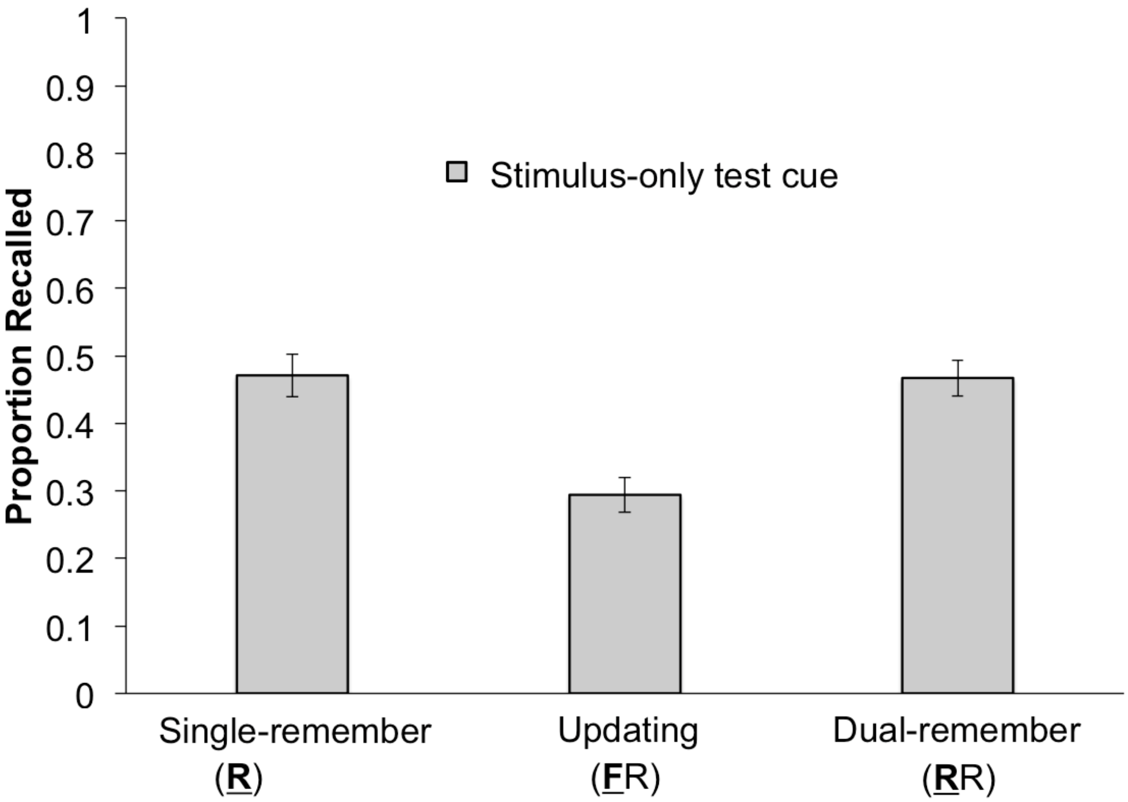


Figure 4. Proportion correct recall (and standard errors) for the first learned stimulus-response pair in Experiment 1B as a function of memory instruction and test cue. Means pertain to the item in each condition that is underlined and bolded below the condition label.

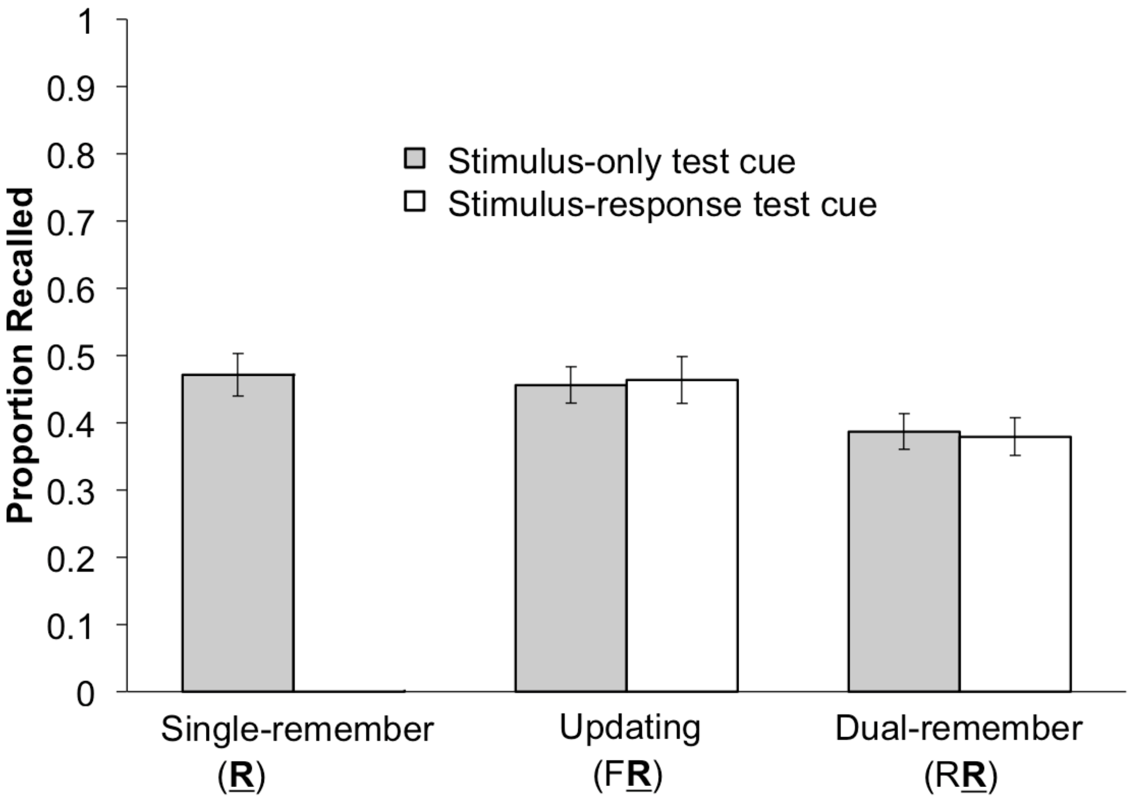


Figure 5. Proportion correct recall (and standard errors) for the second-learned stimulus-response pair in Experiment 1B as a function of memory instruction and test cue. Means pertain to the item in each condition that is underlined and bolded below the condition label.

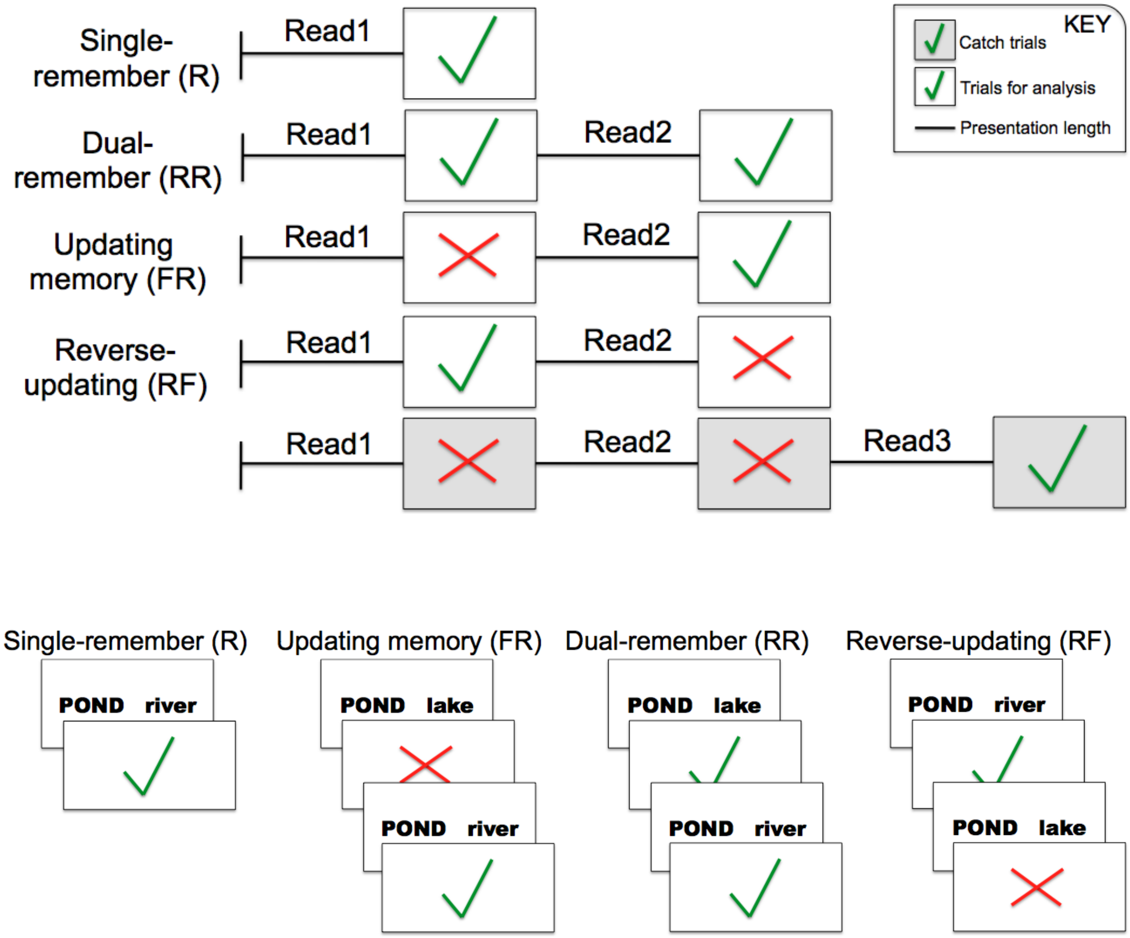


Figure 6. Research design for Experiments 2-3 with four paired-associate learning conditions of interest and the catch trial set; the illustration displayed beneath provides an example of condition study trials.

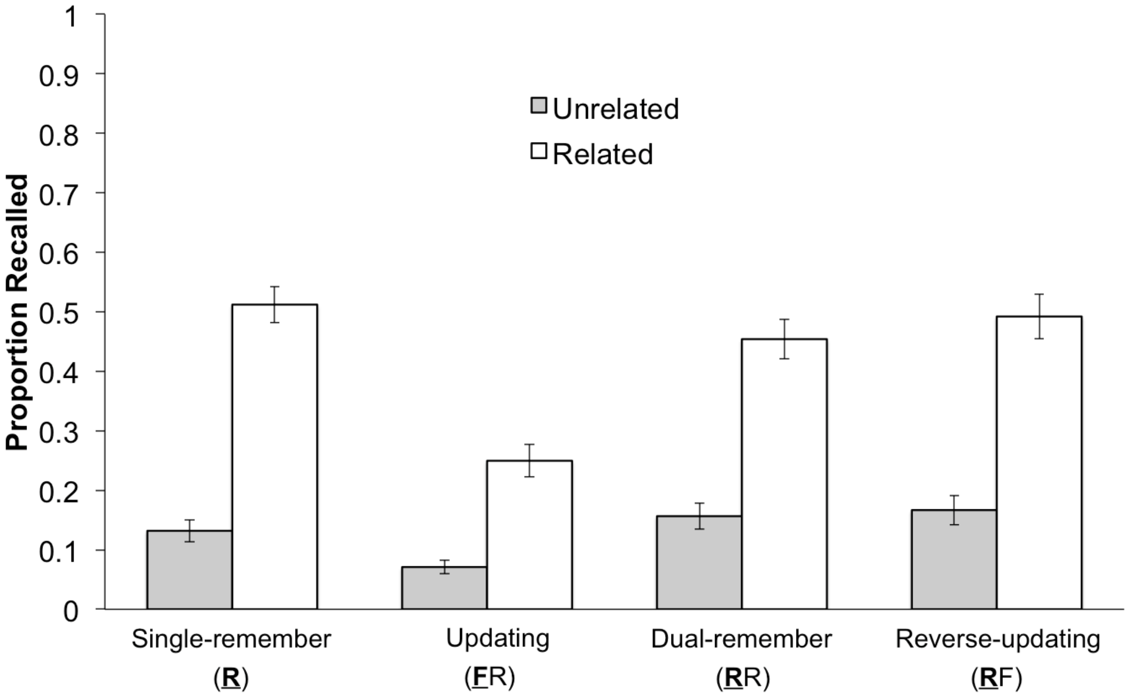


Figure 7. Proportion correct recall (and standard errors) for the first-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label.

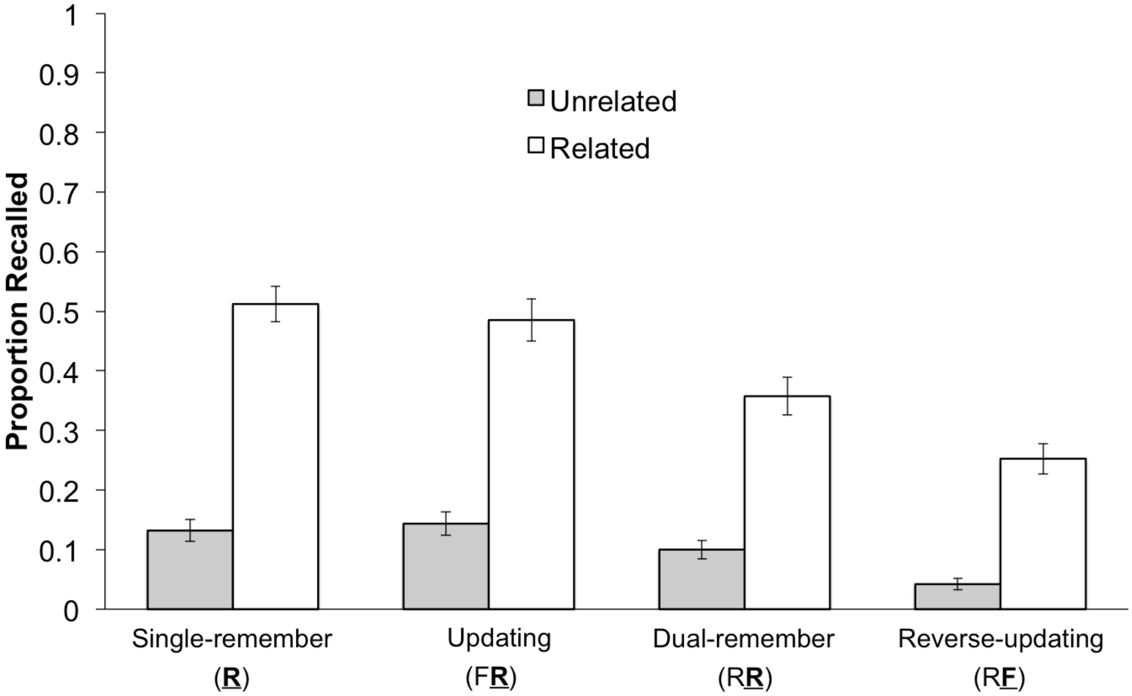


Figure 8. Proportion correct recall (and standard errors) for the second-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label.

Table 1

False Alarm and Hit Rates for Experiment 2 Recognition Testing

	Unrelated				**Related**			
	Hits		False alarms		Hits		False alarms	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Associate Learning Conditions								
(**R**) Single-remember	.62	.22	.17	.14	.78	.15	.17	.12
First-learned associations								
(**F**R) Updating	.59	.20	.18	.17	.74	.16	.22	.15
(**R**R) Dual-remember	.70	.18	.19	.15	.84	.14	.19	.12
(**R**F) Reverse-updating	.71	.21	.17	.14	.81	.17	.19	.13
Second-learned associations								
(F**R**) Updating	.69	.20	.19	.18	.81	.15	.23	.17
(R**R**) Dual-remember	.61	.19	.20	.21	.77	.15	.20	.16
(R**F**) Reverse-updating	.55	.19	.20	.19	.72	.18	.18	.13

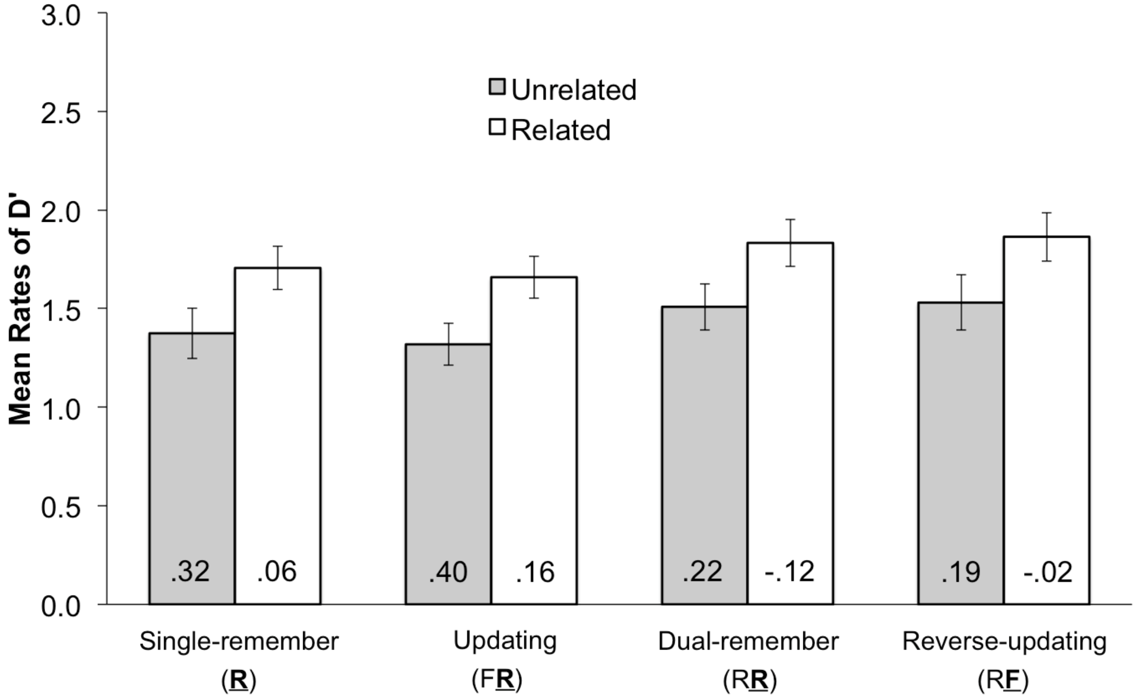


Figure 9. Recognition mean *d*‘ prime rates (and standard errors) for the first-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label. Values inside bars indicate mean bias, *C*, for that particular condition.

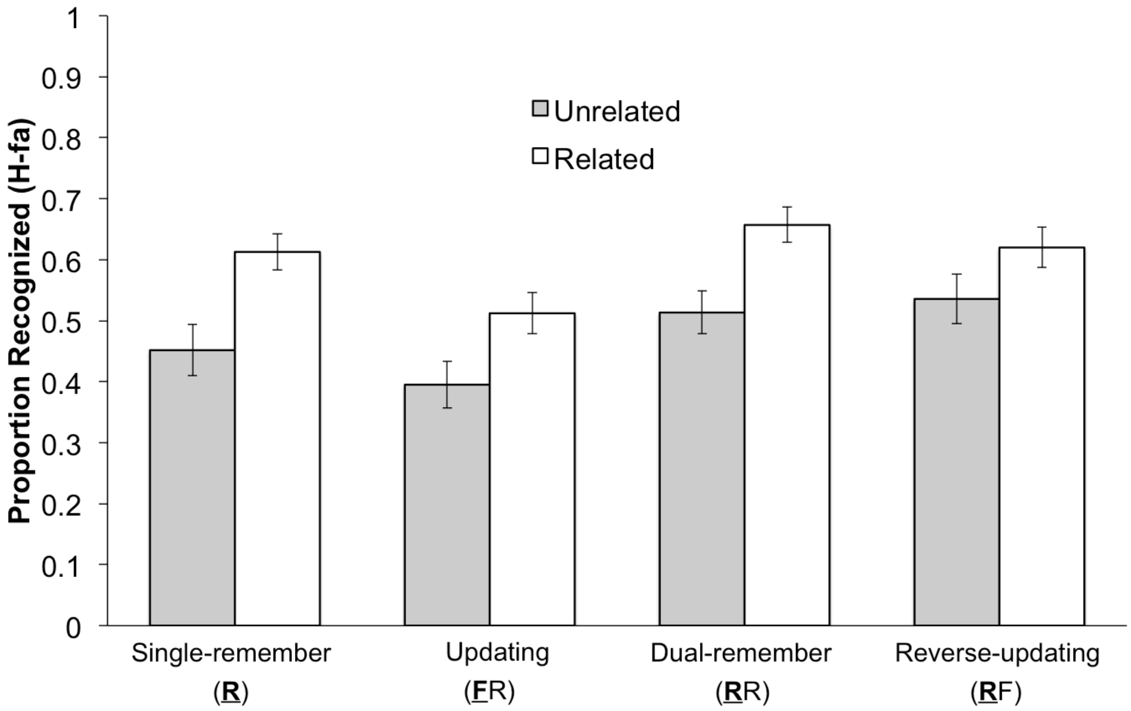


Figure 10. Recognition accuracy rates (and standard errors) for the first-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label.

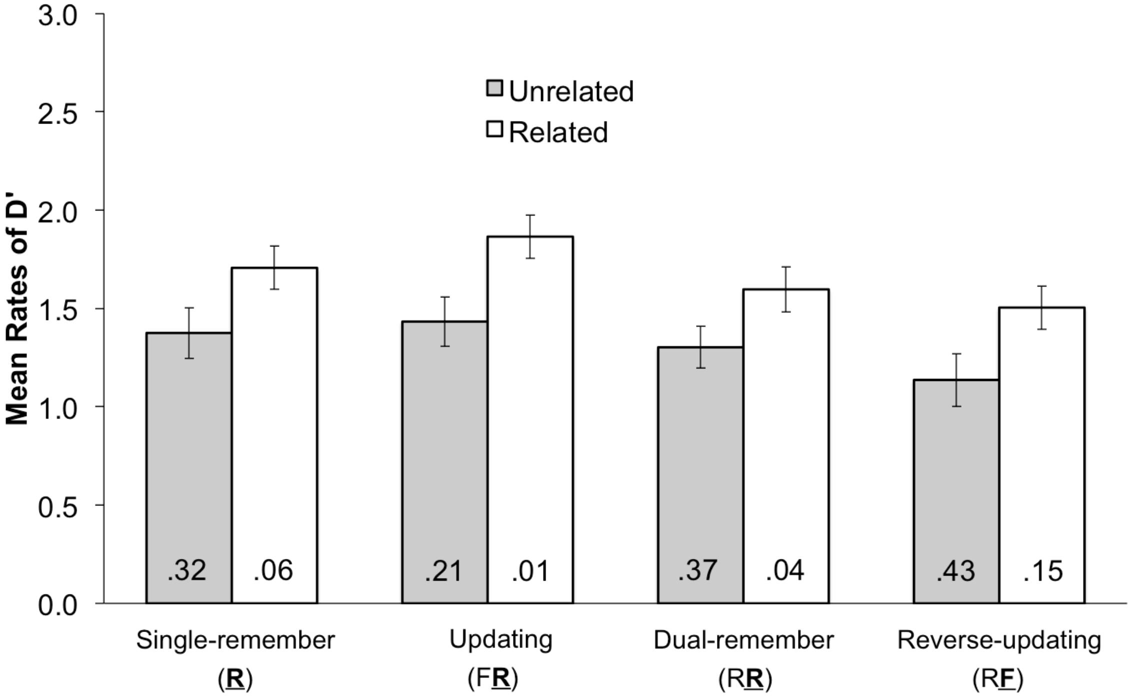


Figure 11. Recognition mean *d*' prime rates (and standard errors) for the second-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label. Values inside bars indicate mean bias, *C*, for that particular condition.

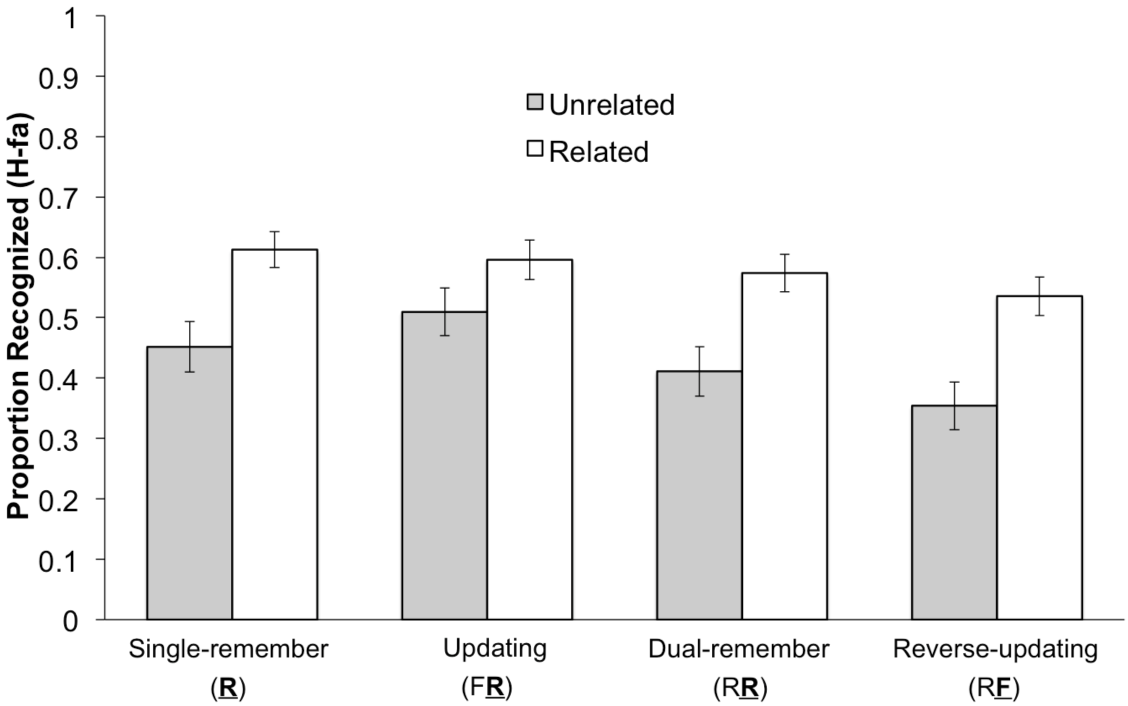
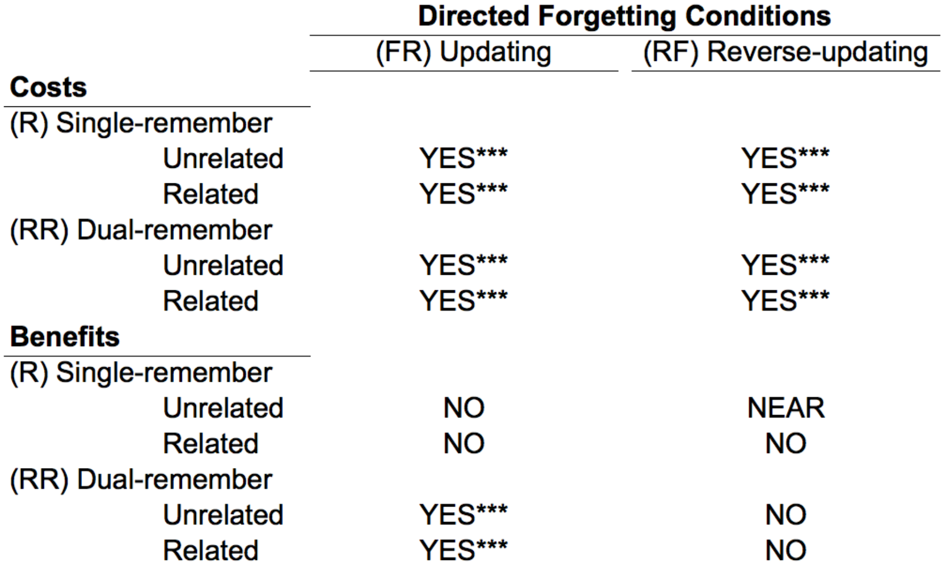


Figure 12. Recognition accuracy rates (and standard errors) for the second-learned stimulus-response pair in Experiment 2 as a function of memory instruction and stimulus-response relatedness. Means pertain to the item in each condition that is underlined and bolded below the condition label.

Table 2

Summary of Directed Forgetting Effects from Cued Recall Test in Experiment 2



	Directed Forgetting Conditions	
	(FR) Updating	(RF) Reverse-updating
Costs		
(R) Single-remember		
Unrelated	YES***	YES***
Related	YES***	YES***
(RR) Dual-remember		
Unrelated	YES***	YES***
Related	YES***	YES***
Benefits		
(R) Single-remember		
Unrelated	NO	NEAR
Related	NO	NO
(RR) Dual-remember		
Unrelated	YES***	NO
Related	YES***	NO

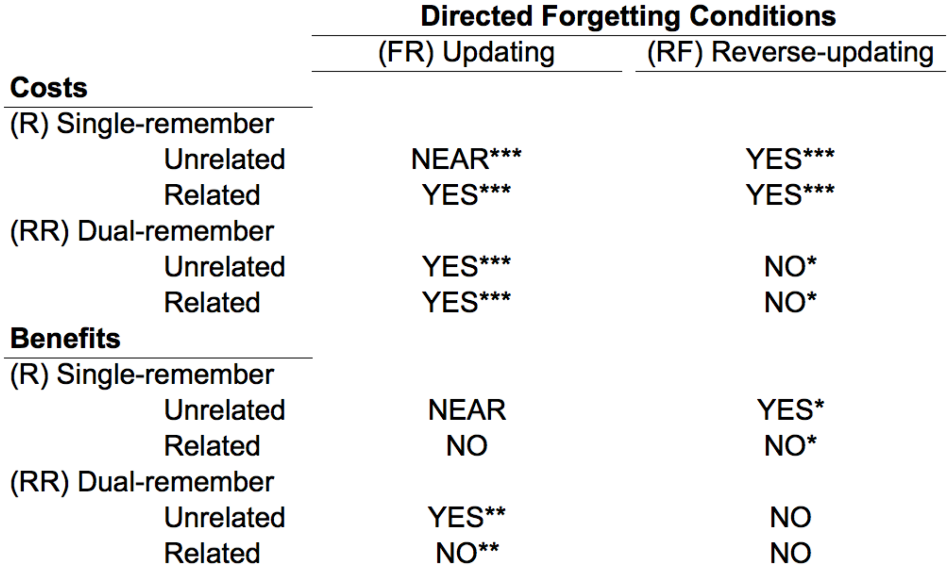
Note. Asterisks indicate presence of main effect collapsing across stimuli relatedness conditions.

NEAR: $.05 < p < .0825$

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 3

Summary of Directed Forgetting Effects from Recognition Test in Experiment 2



	Directed Forgetting Conditions	
	(FR) Updating	(RF) Reverse-updating
Costs		
(R) Single-remember		
Unrelated	NEAR***	YES***
Related	YES***	YES***
(RR) Dual-remember		
Unrelated	YES***	NO*
Related	YES***	NO*
Benefits		
(R) Single-remember		
Unrelated	NEAR	YES*
Related	NO	NO*
(RR) Dual-remember		
Unrelated	YES**	NO
Related	NO**	NO

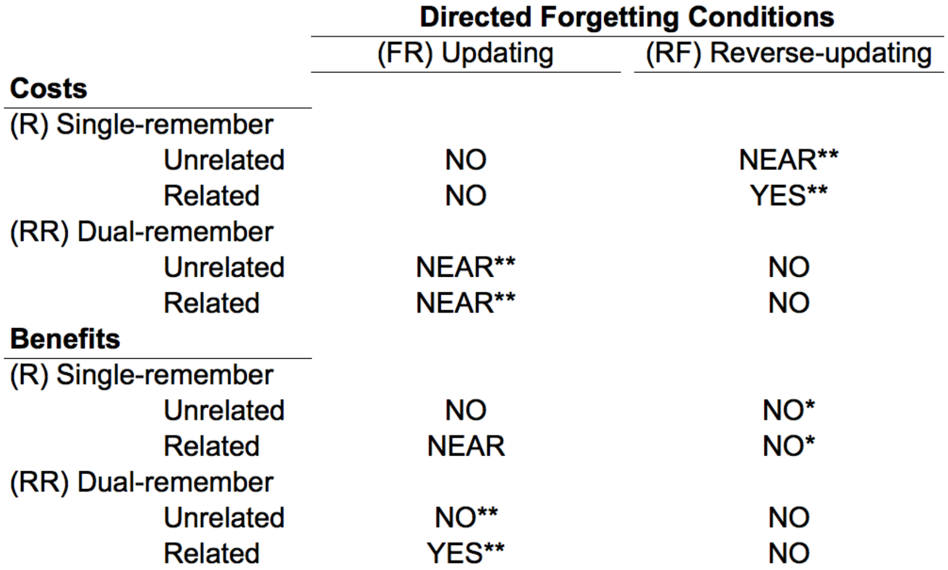
Note. Directed forgetting effects were those established with accuracy rates (*H-fa*). Asterisks indicate presence of main effect collapsing across stimuli relatedness conditions.

NEAR: $.05 < p < .0825$

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

Summary of Directed Forgetting Effects from Recognition Test in Experiment 2



	Directed Forgetting Conditions	
	(FR) Updating	(RF) Reverse-updating
Costs		
(R) Single-remember		
Unrelated	NO	NEAR**
Related	NO	YES**
(RR) Dual-remember		
Unrelated	NEAR**	NO
Related	NEAR**	NO
Benefits		
(R) Single-remember		
Unrelated	NO	NO*
Related	NEAR	NO*
(RR) Dual-remember		
Unrelated	NO**	NO
Related	YES**	NO

Note. Directed forgetting effects were those established with discriminability rates (*d'*). Asterisks indicate presence of main effect collapsing across stimuli relatedness conditions.

NEAR: $.05 < p < .0825$

* $p < .05$, ** $p < .01$, *** $p < .001$

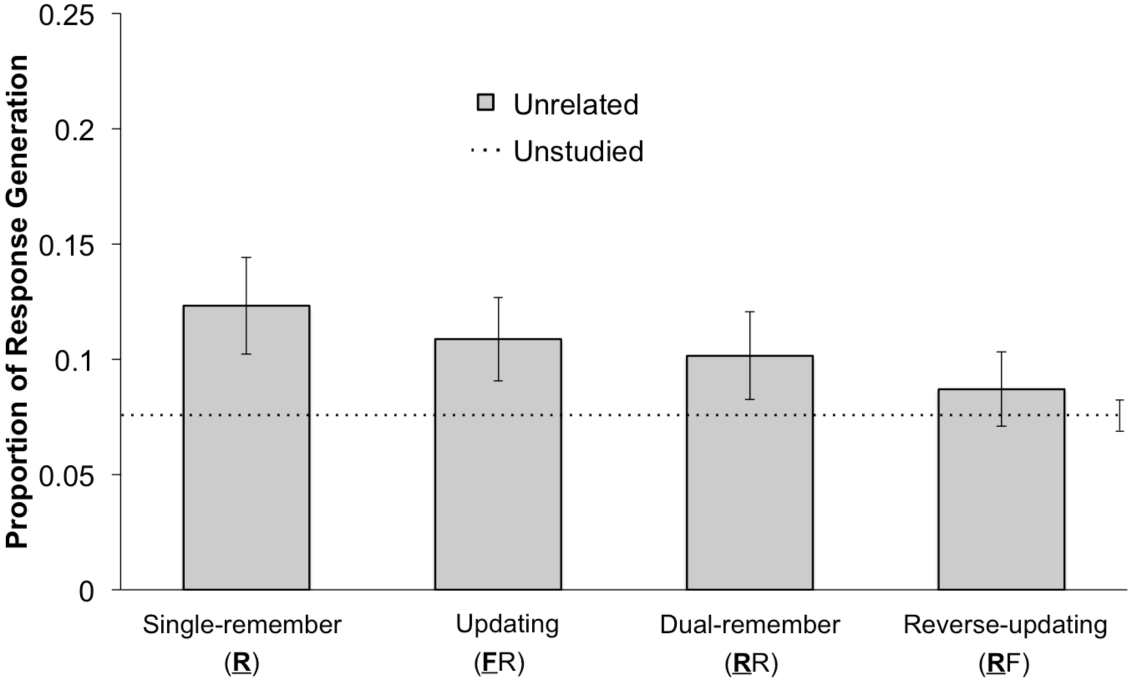


Figure 13: Proportion of first-learned response generation (and standard errors) on the free association conceptual implicit test in Experiment 2 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.

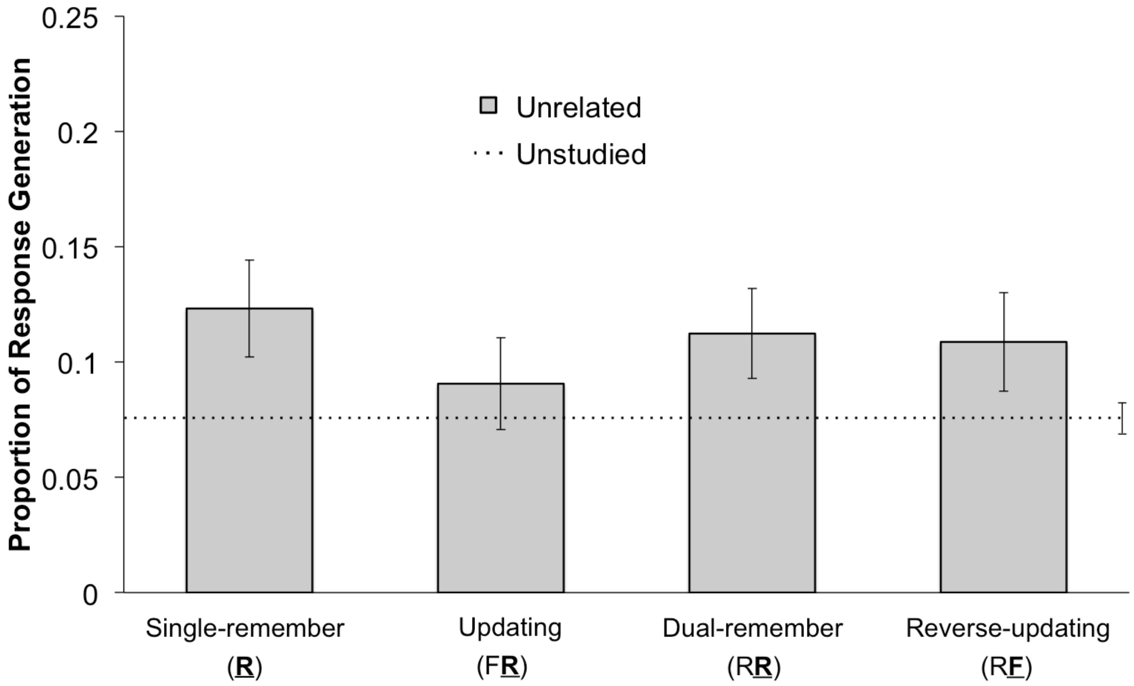


Figure 14: Proportion of second-learned response generation (and standard errors) on the free association conceptual implicit test in Experiment 2 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.

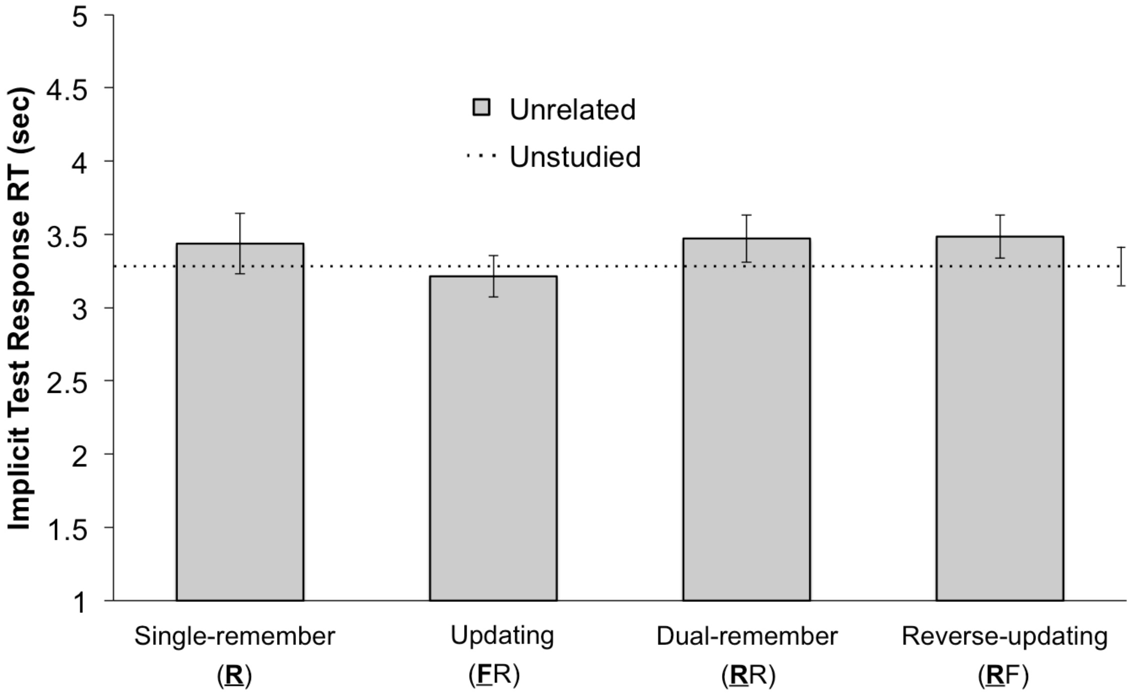


Figure 15: Response latencies of first-learned response generation (and standard errors) on the free association conceptual implicit test in Experiment 2 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.

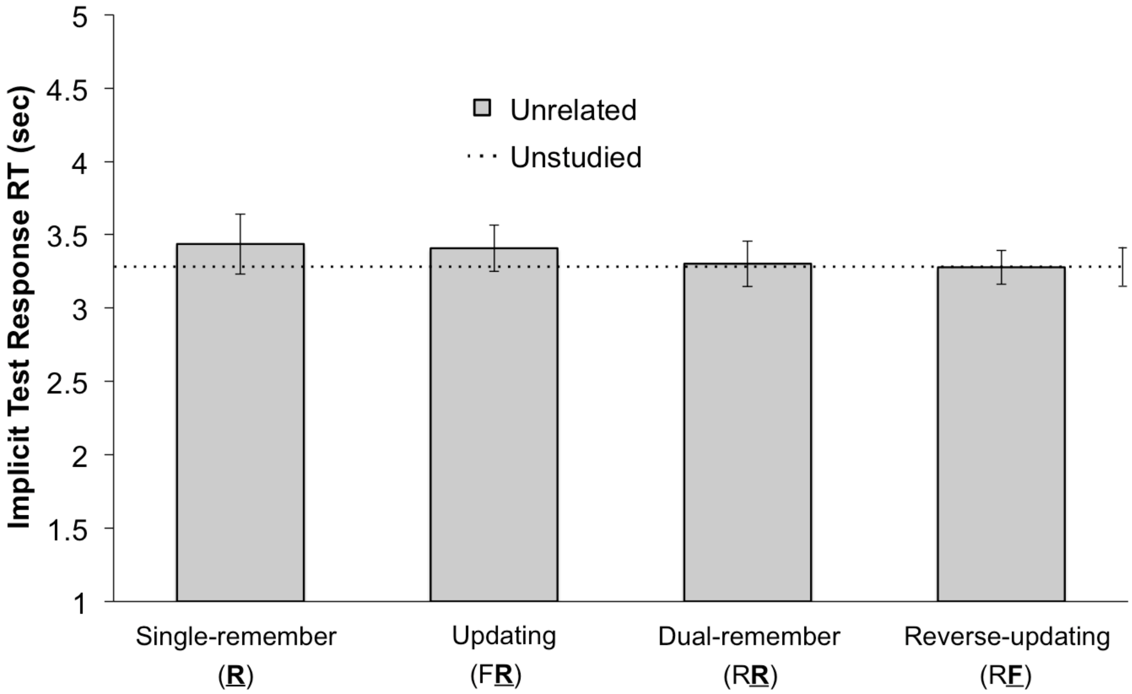


Figure 16: Response latencies of second-learned response generation (and standard errors) on the free association conceptual implicit test in Experiment 2 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.

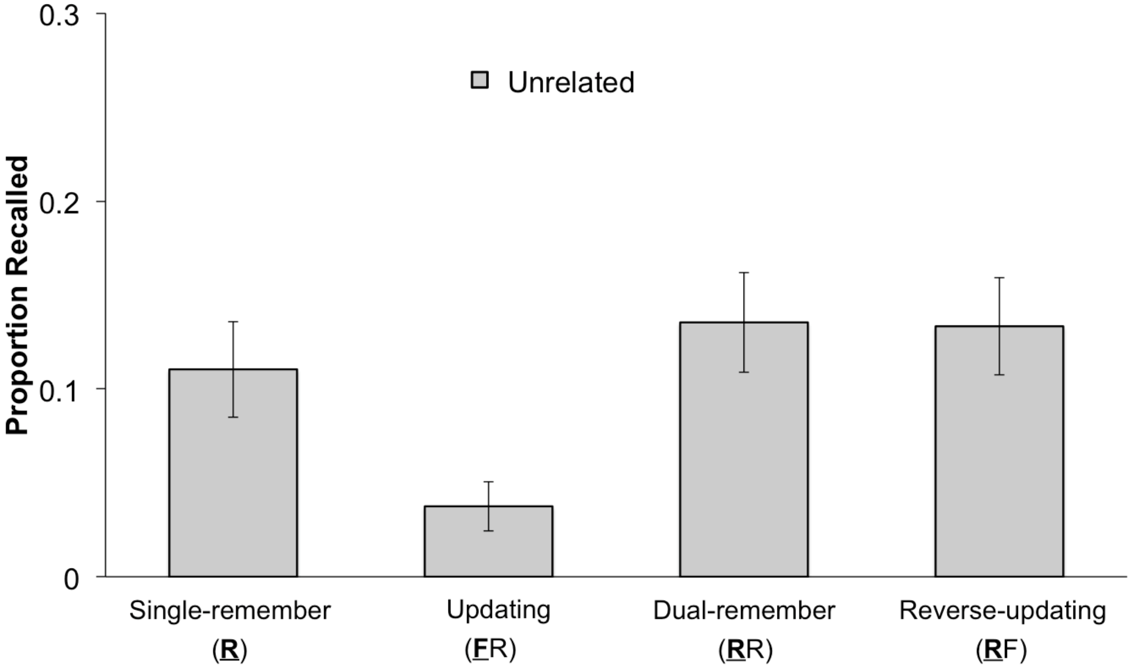


Figure 17: Proportion correct recall (and standard errors) for the first-learned stimulus-response pair in Experiment 3 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.

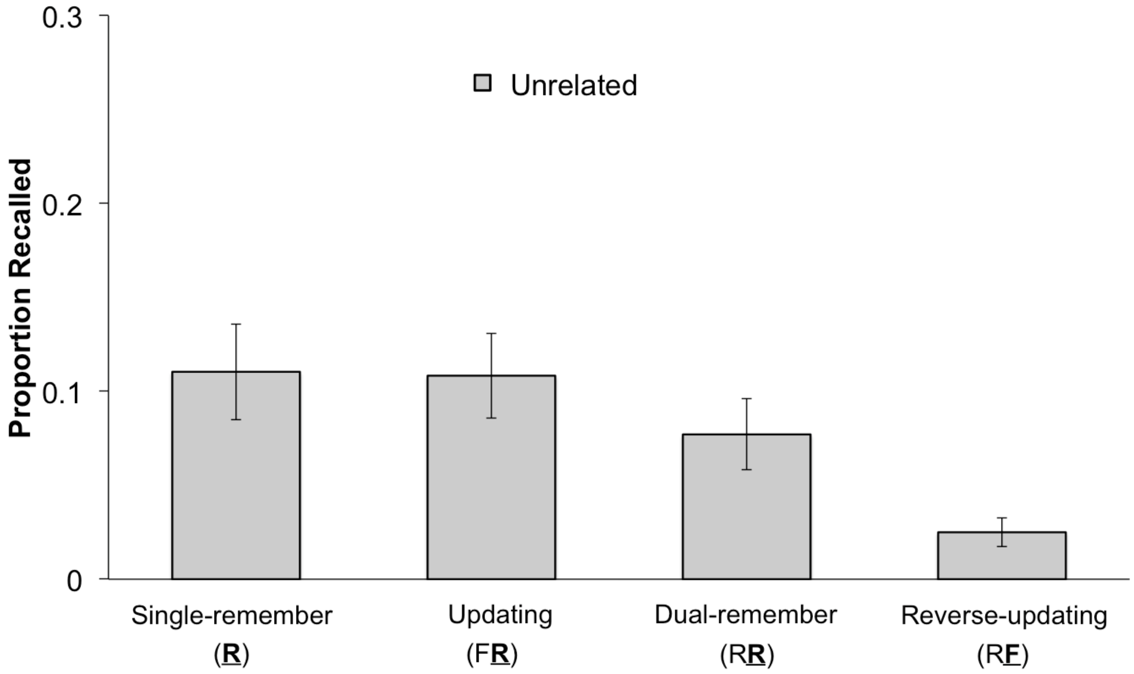


Figure 18: Proportion correct recall (and standard errors) for the first-learned stimulus-response pair in Experiment 3 as a function of memory instruction. Means pertain to the item in each condition that is underlined and bolded below the condition label.