CAN WE INTENTIONALLY FORGET ASSOCIATIVE INFORMATION?

BY

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THESIS

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ABSTRACT

I report three item-method directed forgetting (DF) studies to evaluate whether DF impairs primarily item information, or whether it also impairs associative information. Previous research obtained DF in an associative recognition paradigm, implicating possible impairment of associative information. However, impaired associative recognition could also arise from impaired item information, and reflect the downstream effect of item impairment. The current studies employed a modified associative recognition paradigm that allowed dissociating item impairment from associative impairment in DF. In Experiment 1, under strong associative encoding conditions, DF impairment was observed only when the lures came from the same cue condition as the target; however, DF was eliminated when the Forget targets were paired with Remember lures, possibly due to a recall-to-reject strategy. The exact opposite was found in Experiment 2, under weak associative encoding conditions, where pairing the Forget targets with Remember lures resulted in substantial DF, whereas there was no DF when the lures and the target came from the same memory instruction. In Experiment 3, I employed the use of eye-tracking to assess how DF impairment of associative information is reflected in eye-movements. The results showed that eye-movements differentiated between incidental forgetting (Remember items that are forgotten) and successful intentional forgetting (Forget items that are forgotten), providing support for the active account of DF. I conclude that the results provide strong support for the impairment of associative information by DF.
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This body of work is dedicated to Mike Schatz, the ceaseless adventurer.
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CHAPTER 1: DIRECTED FORGETTING, ASSOCIATIVE MEMORY, & EYE-TRACKING

To most people, remembering is a successful outcome of memory, while forgetting is a failure of memory, or a nuisance that needs to be avoided. Contrary to lay beliefs, however, forgetting has been shown to serve a positive function, something that benefits rather than hinders the learning process (Bjork, 2011). It is not always necessary to retain all information, and sometimes we need to let go of information that may be outdated, wrong, or painful to remember. For example, we keep in mind the specific room number in a hotel while we stay in it, but we forget that information the moment we check out. At times we need to update information, such as forgetting an old email address when switching places of employment and learning the new email address, or switching from an old operating system to a new one in the time of rapid growth of new technologies. Finally, we may feel a need to downregulate emotionally painful or traumatic memories. These examples illustrate that sometimes we implicitly or explicitly evoke a need to forget certain information. In the laboratory, memory control has been studied using the Think/No-Think paradigm (Anderson & Green, 2001) or the Directed Forgetting (DF) paradigm (Bjork, LaBerge, & LeGrand, 1968). The current study employs the DF paradigm and it investigates whether DF impairs information that accompanies the event one is trying to forget, such as contextual or associative information.

1.1 DIRECTED FORGETTING PROCEDURES

The DF paradigm has item-method and list-method variants. In both procedures, participants are presented with items to learn, some of which are subsequently cued to be remembered (R) or to be forgotten (F). Participants may be told that R-items will appear on a subsequent memory test, so they should keep them in mind, while F-items will not be tested, and participants should attempt to forget them. In the list-method, an entire list is presented before an R or F instruction is administered, whereas in the item-method, the R or F instruction is administered on an item-by-item basis. During the test, participants are tested on all items regardless of the memory instruction. Typically, F-items show a memory impairment compared to R-items, demonstrating that participants can comply with an instruction to forget, and the critical question concerns the mechanisms that produce the impairment of F-items, known as the DF effect. My investigation employed an item-method
DF procedure, and therefore I limit the discussion to item-method studies. The explanations for the item-method DF effect have focused on selective rehearsal of R-items (Bjork, 1970; Basden, Basden, & Gargano, 1993; MacLeod, 1999), and inhibition of F-items (Fawcett & Taylor, 2008; 2010; Hourihan & Taylor, 2006; Lin, Kuo, Liu, Han, & Cheng, 2013; Wylie, Foxe, & Taylor, 2008), with former highlighting the processes aimed at remembering the R-items, and latter highlighting more active and effortful processes aimed at downregulating memory for F-items. A more thorough explanation of these competing theoretical accounts surrounding the mechanism producing the DF effect in item-method is provided in Chapter 5, where I introduce eye-tracking as a means of testing the contrasting predictions between these two accounts.

1.2 ASSOCIATIVE PROCESSES IN DIRECTED FORGETTING

Typically, DF research has focused on the impairment of individual items in memory, and less attention has been devoted to how DF impacts associative information that accompanies individual items. Associative information broadly refers to knowledge of the relationships and co-occurrence between components of an event, also known as relational memory (Cohen, Poldrack, & Eichenbaum, 1997; Eichenbaum & Cohen, 2001). Throughout the manuscript, the terms relational and associative memory are used interchangeably. Critically, associative information concerns associations that are arbitrary or incidental to each episodic event. Examples of arbitrary, episode-specific relationships include the mapping of names to faces, or how items relate to each other in space (spatial arrangement) or in time (temporal order). Common operationalizations of associative information in experiments include presentation of word pairs, or other items in contexts (e.g. an image of a scene with an object superimposed on it). The current investigation is aimed at better understanding whether an instruction to forget primarily impairs item memory, or whether it also impairs associative information.

The effect of DF on associative information in item-method DF has been indirectly examined via manipulating context cues provided during the tests, and the results have produced mixed findings. It is well known that memory for items improves when study context is reinstated during test, known as the “context reinstatement effect” (Godden & Baddeley, 1975; Smith, Glenberg & Bjork, 1978). For example, Hourihan, Goldberg, and Taylor (2007) tested for recognition of R and F words presented in screen locations that
were either the same or changed from the studied location between encoding and test. They found F-words with reinstated screen locations had higher recognition performance than F-words without the reinstated screen location, but the same was not true of the R-words, which did not show the benefit of context reinstatement. In another study, Burgess, Hockley, and Hourihan (2017) employed trial-unique scene images as the context cue for F- and R-words, and found that providing the original background scenes for the words during the test benefited memory for F- and R-items equally. Importantly, these studies used context cuing to infer how the magnitude of DF is affected by context reinstatement; however, they do not directly assess how DF affects associative/contextual information.

Direct tests of associative information require the use of associative recognition tests, where pairs of items are presented at study, and the test requires discriminating pairs that were presented together (intact, e.g. chair-tree, cat-water) from pairs that are a recombination of studied items (rearranged, e.g. chair-water). The participant’s task consists of endorsing intact pairs as “old” (i.e. hits) and endorsing rearranged pairs as “new” (failure to endorse rearranged pairs as “new” is considered a false alarm). Because all constituent items in test trials are equally familiar, in order to correctly endorse rearranged pairs as “new”, participants must have specific information for which items co-occurred (i.e. associative information). One of the ways that rearranged pairs can be correctly endorsed as “new” is by employing a recall-to-reject strategy (Humphreys, 1978; Clark, 1992; Clark & Gronlund, 1996). This strategy consists of using one of the items in a test pair (e.g. chair) and recalling its associated item (e.g. tree) and then using the memory of this original pairing (e.g. chair-tree) to reject the rearranged test pair as “old” (e.g. chair-water).

To date, only a handful of studies have directly tested the effect of item-method DF on associative information using associative recognition tests. In these studies, participants were asked to discriminate between intact and rearranged word pairs (Bancroft, Hockley, & Farguhar, 2013; Wang, Mao, Li, Wang, & Guo, 2016; Hockley, Ahmad, & Nicholson, 2016). Hockley et al. (2016) found lower recognition accuracy on intact F-pairs compared to intact R-pairs, indicating a DF effect in associative recognition. Although impaired recognition of intact pairs is consistent with the notion that DF impaired the associative information between the words, such an outcome could also arise from impaired recognition of the
items comprising the word pair. Impaired recognition of individual items is well-established in item-method DF (e.g., Basden et al., 1993; MacLeod, 1999), and, if participants have impaired memory for the constituents of the pair as a result of forget instruction, they will also show impaired recognition of word pairs. That is, associative recognition performance can suffer simply from a failure to retrieve item information. Overall, impaired accuracy in existing associative recognition studies does not allow disentangling the effect of impaired item information from the impairment of associative information, and could, instead, simply reflect the impairment of the constituent items of the word pairs.

1.3 PARADIGM FOR ASSESSING ASSOCIATIVE PROCESSES

A novel contribution of the current study is that I adopted a modified associative recognition paradigm (Hannula, Ryan, Tranel, & Cohen, 2007) that allowed us to observe the impact of DF on associative information separate from the impairment of item information. This paradigm involves identifying which test items had been studied together, requiring distinctions regarding which elements of the test display were related. Specifically, participants are presented with arbitrary and unique item-scene pairings, and at test they are presented with a previously studied scene followed by a 3-item test display superimposed on that scene. One of the items was paired with that scene during encoding (target), whereas the remaining two items are familiar from the study phase, but were studied with different scenes (lures). The participant’s task is to select the item that was paired with the presented scene at encoding. Previous research has established that because all test items and scenes are familiar, successful identification of the target is driven by relational memory (Hannula, Smith, Ryan, & Cohen, 2007). Importantly, all the test elements are equated for item strength within each test block. Controlling for item strength in this manner allowed for more nuanced analysis of associative processes in completion of the task. Therefore, this modified associative recognition paradigm was ideal for disentangling the impact of DF on item information from associative information.

In addition, this paradigm has been successfully integrated with eye-tracking measures, demonstrating that eyes are disproportionately drawn to test items that were previously studied with the background test scene, indicating eye-movements are sensitive to memory for associations between items and their previously studied context. Given the
current goal of investigating how DF impacts associative information, using a concurrent measure such as eye-tracking along with an adapted associative recognition paradigm afforded the opportunity to investigate how impaired associative information may be reflected in eye-movements. This will be unpacked to a greater degree in Chapter 5 where I employ eye-tracking to investigate impairment of associative information as a result of DF.

1.4 CURRENT STUDIES

The details of the paradigm employed in the current studies is shown in Figure 1. Participants were first presented with a scene, followed by an object superimposed on that scene. During encoding, participants in Experiment 1 were instructed to think about how well the object and the scene “go together” (i.e. Associative instruction), whereas participants in Experiment 2 were encouraged to think of whether the object can fit inside a shoebox (i.e. Item-emphasis instruction). Following the object-scene pairing, participants received either a forget (F) or remember (R) instruction about the previously shown object. Immediately after encoding, participants received a memory test. Importantly, both experiments were run simultaneously, but are presented as two separate studies for exposition.

Test trials consisted of a three-alternative forced choice task, presenting an intact pair and two rearranged pairs (formed by using objects from other object-scene studied pairs) all at once. Specifically, participants were first shown a brief preview of a scene, followed by three objects superimposed on that scene. One of the objects was studied with that scene (i.e., target item), whereas the remaining two objects were previously studied with different scenes (i.e., lures). The participant’s task was to select the object that was studied with that scene. Because all presented objects and scenes had been previously studied, in order to correctly select the target, participants must rely on the association between the target object and the scene. Since the task relies on participants being able to correctly identify which scenes the objects were studied with, stronger associative information for object-scene pairs facilitates identifying which scenes the objects were paired with. This could be driven by superior recognition of the target object or superior rejection of lures, and would be more likely under strong associative encoding conditions. If participants have difficulty recalling which scene the target object was studied with, recalling which scenes the lures were studied with in order to reject them will benefit
selection of the target object. When associative encoding is weak, retrieving associative information will be more difficult, potentially biasing participants to rely on item strength differences in their associative recognition. Under these conditions, rejection of lures will be more difficult compared to strong associative encoding conditions. Note that chance performance in a three-alternative forced-choice task is 33%.

Importantly, I manipulated the strength of the three test objects to allow dissociating the impact of DF on item information and associative information. For half of the participants, all three test objects were selected either from F-trials or from R-trials (Same Lures condition). Thus, in the Same Lures condition, item and associative strength was held constant in a given test trial, as both target and lures were given identical memory instructions. For the remaining half of participants, the target object was selected from F-trials and two lures were selected from R-trials, or vice versa (Switched Lures condition). Thus, in the Switched Lures condition, item and associative strength of target and lures was intentionally confounded in order to bias the selection of the target or the lure (explained below). Therefore, dissociating the effect of DF on item information from the effect of DF on associative information is accomplished by comparing the Same Lures and Switched Lures conditions.
Figure 1. Participants are first presented with object-scene pairings at encoding. Half are followed by a remember instruction, the other half by a forget instruction. At test, participants are presented with three previously studied objects superimposed onto a previously studied scene. One of the objects had previously been paired with the scene (target). Participants are to indicate which object is the target. Lures can come from the same or opposite memory instruction trial as the target. Targets and lures could appear in any of the three test locations equally often. Red and green borders are used here to highlight F and R cued items, respectively, and were not present during the experiment.
CHAPTER 2: EXPERIMENT 1 - ASSOCIATIVE INSTRUCTION

2.1 INTRODUCTION

Figure 2a summarizes the main manipulations of the study, along with their anticipated influence on item strength and associative strength. In order to assess whether associative information is impaired due to DF instructions, I wanted to ensure that associative information was encoded as strongly as possible. Research shows that encoding instructions that encourage learning the associations between items (or in my case, items and their context) improve performance on associative recognition tests compared to instructions that encourage learning individual item’s features (Hockley & Cristi, 1996; Dulas & Duarte, 2013; Henson, Rugg, Shallice & Dolan, 2000). Thus, the purpose of the Associative instructions was to encourage explicit encoding of associative information.

If DF impairs associative information, I expect F-targets to have weaker associative strength than R-targets. This would make it more difficult to retrieve the associative information for both F-targets and F-lures compared to R-targets and R-lures, therefore making it more difficult overall to recognize which scenes F-cued objects were paired with compared to R-cued objects. Thus, I expect to observe a DF effect in the Same Lures condition. Note that impaired associative recognition can result from item impairment due to impaired recognition of the object itself. Therefore, the Switched Lures condition is necessary to separate item impairment from associative impairment due to DF instructions, as predictions from item-only impairment contradict predictions resulting from associative impairment for Switched Lures condition, specifically for F-trials. In the Switched Lures condition, when F-targets are paired with R-lures, the lures will have greater associative strength with their original partnered scene than the target. Therefore, when participants are unable to directly retrieve the scene information for F-targets due to its weak associative strength, they could use the scene information of the R-lures to reject them and select the F-target more often than in the Same Lures condition (by employing a “recall-to-reject” strategy). Thus, accuracy in the F condition might counterintuitively benefit from having strong lures and improve in the Switched Lures compared to the Same Lures condition, due to F-lures being more difficult to reject than R-lures. However, the source of this “benefit” is driven by differential amounts of associative strength between
the F- and R-objects. Conversely, when R-targets are paired with F-lures, the lures will have weaker associative strength than the target. However, since the R-target will have strong associative strength, retrieving scene information for that target should be relatively successful, and therefore relying on a strategy of rejecting the lures is likely to be minimal in the R-condition. Thus, the strength of the lures in either R-condition should have minimal impact on recognition of the R-targets.

To summarize, the magnitude of the DF effect is expected to be larger in the Same Lures than in the Switched Lures condition if F-trials improve under the Switched Lures condition and R-trials are relatively unaffected by the Lures manipulation. Therefore, the critical manipulation that distinguishes between the effects of DF on item information from associative information comes from the Switched Lures condition. That is, F-trials are expected to improve, whereas R-trials are expected to be affected minimally, as R-targets will have strong associative strength, minimizing any influence of the lures on selecting the R-target between the Same and Switched Lures conditions.

2.2 Methods
2.2.1 Participants & Design
Participants were 108 undergraduate students from the University of Illinois who received course credit for participation. The study was approved by the Institutional Review Board of University of Illinois at Urbana-Champaign and complied with APA ethical standards in the treatment of participants. All participants gave informed consent prior to inclusion in the study. They were tested in small groups of no more than four people at a time. Participants were assigned equally to one of two between-subject conditions (Same Lures vs. Switched Lures). Memory cue (F vs. R) was manipulated within-subjects.

2.2.2 Stimuli
The stimuli included 108 colored images of nameable, everyday objects taken from various online sources including Google Images (sized to 300 x 300 pixels) and 108 colored images of scenes taken from Brand X photography (sized to 800 x 600 pixels). Objects were a ¼ screen size and superimposed centrally on the scenes. Objects were everyday objects, such as fruits, toys, sports balls, musical instruments, etc. Scenes were either outdoor
landscapes (fields, beaches) or man-made areas (cities, towns, farms). No scenes included the presence of people. There were roughly equal amounts of outdoor landscapes and man-made areas, so as to include a wide variety of scene types. There were no repeated presentations of test items, as each object and test scene was presented only once as a test stimulus.

2.2.3 Procedure

Participants were first provided practice study and test trials to familiarize them with the procedure as well as to emphasize the use of associative information during the testing phase. Everything in the practice trials was identical to the actual procedure, with the exception of not including the DF manipulation. The study consisted of 108 study trials, half of which were instructed to be remembered while the other half were instructed to be forgotten. During the encoding phase, participants received an Associative instruction (“think about how well does the object and scene go together”). Each encoding trial began with a 1 s fixation point, followed by a 2 s scene preview, where the entire scene was shown unobstructed by any objects. Afterwards, an object was superimposed on that scene for 4 s, during which participants engaged in the Associative encoding task. Finally, a forget or remember memory cue was shown for 2 s, indicating whether the object just presented needs to be remembered for a later test or forgotten. All objects were equally likely to be cued as to be remembered or forgotten, and no more than three consecutive trials with the same memory cues. When all object-scene pairings had been presented, participants received the associative recognition test.

At test, participants were told that they would be presented with three previously studied objects against a previously studied scene, and their task was to indicate which of the objects had been presented with that scene during encoding. Participants were tested on all objects, regardless of the memory instruction. Every test trial began with a 1 s fixation cross, followed by a 2 s scene preview. Afterwards, three objects were presented superimposed on the scene, during which time participants were to select the object that had previously been presented with that scene. This three-object test display terminated upon selection of an object, or after a maximum of 6 s (if participants failed to make a response within this time frame, that trial was not included in the analysis). Test trials
ended with a 4 s probe for participants to provide a binary confidence judgment, which asked participants how confident they were that the object they selected was presented with that scene (i.e. 1 for low confidence, 2 for high confidence)\(^1\). Participants were assigned equally to one of two test Lures conditions; half of the participants were given Same Lures test displays, in which target and lures were selected from the same memory instruction trials, and the other half were given Switched Lures test displays, in which the lures came from the opposite memory instruction trials as the target.

### 2.3 Results

#### 2.3.1 Data Analysis

The process of data collection was conducted using E-Prime 2.0 (Psychology Software Tools, 2015). Statistical analyses were computed using R software (R Development Core Team, 2008). Recognition performance analyses were performed using Mixed Effects Models, fitted with the glmer function in the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) and the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). All follow up analyses involving analyzing contrasts following an interaction were performed using the emmeans package (Length, Singmann, Love, Buerker, & Herve, 2014), and alpha was corrected using Tukey’s HSD test.

#### 2.3.2 Associative Recognition Accuracy

Associative recognition accuracy (averaged across both trials and participants) by cue and lure condition is summarized in Figure 2b. To assess the relationship between cue, lure condition, and behavioral accuracy on a trial-by-trial basis, I used multilevel modeling analyses (i.e., Jaeger, 2008). Specifically, a mixed level logit-regression was conducted on behavioral accuracy of individual trials, using memory cue and lure condition as fixed effects, and treating participants as a random effect.

Associative recognition accuracy was fit using a Mixed Logit Regression Model using Cue (R vs. F) and Lures (Same vs. Switched) as fixed effects and Participants as a random intercept. There was a main effect of Cue, \( \beta_{\text{cue}} = 0.16, SE = 0.07, Wald Z = 2.26, p = .024 \), indicating that DF instructions impaired associative recognition. The main effect of Lures

\(^{1}\) Confidence judgments are not analyzed in this thesis.
was not significant, $\beta_{\text{lures}} = 0.09$, $SE = 0.18$, $Wald Z = 0.52$, $p = .606$. The main effect of Cue was qualified by a significant Cue x Lures interaction, $\beta = -0.33$, $SE = 0.15$, $Wald Z = 2.26$, $p = .024$ (the variance associated with random effect of participants was $\sigma^2 = .75$, $SD = .86$).

To follow-up the interaction, I assessed the effect of Cue within Lures conditions separately. In the Same Lures condition, where the lures and targets were equated for item strength within the test display, participants were less likely to endorse a Forget compared to Remember target, $\beta_{\text{Cue}} = 0.32$, $SE = 0.10$, $Wald Z = 3.05$, $p = .012$, demonstrating a DF effect of associative memory. In contrast, in the Switched Lures condition, where the lures and targets differed in item and associative strength within the test display, participants were no more likely to endorse a Forget compared to a Remember target, $\beta_{\text{Cue}} < 0.01$, $SE = 0.10$, $Wald Z = 0.04$, $p = 1$, demonstrating a null DF effect of associative memory.

### 2.4 Discussion

In Experiment 1, participants were instructed to associate the objects with the presented scenes to ensure that associative information was explicitly encoded and could therefore be potentially impaired by DF instructions. This allowed examining whether pairing weak F-targets with strong R-lures benefited F-targets compared to when weak F-targets were paired with weak F-lures. Importantly, a significant DF effect was obtained in the Same Lures condition, indicating that when associative information is explicitly encoded, the forget instruction impairs associative information, resulting in a DF effect. A Bayesian t-test was performed aggregating across both trials and subjects, revealing that the significant DF effect in the Same Lures condition is 5.17 times more likely to be observed under a model that assumes there are significant differences between the Forget and Remember conditions, $BF_{01} = 0.19$. However, this pattern of accuracy could be obtained also if DF impaired only item information, making it more difficult to recognize which scenes Forget-targets were paired with through a failure to recognize the target object itself.

Implementing the Switched Lures condition was critical in establishing that DF impaired associative information. Consistent with my predictions, DF effect in the Switched Lures condition was substantially reduced, and practically eliminated. A Bayesian t-test was performed aggregating across both trials and subjects, revealing the null DF effect in
the Switched Lures condition is 6.64 times more likely to be observed under a model that assumes there are no differences between the Forget and Remember conditions, $BF_{01} = 6.64$. Counterintuitively, impaired associative information of F-targets resulted in _less_ frequent selection of F-targets than when they were paired with R-lures. That is, F-targets were selected more often when the lures were strong (i.e., Remember-cued) than weak (i.e., Forget-cued). Since the task required use of associative information linking objects to scenes, recognizing which scenes the test objects were paired with was more successful overall for R- compared to F-cued objects overall. Greater associative recognition success for F-targets when there were strong compared to weak lures implicated both the use of strong associative encoding of R-lures to reject them as well as weak associative encoding of F-lures making them more difficult to reject. Additionally, recognition of R-targets did not improve compared to Same Lures condition, indicating that participants were just as successful recognizing the R-target when it was paired with weak compared to strong lures. Therefore, strong R-targets were minimally affected by the strength of the lures, presumably because the relative success in recognizing the R-target as having been studied with the test scene made it less likely to rely on correctly rejecting the lures.
Figure 2a. Test displays showing the main manipulations of this experiment along with their expected effects on the item strength and associative strength. Three objects are denoted by small white boxes, with the grey box denoting the background “scene”. Subscripts T and L refer to target and lures, with R and F inside the boxes referring to Remember and Forget memory instruction (e.g., RT refers to a target object that was paired with the presented test scene during encoding and was given a Remember instruction). Thicker boxes around R-objects indicate higher item strengths compared to F-objects. Solid vs. dashed arrows from the objects towards the background scene denote differential object-scene associative strength for the R and F conditions, with solid arrows indicating higher associative strength of an object to its paired scene. For lures, the arrows extending outside the grey box reflect the association between that object and a different scene that was paired with it during encoding.
Figure 2b. Recognition accuracy in Experiment 1 as a function of DF Instruction and Lures conditions. Performance is in terms of proportion of correct responses. The error bars reflect SE of the mean.
3.1 INTRODUCTION

Experiment 1 demonstrated DF impairment of associative information under conditions in which its encoding was emphasized. Critically, pairing weak F-targets with strong R-lures eliminated the DF effect in the Switched Lures condition in a manner that implicates impaired associative, and not just item information by DF manipulation. The purpose of Experiment 2 was to further test how DF would affect performance in the same paradigm, if I minimize the encoding of associative information by implementing an orienting task that focuses attention on the object rather than the associative information between the object and the paired scene. Thus, Experiment 2 differed from Experiment 1 in implementing an Item-emphasis encoding instruction and by eliminating the practice trials. This could potentially encourage spontaneous associative encoding strategies if participants were familiarized with the testing procedure. An opposite set of predictions is derived for Experiment 2 in regard to which conditions showed the greater magnitude of DF. In Experiment 2, DF is likely to impair primarily item information, with relatively lesser impact on associative information presumably because the latter was minimally encoded.

Since DF instructions impair item information, F-objects will have weaker item strength than R-objects, and any differences in recognition of F- compared to R-targets should be driven primarily by item strength differences. The Same Lures condition controls for item strength between target and lures, as they were all given the same DF instruction during learning. Due to emphasizing primarily item information, associative information should be poorly encoded and thus the effect of DF on associative information should be minimal in the Same Lures condition for Experiment 2. Most critically, in the Switched Lures condition, the differences in item strength between F- and R-items means that F-targets being paired with stronger R-lures may result in the selection of R-lures more often (i.e., making a false alarm). That is, direct retrieval of associative information should be comparably difficult for both F- and R-objects, potentially leading participants to adopt an item-based strategy when there are differences in item-strength, as in the Switched Lures condition. I expect this to result in a DF effect in Switched Lures condition, due to R-targets and R-lures having greater item familiarity. Thus, F-targets in the Switched Lures condition
will be selected *less* often compared to F-targets in the Same Lures condition, whereas R-targets in the Switched Lures condition will be selected *more* often compared to R-targets in the Same Lures condition. The net result is that the magnitude of the DF effect in the Switched Lures condition will be *greater* than in the Same Lures condition because recognition of the F-targets will decrease, and recognition of the R-targets may increase.

Overall, the critical manipulation distinguishing Experiment 1 from Experiment 2 is the encoding instruction and lack of familiarization with the testing procedure, such that in Experiment 2, the use of associative information should be minimal, biasing participants to make their responses based on item-strength differences where such differences exist. Critically, the set of predictions laid out for Experiment 2 are the *opposite* set of predictions laid out for Experiment 1, where the largest DF effect is expected in the Switched Lures, compared to the Same Lures, condition. Note that this opposite set of predictions for Experiment 2 is based on the impairment of primarily item information, whereas the strength of associative information should be comparable between F- and R-objects.

3.2 Methods

3.2.1 Participants & Design

Participants were 108 undergraduate students from the University of Illinois who received course credit for participation. They were tested in small groups of no more than four people at a time. Participants were assigned equally to one of two between-subjects conditions that resulted from crossing the Lure condition (Same Lures vs. Switched Lures). Memory cue (F vs. R) was manipulated within-subjects.

3.2.2 Stimuli

The stimuli were identical to that used in Experiment 1.

3.2.3 Procedure

The procedure for Experiment 2 is identical to that Experiment 1, with the exception of the encoding instructions. Instead of an Associative encoding instruction, participants were given an Item-emphasis instruction ("think about whether the object can fit inside a shoebox"). Participants were also not provided with any practice study and test trials, to prevent adoption of an associative encoding strategy.
3.3 Results

3.3.1 Data Analysis

Associative recognition accuracy (averaged across both trials and participants) by cue and lure condition is summarized in Figure 3. I assessed the relationship between cue, lure condition, and behavioral accuracy on a trial-by-trial basis using multilevel modeling analyses. Specifically, a mixed level logit-regression was conducted on behavioral accuracy of individual trials, using memory cue and lure condition as fixed effects, and treating participants as random effects. Note that, despite the Item-emphasis instruction minimizing the encoding of associative information, associative recognition performance was above chance, implicating incidental encoding of associative information (Hockley & Cristi, 1996; Jou, 2010). Bayes factors were calculated after aggregating across trials and across participants.

3.3.2 Associative Recognition Accuracy

Associative recognition accuracy was fit using a Mixed Logit Regression Model using Cue (R vs. F) and Lures (Same vs. Switched) as fixed effects and Participants as a random intercept. There was a main effect of Cue, $\beta_{\text{Cue}} = 0.24$, $SE = 0.07$, $Wald Z = 3.58$, $p < .001$, indicating that DF instructions impaired associative recognition. The main effect of Lures was not significant, $\beta_{\text{Lures}} = -0.06$, $SE = 0.12$ $Wald Z = 0.53$, $p = .596$. The main effect of Cue was qualified by a significant Cue x Lures interaction, $\beta = 0.28$, $SE = 0.13$, $Wald Z = 2.12$, $p = .034$ (the variance associated with random effect of participants was $\sigma^2 = .28$, $SD = .53$).

To follow-up the interaction, I assessed the effect of Cue in Lure conditions separately. In the Same Lures condition, participants were no more likely to endorse a Forget compared to a Remember target, $\beta_{\text{Cue}} = 0.12$, $SE = 0.09$, $Wald Z = 1.24$, $p = .604$, demonstrating a null DF effect of associative memory. In contrast, in the Switched Lures condition, participants were more likely to endorse a Forget compared to Remember target, $\beta_{\text{Cue}} = 0.41$, $SE = 0.10$, $Wald Z = 4.27$, $p < .001$, demonstrating a DF effect of associative memory.

3.4 Discussion

Overall recognition performance was lower in Experiment 2 compared to Experiment 1, indicating that the Item-emphasis instruction was successful at minimizing
the encoding of associative information. Nevertheless, the performance was still above chance (33%), indicating that some degree of associative information was encoded spontaneously. F-targets were selected less often in the Switched than the Same Lures condition. This was due both to increased item-familiarity of R- compared to F-objects, as well as difficulty rejecting the strong lures, leading participants to false-alarm more on strong compared to weak lures, resulting in a DF effect in the Switched Lures condition. A Bayesian t-test in the Switched Lures condition revealed that the DF effect is 83.51 times more likely to be observed under a model that assumes there are significant differences between the Forget and Remember conditions, $BF_{01} = 0.01$. Importantly, this pattern is expected if participants rely mostly on item-strength differences between targets and lures, even for associative recognition judgments. In contrast, the DF effect was absent in the Same Lures condition, where objects of equal item strength are paired with each other. A Bayesian t-test in the Same Lures condition revealed that the null DF effect is 3.33 times more likely to be observed under a model that assumes there are no differences between the Forget and Remember conditions, $BF_{01} = 3.33$. Minimizing the extent to which associative information was encoded resulted in equal rates of retrieving the scene information of both F- and R-objects, and thus equal rates of associative recognition accuracy.

Implementing the Switched Lures condition was critical in establishing that only item information was impaired by DF instructions. When associative information is minimally encoded, DF instructions impair primarily item information, producing a significant DF effect when objects of varying item strength are paired with each other. Impaired item information of F-cued targets meant they were selected less often when they were paired with R-lures, resulting in a DF effect. Note that this DF effect is a result of impaired item information, and an opposite set of results would have been predicted had associative information been impaired due to DF instructions.
Figure 3. Recognition accuracy in Experiment 2 as a function of DF Instruction and Lures conditions. Performance is in terms of proportion of correct responses. The error bars reflect SE of the mean.
4.1 INTRODUCTION

Experiments 1 and 2 established DF impairment of associative information. Experiment 3 employed eye-tracking methodology using the same paradigm as the previous two experiments in order to assess how impaired associative information is reflected in eye movement behavior. In addition, the purpose of Experiment 3 was to address competing theoretical accounts of item-method DF (expanded on below).

Established research indicates that eye movements are an extremely sensitive marker of memory (e.g., Hannula et al., 2007; Ryan et al., 2000; Ryan & Cohen, 2004; Ryan & Villate, 2009). Furthermore, the influence of retained memory on viewing patterns was observed even when behavioral selection suggested memory retrieval failure (Ryan et al., 2000; Ryan & Cohen, 2004; Hannula & Ranganath, 2009; Hannula et al., 2012; Nickel, Henke, & Hannula, 2015). In addition to replicating DF impairment of associative information, use of eye-tracking within this paradigm could provide insight into forgetting processes by revealing potential differences between incidental forgetting (R items that are subsequently forgotten) and successful intentional forgetting (F items that are subsequently forgotten).

Typical DF studies have relied on observable behavioral measures such as percent correct or accuracy to assess impairment of F-cued items. However, this measure limits investigation to items that were retained in memory despite the instruction to forget (i.e., a failure of DF). In other words, much research has examined “anti-forgetting” rather than successful DF. The critical question is what happens to F-items when DF is successful. Addressing this question is challenging and requires employing a concurrent measure that accompanies behavior. This has traditionally been in the purview of neuroscience studies, which include electrophysiological or imaging measures. Experiment 3 is completely novel in the use of eye-tracking to investigate DF.

4.1.1 EYE-MOVEMENT FINDINGS IN THE CURRENT PARADIGM

The paradigm used in Experiments 1 and 2 was borrowed from the neurocognitive literature that assesses memory for associations between items and their originally studied context, also known as associative, or relational, memory. Importantly, there was no DF
manipulation in these original experiments. In a series of experiments, Hannula et al. (2007) examined eye movements during the test phase, linking behavioral outcomes to eye-movement behavior indicative of retained associative memory. Specifically, the viewing patterns demonstrated disproportionately greater viewing towards the target that was previously studied with the test scene relative to a selected lure, a phenomenon known as *preferential viewing* (Hannula et al., 2007; 2009; 2012; Ryan 2007; Baym et al., 2014). Critically, the difference in viewing behavior is between the two items which were selected behaviorally (i.e., selecting a Target represents a correct trial, and selecting a Lure represents an incorrect trial). Therefore, differences in viewing observed at the time of test between the two types of selected objects are not driven by object selection alone, but rather reflect the influence of memory of the target having been studied with that particular background scene. Previous research demonstrates that preferential viewing emerges extremely rapidly, rising and peaking within approximately 500-750 ms after the onset of the 3-item test display. This time course is similar to ERP recordings showing brain activity that discriminated studied pairs from repaired items beginning approximately 600 ms following stimulus onset (Donaldson & Rugg, 1998; 1999). Also similar to ERP studies, viewing behavior can be shifted to align with the overt behavioral response (i.e., response-locked analysis), where preferential viewing was shown to peak approximately 1000-500 ms prior to item selection. The time course of eye-movement behavior is quite robust across many studies. It is uninfluenced by task demands and emerges even when viewing the target was counterproductive to the task (Ryan et al., 2007).

This paradigm has been used extensively to assess associative retrieval processes, including memory impairment in amnesia (Hannula et al., 2006; 2007; 2015; Ryan et al., 2000; Ryan & Cohen, 2003), aging (Ryan et al., 2007), and schizophrenia (Williams et al., 2010; Hannula et al., 2010). Critically, associative memory impairments observed in different populations were reflected in either diminished or lack of preferential viewing, demonstrating that eye movements can reveal impairment of associative memory. Therefore, use of eye monitoring could reveal insights into forgetting processes that are not observable using accuracy alone, and therefore served as the motivation for the current experiment.
4.1.2 CURRENT STUDY AND PREDICTONS

Note that most of the procedures were identical to those of Experiment 1, with the exception of (a) employing eye-tracking during testing, and (b) all items in the test display were from the Same Lures condition, whereas the Switched Lures condition was not included in this study.

The purpose of this investigation was to assess how impaired memory for associative information is expressed in eye movements. More specifically, the first goal was to assess how item-method DF affects the magnitude of preferential viewing. As discussed above, preferential viewing is defined as disproportionate amount of viewing directed towards the Selected Target than towards the Selected Lure, reflecting the expression of memory in eye movement behavior. I had reasons to suspect that preferential viewing would be reduced in item-method DF in part because various populations with impaired relational memory were examined in this paradigm, and showed such pattern. Thus, I suspected that viewing to the Selected Target may be reduced in the F-condition.

My second goal was to assess viewing patterns on incorrect trials, when participants select the Lure. The critical question is what happens to viewing to the Unselected Target on those trials, and whether it differs between the cue conditions. Evidence of retained memory traces for target items (despite selecting the lure) would be reflected in greater viewing directed towards the Unselected Target compared to the Unselected Lure. Given that on incorrect trials participants select a lure, there is no reason to expect viewing differences between the remaining two unselected objects (i.e., target and the second lure), unless there was lingering memory for the target item, leading to greater viewing of that Unselected Target compared to Unselected Lure. I aimed to examine whether viewing patterns to the Unselected Target distinguish intentional forgetting from incidental forgetting.

The theoretical debate in item-method DF literature centers around whether impaired memory is driven by passive withdrawal of rehearsal in response to forget cues (Bjork, 1970; Basden, Basden, & Gargano, 1993; MacLeod, 1999), or due to active inhibitory processes that downregulate memory for F-items (Fawcett & Taylor, 2008; 2010; Hourihan & Taylor, 2006; Lin, Kuo, Liu, Han, & Cheng, 2013; Wylie, Foxe, & Taylor, 2008). By examining viewing patterns on incorrect trials, I tested two different predictions.
of these accounts. The inhibitory account predicts diminished viewing to the Unselected Target in the Forget condition compared to the Remember condition because according to this account active inhibitory processes are engaged to downregulate the processing of F-items. Therefore, successfully forgotten F-items result from the consequences of active inhibitory processes impairing memory, as opposed to forgotten R-items, which arise from selective encoding differences. In contrast, the selective rehearsal account attributes DF to selective encoding, such that withdrawing rehearsal from R-items turns them functionally into F-items, and therefore forgotten R-items should be similar to F-items in viewing patterns on incorrect trials.

4.2 Methods
4.2.1 Participants

Participants were 31 undergraduates from the University of Illinois who were compensated with course credit. Eye-movement recordings were not recorded for one participant due to equipment failure, and eye-movement analyses were conducted on 30 participants, whereas recognition accuracy was based on 31 participants. The study was approved by the Institutional Review Board of University of Illinois at Urbana-Champaign and complied with APA ethical standards in the treatment of participants. All participants gave informed consent prior to inclusion in the study.

4.2.2 Apparatus

Eye position was recorded at a rate of 1000 Hz using an Eyelink 1000 eye-tracking system (SR Research). After the study block and prior to the test block, eye position was calibrated using a 3 x 3 spatial array. Calibration ended with participants fixating on a centrally located cross-hair, which began the test block. The computer screen resolution was set to 1280 x 1024.

4.2.3 Stimuli

The stimuli were identical to Experiment 1.

4.2.4 Procedure

The procedure was identical to Experiment 1, using only the Same Lures condition (targets and lures were given the same memory instruction), with the exception that eye-movements were monitored during the time of test.
4.3 Results
4.3.1 Data Analysis

The study procedure and data collection were conducted using E-Prime 2.0 (Psychology Software Tools, 2015). Eye tracking data was extracted for analysis using MATLAB software (The MathWorks, Inc, 2017). All statistical analyses were done using R software (R Development Core Team, 2008). The eye movement analyses (i.e., proportion of viewing time on individual trials) were performed using Mixed Effects Models, fitted with the lmer function in the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) as well as the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). In evaluating proportion of viewing, Cue (F vs. R), Selected Object (Target vs. Lure) and Bins (four 500 ms time bins amounting to 2 s prior to response selection) were used as the fixed effects, and Participants as random effects. The Cue, Selected Object, and Unselected Object variables were centered and dummy coded, and Bins variable was coded with orthogonal polynomial coding. Further details about analyses are explained below.

My analyses centered around two broad goals of this investigation. The first goal was to assess how DF instructions affect the magnitude of preferential viewing. Prior research indicates that preferential viewing unfolds over time, rising and peaking prior to the overt behavioral response, after which it diminishes and levels off. Therefore, first I identified the time point at which preferential viewing is fully established (i.e., when viewing peaks and is at its maximum), using response-locked analyses. Afterwards, I performed targeted hypothesis testing examining the effect of Cue on preferential viewing in that critical time bin. The second goal of this investigation was to assess viewing patterns on incorrect trials, when participants select the lure. The critical question is what happens to viewing to the Unselected Target on those trials, and whether it differs between the cue conditions.

4.3.2 Associative Recognition Accuracy

Recognition accuracy was fit using a Mixed Logit Regression Model using Cue (R vs. F) as a fixed effect and Participants as a random intercept. Recognition accuracy replicated the DF effect – participants were more likely to select the target in the Remember condition ($M=.81, SD=.39$) than the Forget condition ($M=.73, SD=.44$), $\beta_{\text{cue}} =$
0.48, $SE = 0.15$, $Wald Z = 3.17, p = .002$ [the effect size for the DF impairment assessed across participants is $d_z = 0.50$]. This finding confirms the impairment of relational memory as a result of the DF manipulation (the variance associated with random effect of participants was $\sigma^2 = .76, SD = .87$).

### 4.3.3 Eye Movement Analyses

**Preferential Viewing Analyses.** For eye movement analyses, I followed the established practices in the literature and calculated a measure of viewing time to an element of a test display as a proportion of total time viewing all three elements (“proportion of viewing time”). In order to measure proportion of viewing time, three distinct regions of interest (ROI) were defined, where each ROI indicated the area on the screen where one of the objects was presented during the test.

**Figure 4a** summarizes mean proportion of viewing (averaged across participants and across trials) to a Selected Object (Target vs. Lure), by Cue (F vs. R), and Time Bins (in increments of 500 ms), shifted to align with respect to behavioral response on each trial (i.e., response-locked figure). To assess preferential viewing, a Mixed Effects Model was fit to the proportion of viewing on each trial, using Cue (F vs. R), Selected Object (Target vs. Lure), and Bin (four 500 ms time bins, equating to 2 s prior to response) as fixed effects, and Participants as a random effect. There was a significant effect of Selected Object, $\beta_{\text{object}} = 0.13, SE = 0.02, t = 8.09, p < .001$, indicating disproportionately more viewing to the Selected Target than to the Selected Lure, confirming preferential viewing. There was also an effect of Bins, $\beta_{\text{bin}} = 0.17, SE = 0.02, t = 11.49, p < .001$, confirming that overall viewing increased over time. Critically, these effects were qualified by a significant Selected Object $\times$ Bin interaction, $\beta = 0.22, SE = 0.03, t = 7.02, p < .001$, indicating that the magnitude of preferential viewing varied across the time bins (the variance associated with random effect of participants was $\sigma^2 = .006, SD = .08$). Preferential viewing peaked in the 500 ms bin, with approximately 75% of the total viewing time being devoted to the Selected Target over the Selected Lure, $\beta_{\text{object}} = 0.25, SE = 0.03, t = 8.36, p < .001$.

These analyses confirmed the established effects in the literature that preferential viewing peaks prior to the behavioral selection, establishing itself by 500 ms prior to response. In order to assess how DF affected preferential viewing, I examined the effect of
Cue on Selected Objects in the 500 ms time bin prior to response with Mixed Effects Models. In addition to the significant effect of Selected Object, $\beta_{\text{object}} = 0.25$, $SE = 0.03$, $t = 8.59$, $p < .001$, there was a significant Selected Object × Cue interaction, $\beta = 0.12$, $SE = 0.03$, $t = 2.10$, $p = .036$. Namely, there was reduced preferential viewing for the F-items, $\beta_{\text{object}} = 0.20$, $SE = .04$, $t = 5.19$, $p < .001$, compared to the R-items, $\beta_{\text{object}} = 0.32$, $SE = .04$, $t = 7.23$, $p < .001$. Reduced viewing in the Forget condition did not arise from the differences in viewing to the Selected Target ($\beta_{\text{target}} = 0.01$, $SE = 0.04$, $t = 0.44$, $p = .662$), but rather from enhanced viewing towards the Selected Lure in the Forget condition ($\beta_{\text{lure}} = -0.13$, $SE = 0.06$, $t = 2.70$, $p = .007$). Taken together, the viewing pattern in the Remember condition replicated the established findings in the literature. The novel findings in the Forget condition indicated that preferential viewing was reduced by the DF manipulation, and that it was driven by enhanced viewing on incorrect trials, rather than reduced viewing on correct trials.

4.3.4 Analyses of Retained Traces. Previous literature has identified eye movement behavior as a marker of retained memory traces in the absence of conscious recollection. Even when behavioral accuracy failed, eye movements were shown to indicate the influence of memory on viewing patterns, suggesting that they are a more sensitive (albeit indirect) marker of memory compared to explicit accuracy. My interest was whether viewing towards the Unselected Target would distinguish between incidental forgetting and intentional forgetting, which would indicate differential retention of memory traces for Targets across Forget and Remember conditions.

Figure 4b summarizes average proportion of viewing on incorrect trials (averaged across participants) to Unselected Objects (Target vs. Lure), by Cue (F vs. R), and Time Bins (in increments of 500 ms), shifted to align with respect to behavioral response (i.e., response-locked figure). Although Bin was not a variable of interest in this analyses, I presented the results across the time bins for completeness. A mixed effects model was fit to proportion of viewing time on incorrect trials (collapsed across bins) using Cue and Unselected Object as fixed effects, and Participants as a random effect. There was an effect of Unselected Object, $\beta_{\text{object}} = 0.10$, $SE = .02$, $t = 4.74$, $p = .002$, indicating greater viewing
to the Unselected Target than the Unselected Lure (the variance associated with random effect of participants was $\sigma^2 < .001$, $SD < .001$). Although the Cue × Unselected Object interaction did not reach statistical significance ($\beta = 0.07$, $SE = .04$, $t = 1.71$, $p = .08$), there was a significant effect of Cue in viewing to the Unselected Targets, $\beta_{\text{cue}} = 0.07$, $SE = .03$, $t = 2.43$, $p = .02$, but no effect of Cue in viewing to the Unselected Lures, $\beta_{\text{cue}} = 0.001$, $SE = .002$, $t = 0.17$, $p = .87$. These findings indicate that on incorrect trials, participants tend to view the Unselected Target substantially less in the Forget condition than in the Remember condition, indicating reduced retention of memory traces of target objects as a result of successful DF.

### 4.4 Discussion

In this experiment, I obtained a DF effect in recognition accuracy, indicating impaired associative information as a result of the Forget cue, replicating the results from Experiment 1. A Bayesian $t$-test was performed aggregating across both trials and subjects, revealing the DF effect is 4.27 times more likely to be observed under a model that assumes there are significant differences between the Forget and Remember conditions, $BF_{01} = 0.23$. Eye movements revealed reduced preferential viewing in the Forget compared to the Remember condition. This was driven by enhanced viewing towards the Selected Lure in the Forget compared to the Remember condition, whereas viewing to the Selected Target remained invariant across the cue conditions. This pattern indicates that when participants failed to forget the target (despite being told to forget), their eye movements were indistinguishable from the Remember condition. On the other hand, when participants forgot the target (consistent with the instruction to forget), they viewed those missed targets substantially less in the Forget condition compared to the missed targets in the Remember condition. Therefore, the assessment of viewing on incorrect trials indicated that there was reduced evidence of retained memory traces for the Unselected Targets in the Forget condition compared to the Remember condition. Thus, eye-movements provided a new marker of intentional forgetting, distinguishing intentional from incidental forgetting.
Figure 4a. Mean proportion of viewing to the Selected Target and Selected Lure across Cue and Time Bins (grouped by 500 ms time.) in Experiment 1. Error bars represent SE of the mean.

Figure 4b. Mean proportion of viewing time on incorrect trials directed towards the Unselected Target and Unselected Lure as a function of Cue and Time Bins in Experiment 1. Error bars represent SE of the mean.
CHAPTER 5: GENERAL DISCUSSION

The aim of these three experiments was to test for whether DF impairs associative information beyond impairing only item information, as well as investigating how this potential impairment would be reflected in eye-movements. While impairment of item information by DF instructions is firmly established in the literature (Bjork, 1970; 1989), its impact on associative information is relatively less well understood (Hockley, et al., 2016; Bancroft, et al., 2013; Wang et al., 2016). Importantly, this study employed a novel paradigm to dissociate the impairment of associative information from impairment of item information arising from DF, as well as relating impairment of associative information to eye-movement patterns that reflect the influence of associative information. By presenting the intact and rearranged pairs simultaneously within the same test trials, I was able to vary the associative strength between targets and lures in experiment 1, and the item strength between targets and lures in experiment 2. Doing so allowed performance in the F-trials to improve or to suffer due to the availability of the associative information.

Previous research using this paradigm was conducted solely in the context of a “remember-all” procedure, and manipulated only associative strength while equating for item strength within each test trial. That is, all presented objects were approximately equally familiar because they had been studied during encoding (roughly equating item strength), but only one of the objects had associative information linking it to the scene (Hannula et al., 2007). In contrast, in Experiments 1 and 2, I purposefully manipulated not only the associative strength but also the item strength by introducing a DF manipulation during encoding, and testing participants using a test display containing either targets and lures from the same memory instruction or from the opposite memory instruction (i.e., Same vs. Switched Lures). The purpose of the Switched Lures conditions was to present items that differed simultaneously on item and associative strength. This manipulation produced different magnitudes of the DF effect in Same and Switched Lures conditions depending on whether associative information encoding was emphasized or minimized during encoding. Importantly, the manner in which the magnitude of the DF effect varied implicated contrasting memory processes driving associative recognition among the different conditions.
To ensure that associative information was explicitly encoded and could therefore be potentially impaired by DF, participants in Experiment 1 were encouraged to associate the objects with the presented scenes. Doing so produced overall better recognition accuracy than when associative encoding was minimized in Experiment 2, demonstrating greater encoding of associative information in Experiment 1 (Dulas & Duarte, 2013; Henson, Rugg, Shallice & Dolan, 2000; Hockley & Cristi, 1996). Importantly, I observed a significant DF effect in the Same Lures condition when associative encoding was encouraged, whereas there was no significant DF effect in the Same Lures condition when associative encoding was discouraged. This pattern suggests that when associative information is explicitly encoded (i.e., under the Associative instruction in Experiment 1), DF impairs associative information, producing a significant DF effect. In contrast, minimizing encoding of associative information (i.e., under the Item-emphasis in Experiment 2) eliminated the DF effect, further implicating the importance of associative information in this paradigm, as well as the importance of encoding associative information if it is to be subsequently impaired due to DF.

Implementing the Switched Lures conditions was also critical in establishing that associative information was impaired due to DF. When associative information is strongly encoded, it is much easier to recall which scene the test objects were studied with, resulting in greater rejection rates of strong compared to weak lures, resulting in a null DF effect in the Switched Lures condition in Experiment 1. Ironically, impaired associative information of F-cued objects resulted in selecting F-targets more often when they were paired with R-lures in Experiment 1 because participants could use the associative information of the R-lures to reject them more successfully than F-lures. Note, that this elimination of the DF effect arises from a difference in associative strength between the F- and R-objects, providing additional support that DF impaired associative information during encoding. Minimizing encoding of associative information led to the opposite pattern of results, such that F-targets were selected less often when they were paired with R-lures in Experiment 2, producing the largest DF effect in the Switched Lures condition.

The paradigm used in the current set of experiments was adapted from one used in the neurocognitive literature that has been extensively examined using eye movements, revealing eye-movements to be a sensitive marker of associative memory (Hannula et al.,
2007; 2009). In the literature using this paradigm to assess associative processes, eye-movement behavior indicating retained associative memory was evident even in cases where behavioral accuracy indicated a failure to retrieve those memories. From the point of behavioral accuracy in item-method DF, correct selection of the F-Target on a given test trial represents a failure of intentional forgetting because memory for the Target “survived” despite the previous instruction to forget it. In contrast, selection of the F-Lure represents successful intentional forgetting, because participants did not select the Target (presumably because it was successfully forgotten). Finally, selection of the R-Lure represents incidental forgetting because the target was missed despite the intention to remember. The purpose of Experiment 3 was to assess eye movements associated with these behavioral outcomes.

By using a concurrent measure such as eye-tracking alongside behavioral accuracy in Experiment 3, I was able to differentiate between incidental and successful intentional forgetting. Typical measures such as accuracy fail to distinguish between incidental and intentional forgetting. Therefore, the use of eye-tracking as a concurrent measure was critical in testing predictions made by the two competing theoretical accounts of item-method DF. The selective rehearsal account of item-method DF suggests that forgotten F-items are similar to forgotten R-items simply because of passive decay due to insufficient rehearsal (Bjork, 1970; Basden, Basden, & Gargano, 1993; MacLeod, 1999). In contrast, active accounts of item-method DF suggest additional mechanisms, potentially inhibitory in nature, further degrade forgotten F-items, and therefore suggest that forgotten R-items differ from forgotten F-items (Fawcett & Taylor, 2008; 2010; Hourihan & Taylor, 2006; Lin, Kuo, Liu, Han, & Cheng, 2013; Wylie, Foxe, & Taylor, 2008). Some evidence for the active inhibitory account comes from studies using concurrent imaging measures such as fMRI and EEG that show differences in brain activity between incidentally and intentionally forgotten items (for a review, Anderson & Hanslmayr, 2014). The novel approach of Experiment 3 was the use of eye-tracking as another concurrent measure to add to the growing body of literature investigating the mechanism producing successful DF.

In Experiment 3, there was impaired recognition accuracy for F-items, replicating findings from Experiment 1 indicating that item-method DF impaired associative information. The eye movements in the Remember condition replicated the established
findings of preferential viewing, indicating that participants devoted a disproportionate amount of time viewing the Selected Target compared to the Selected Lure. Greater viewing towards the Target indicates the influence of memory (as opposed to the influence of selection) on eye movement behavior.

The viewing behavior in the Forget condition revealed several novel findings. Namely, failure of intentional forgetting was virtually identical to the Remember condition. That is, on the trials when participants failed to forget the Target and correctly selected it on the recognition test, they viewed that Target as much as in the Remember condition. In contrast, on the trials when they selected the Lure (presumably because they successfully forgot the Target), participants viewed the Selected Lure more in the Forget condition than in the Remember condition. Overall, there was a reduction in preferential viewing in the Forget condition that was driven by enhanced viewing towards the Selected Lure. Note that this viewing pattern is the opposite of my prediction, where I thought that DF may reduce preferential viewing because participants may view the selected Target less in the Forget condition. In contrast, the results showed that preferential viewing was reduced because of the enhanced viewing towards the Selected Lure in the Forget condition.

Importantly, eye movements distinguished successful intentional forgetting from incidental forgetting as evident in differential retention of memory traces between the Forget and Remember conditions. The critical question was what happened to viewing the two remaining objects whenever participants selected the lure (i.e., Unselected Target and Unselected Lure), and whether there were differences between the Forget and Remember conditions. Whenever participants select a lure, there is no reason to expect differences in viewing the two unselected objects, unless a lingering memory for the Unselected Target influenced the viewing behavior, producing greater viewing towards that Unselected Target than the Unselected Lure (i.e., Nickel, et al., 2015). The results showed that whenever participants selected a lure, they tended to view that Unselected Target more than the Unselected Lure, confirming the influence of retained memory traces of Unselected Targets on the viewing behavior. Importantly, however, they viewed the Unselected Target substantially less in the Forget condition than in the Remember condition, indicating that successful intentional forgetting impaired memory beyond what was observed in instances of incidental forgetting, producing differences in the viewing
behavior between the two instruction conditions. To the best of my knowledge, Experiment 3 was the first study to establish eye movements as a marker distinguishing successful intentional forgetting from incidental forgetting.

From a theoretical viewpoint, the eye movement findings provide support for the inhibitory account of item-method DF, and are inconsistent with the selective rehearsal view. The inhibitory account of item-method DF makes a prediction that successful DF should be distinguished from incidental forgetting – in this case, it predicts that successful intentional forgetting should show suppressed viewing to the Unselected Target in comparison with incidental forgetting. In contrast, the selective rehearsal account does not make this prediction because it suggests that impaired memory for F-items arises from terminating rehearsal of those items. Thus, passively forgotten R-items and successfully forgotten F-items should produce similar signatures in eye movements. My findings were inconsistent with the rehearsal view, and supported the inhibitory view.

Collectively, the findings of the current set of experiments support previous findings in the literature documenting impaired associative recognition in item-method DF (Hockley, et al., 2016; Bancroft, et al., 2013; Wang et al., 2016). The strength of the current paradigm is its ability to dissociate DF impairment of item information from the DF impairment of associative information, and to demonstrate both findings within a single paradigm. The finding that associative information is impaired due to DF instructions is novel in that the field has mainly focused on the impairment of item information. In addition, previous research reporting DF impairment in associative recognition could not rule out the impairment of item information being the cause of impaired recognition (Bancroft, et al., 2013; Wang et al., 2016; Hockley et al., 2016). The unique contribution of the current paradigm to this body of literature is that both intact and rearranged pairs were used in every trial. Due to the simultaneous use of both intact and rearranged pairs in every trial and the various instructional manipulations, I was able to dissociate the contributions of item and associative information on associative recognition performance, and to isolate and identify the impairing effect of DF on associative information.

In conclusion, the current results provide strong support that DF impaired associative information in the item-method DF paradigm. This was evidenced by the DF effect in multiple conditions, and, critically, by the opposite effects of DF under the
Switched Lures conditions in Experiments 1 and 2. Additionally, Experiment 3 demonstrated the effect of successful intentional forgetting on eye-movements that contrasted with incidental forgetting, lending support for the active inhibitory view of item-method DF, which contrasted with the predictions made by the selective rehearsal view. Typical DF studies investigate successful intentional forgetting through items that participants failed to forget, which amounts to studying anti-forgetting despite an intention to do so. More recent investigations using concurrent measures such as EEG and fMRI have begun to dissociate incidental from successful intentional forgetting by identifying differential brain activity between the two types of forgetting (for a review, see Anderson & Hanslmayr, 2014). By doing so, these studies have argued for inhibitory mechanisms associated with successful intentional forgetting, contrasting with the traditional view of successful DF resulting from terminating rehearsal of F-items during encoding. Using a concurrent measure such as eye-tracking shed further light on this theoretical debate by establishing markers of inhibition in eye movements.
References


