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Running head: F>R IOR – MOTORIC OR VISUAL?

Memory instruction interacts with both visual and motoric inhibition of return

Kate M. Thompson and Tracy L. Taylor

Correspondence should be sent to:

Kate Thompson

Dalhousie University

Phone: 902-494-3001

Fax: 902-494-6585

Email: [thompskm@dal.ca](mailto:thompskm@dal.ca)

## Abstract

In the item-method directed forgetting paradigm, the magnitude of inhibition of return (IOR) is larger after an instruction to Forget (F) than after an instruction to Remember (R). The present experiments further investigated this increased magnitude of IOR after F compared to R memory instructions to determine whether this F>R IOR pattern occurs only for the motoric form of IOR, as predicted, or also for the visual form. In three experiments, words were presented in one of two peripheral locations followed by either an F or R memory instruction. Then, a target appeared in either the same location as the previous word, or the other location. In Experiment 1, participants maintained fixation throughout the trial until the target appeared, at which point they made a saccade to the target. In Experiment 2, participants maintained fixation throughout the entire trial and made a manual localization response to the target. The F>R IOR difference in reaction times occurred for both the saccadic and manual responses, suggesting that memory instructions modify both motoric and visual forms of IOR. In Experiment 3, participants made a perceptual discrimination response to report the identity of a target while the eyes remained fixed. The F>R IOR difference also occurred for these manual discrimination responses, increasing our confidence that memory instruction modifies the visual form of IOR. We relate our findings to postulated differences in attentional withdrawal following F and R instructions and consider the implications of our findings for successful forgetting.

Is F>R IOR in item method directed forgetting a selective modulation of the motoric form of IOR?

Our ability to learn from and remember characteristics of our environment is, arguably, one of the key factors underlying the sophistication of human functioning. Not only does memory provide us with a sense of self and continuity through time (Gallagher, 2000), but information from long-term memory influences even the most basic cognitive functions, such as perception and attention – this is at the heart of well known interactions between top-down and bottom-up processing (e.g., Duncan & Humphreys, 1989; Posner & Petersen, 1990; Ciaramelli, Grady, & Moscovitch, 2008).

In the study of memory, it is clear that forgetting irrelevant information that might otherwise interfere with successful encoding or retrieval can be just as important for creating an accurate representation of the world as remembering relevant information (MacLeod, 1998). For example, it serves us well to forget an instructional error made by a professor. If we were unable to forget such irrelevant information, it might interfere with our memory for the accurate information (Postman & Underwood, 1973; Anderson, Bjork, & Bjork, 1994; Anderson & Neely, 1996). The intentional forgetting of irrelevant or misleading information is studied in the laboratory using the directed forgetting paradigm.

In a directed forgetting paradigm, participants are presented with information (typically words, but a wide variety of stimuli have been used e.g., Quinlan, Taylor, & Fawcett, 2010; Hourihan, Ozubko, & MacLeod, 2009), and are

asked to remember some things and to forget others. There are two main procedures that can be used: the list method and the item method. The present investigation concerns the item method (for a review of both methods see MacLeod, 1998 or Basden & Basden, 1998). Participants in an item-method directed forgetting paradigm are presented with items one at a time, and each is followed by an instruction to Remember (R) or Forget (F). After all items have been presented, participants' memory of *both* R and F items is tested with some kind of explicit test of memory (often yes/no recognition; although see Thompson, Fawcett, & Taylor, 2011). Typical results show greater memory performance for R items compared to F items – the directed forgetting effect (DF effect). Researchers are confident that this effect is not simply the result of demand characteristics on the part of participants (MacLeod, 1999).

The main explanation of the DF effect, the selective rehearsal hypothesis, posits that better memory for R than F items is achieved primarily by selective elaborative rehearsal of R items over F items (e.g., Bjork & Woodward, 1973; Woodward, Bjork, & Jongeward, 1973; MacLeod, 1975). While R items are afforded as much distinctive processing as possible to ensure they are encoded, processing of F items stops when the F instruction is received to limit the transfer of this information to memory.

Interestingly, there exists much evidence to suggest that, rather than passively dropping F items from working memory, instantiation of an instruction to forget is achieved by an active, cognitively effortful process (Fawcett & Taylor, 2008;

Wylie, Foxe, & Taylor, 2008; Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Saletin, Goldstein, & Walker, 2011; Bastin, Feyers, Majerus, et al. 2012). Relevant to the present experiment, there has been a substantial amount of research on inhibition of return (IOR) in item-method DF tasks, which has informed our understanding of the cognitive consequences of instantiating an instruction to forget (Taylor, 2005; Fawcett & Taylor, 2010; Taylor & Fawcett, 2011; Thompson, Hamm, & Taylor, 2014). As will be described below, instantiating memory instructions at encoding produces interactions with IOR that implicate a differential withdrawal of attentional resources from Forget versus Remember items (see Taylor, 2005; Taylor & Fawcett, 2011). The fact that this interaction seems specific to a motor form of IOR further suggests that the allocation of limited-capacity attentional resources during encoding not only determines the contents of memory in the long-term but also influences subsequent information processing in the short-term. In this way, limiting the further encoding of unwanted or irrelevant items in working memory invokes a complex interplay of attentional, memorial, and motor systems.

### **Inhibition of Return**

In an IOR cueing paradigm, participants are presented with an uninformative visual cue to the left or right (e.g., the brightening of an outline box) which participants are instructed to ignore. This cue is followed by a target to the left or right that requires a speeded response. If the stimulus onset asynchrony (SOA) between the cue and the target is relatively short (less than ~300ms), RTs to

respond to the target are faster at the cued location compared to the other, uncued location. This facilitatory effect for target RTs occurs because the cue automatically draws attention to it and attention increases the speed and efficiency of visual processing (Posner, 1980). However, if the target is presented at a longer SOA (more than ~300ms), RT is *slower* at the cued location compared to the uncued location. This latter pattern is known as IOR (Posner & Cohen, 1984). Critically, IOR is observed in RTs only after attention has been withdrawn from the cued location; it is otherwise masked by the opposing facilitatory effects of attentional capture (Danziger & Kingstone, 1999).

IOR can be understood as reflecting a mechanism that promotes efficient search strategies by decreasing the likelihood that a previously inspected location will be reinspected (Klein & MacInnes, 1999; Klein, 2000; MacInnes & Klein, 2003). IOR is initiated by the activation of the oculomotor system by a stimulus (Rafal, Calabresi, Brennan, & Sciolto, 1989; Taylor & Klein, 1998; but see Chica, Klein, Rafal, & Hopfinger, 2010), and/or by modulations of mental spatial saliency maps after attention is withdrawn from a non-informative cue (Henderickx, Maetens, & Soetens, 2012). Critically, though, the subsequent effects on information processing (i.e., the particular kinds of processing that are slowed at the cued relative to the uncued location) vary depending on the state of the oculomotor system. When the oculomotor system is active (i.e., eye movements – or saccades – are allowed/required to the cue and/or target), IOR manifests as a motoric bias against responding towards the cued location. Conversely, when the oculomotor system is suppressed (i.e., saccades are prevented during the task by requiring that



participants maintain fixation in one location), IOR manifests as a perceptual deficit for information presented in the cued location (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica, Taylor, Lupiáñez, & Klein, 2010; Hilchey, Klein, & Ivanoff, 2012). These two forms of IOR are dubbed motoric and visual, respectively (Taylor & Klein 2000). Importantly, these two forms of IOR do not co-occur in behavior (Taylor & Klein, 2000; Chica et al., 2010; Hilchey et al., 2012). For example, Hilchey et al. (2012) found that the magnitude of IOR was the same when participants are required to make saccades regardless of whether the cues and targets were presented centrally or peripherally. If the motoric and visual flavours co-occurred, it would be expected that the magnitude of IOR would be greater when saccades were made to peripheral cues (this type of task involves a motoric component – the saccade – as well as a perceptual component – the stimulation of the target location by a peripheral cue). Similarly, Chica et al. (2010) found that typical visual IOR effects are not observed when participants are required to make saccades to cues or targets. Finally, in investigations of IOR using event-related potential (ERP) technology, reductions in P1 (an early sensory component) occur under conditions that elicit the motoric as well as those that elicit the visual form of IOR. However, these P1 modulations correlate with behavior only when the oculomotor system is suppressed (Satel, Hilchey, Wang, Story, & Klein, 2012). The distinction between these two forms of IOR is also supported by neurophysiological evidence that they are differentially affected by brain damage and rTMS manipulations, where double dissociations have been observed (Bourgeois, Chica, Migliaccio, Thiebault de Schotten, & Bartolomeo, 2012; Bourgeois, Chica, Valero-Cabré, & Bartolomeo, 2013).

## **IOR in Item-Method Directed Forgetting**

Taylor (2005) first investigated IOR in item-method directed forgetting by creating a directed forgetting cueing paradigm (DF cueing paradigm). In this paradigm, participants were presented with a word to the left or right (serving as the 'cue' that initially draws attention) followed by an auditory R or F memory instruction. Then, after a relatively long SOA (1200ms from word onset) a target dot was presented to the left or right, which participants localized using a manual button-press. Taylor found that the magnitude of IOR (RT to 'cued' targets – RT to 'uncued' targets) was greater after an F compared to an R instruction (F>R IOR). Because IOR appears in RTs after attention has been withdrawn from the cued location (Danziger & Kingstone, 1999), the relative magnification of IOR by an F instruction was interpreted as a more ready withdrawal of attention following F instructions than following R instructions. This explanation converges with demonstrations that instantiating a forget instruction is relatively more cognitively demanding than instantiating a remember instruction (Fawcett & Taylor, 2008) and engages frontal mechanisms implicated in executive control over attention (Wylie, Foxe, & Taylor, 2008; Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Saletin, Goldstein, & Walker, 2011; Bastin, Feyers, Majerus, et al. 2012). The differential withdrawal of attention following F and R instructions also accounts for the fact that these instructions impact processing of subsequent task-irrelevant information that appears in close spatial and temporal proximity to the study item (Fawcett & Taylor, 2012). Importantly, when the F instructions occur after the disappearance of the study items, there is no evidence for the reorienting of

processing resources to the opposite location (Taylor & Fawcett, 2012); this establishes that the F>R IOR pattern does, in fact, reflect relative magnification of IOR by an F instruction (i.e., rather than being due to attentional facilitation at the opposite location; see also Thompson et al., 2014). Thus, participants actively withdraw their attention from F items, and this active process may be partially responsible for successful intentional forgetting. However, IOR is a complex phenomenon, and further investigation was necessary to determine specifically what kinds of processing might be shared between intentional forgetting and IOR that would result in their interaction. In particular, investigating whether memory instruction interacts with both the motoric and visual forms of IOR should elucidate which specific mechanisms (motoric or perceptual) are associated with intentional forgetting.

Taylor and Fawcett (2011) replicated Taylor's (2005) methodology, but, in two conditions relevant to the current study, had participants make either a spatially compatible localization response (button-press on the left for a target that appeared on the left, button-press on the right for a target that appeared on the right), or a perceptual discrimination response (one button-press to report the identity of a target as an upright triangle, a different button-press to report the identity as an inverted triangle). The F>R IOR difference emerged only when participants localized the target, not when they reported its identity. The spatial localization response required that a response be made towards the location of a target, whereas the perceptual discrimination response required an analysis of the perceptual quality of the target. As described above, depending on the state of the

oculomotor system, IOR may manifest as either a bias against responding to targets that arise at the cued location (the motoric form of IOR) *or* as impaired/delayed perception of information at the cued location (the visual form). Because the interaction between memory instruction and IOR was observed only with a localization response, Taylor and Fawcett (2011) concluded that the interaction was specific to the motoric form of IOR. They presumed that selective enhancement of the motoric form of IOR by an F instruction could indicate a bias against responding to a source of unreliable information (see Thompson et al., 2014 for additional support for this hypothesis). This reluctance to respond to information arising from the same location as previous mis-information suggests that instructions to forget impact not only the encoding of to-be-forgotten items, but also subsequent information processing. To the extent that episodic memory keeps a record of goal-directed behavior (Conway, 2009), an alteration in behavior due to instantiation of an encoding instruction might provide a means for an encoding instruction to influence memory not only for the instructed item itself, but for the larger episodic event in which the item is embedded. In other words, an instruction to forget might impair episodic memory directly by limiting the encoding of the F item, and indirectly by altering the subsequent goal-directed behaviour that defines the episode for which the trace is established.

### **The Present Experiments**

There has been one potentially critical oversight in the investigation of the F>R IOR difference that warrants some attention. In a typical cueing paradigm

designed to differentiate between the motoric and visual forms of IOR, an important methodological component is the restriction and monitoring of participants' eye movements. Motoric IOR is observed when the oculomotor system is active, and visual IOR is observed when the oculomotor system is suppressed. Critically, Chica et al. (2010) showed that suppression of the oculomotor system is *necessary* to observe the visual form of IOR. In their experiment, they had participants perform a detection task or a colour discrimination task. IOR was observed in both tasks when the oculomotor system was suppressed by preventing eye movements, suggesting an effect on perceptual processing, consistent with visual IOR. However, when the oculomotor system was activated by having participants make eye movements, IOR was only observed in the detection task. This shows that the visual form of IOR (as measured by IOR in the colour discrimination task) is only observed in RTs when the oculomotor system is suppressed, and suppression can only be guaranteed by monitoring participant's eye movements. In addition, Hilchey et al. (2012; see also Taylor & Klein, 2000) found that perceptual and motoric effects on RT are not additive in a motoric IOR task by showing equivalent magnitudes of IOR for both central arrow targets (which could only measure a motoric bias) and peripheral targets (which could measure a motoric bias *and* perceptual degradation).

As described above, Taylor and Fawcett (2011) reported no F>R IOR when participants made a perceptual discrimination response to the target. They interpreted this as evidence that memory instruction does not modulate visual IOR effects, and that the interaction was due to an increased bias (like the one responsible for motoric IOR) against responding towards the source of irrelevant

information. However, it is likely that participants were moving their eyes to fixate the study words on each trial in order to read them in Taylor and Fawcett (2011). According to Rayner (1998), the human perceptual span ranges from 3-4 letters on the left of fixation to 14-15 letters on the right of fixation. At the viewing distance and font size used by Rayner, this corresponds to about 1 degree of visual angle on the left, and 4-5 degrees on the right. In addition, Rayner notes that the identification span (i.e., the distance at which words can be *identified*) is even smaller, at 7-8 letters to the right, or about 2 degrees of visual angle. In previous investigations of IOR in directed forgetting, the minimum distance from fixation to the boundaries of the peripheral locations at which words were presented was 4.5 degrees of visual angle (Taylor, 2005; Fawcett & Taylor, 2010; Taylor & Fawcett, 2011; Thompson et al., 2014). Words are typically centered in either the left or right peripheral location, thus the last (if presented to the left) or first (if presented to the right) letter of each word would be no closer than 4.5 degrees of visual angle from fixation. This, in combination with the fact that participants were never instructed to *refrain* from moving their eyes from fixation, means that participants were almost certainly moving their eyes to read the words, even during the perceptual discrimination task in Taylor and Fawcett (2011). Given that activation of the oculomotor system may mask, override, hide, or cancel any visual IOR effects that would otherwise occur if the oculomotor system were suppressed (Chica et al., 2010), it is unsurprising that the visual IOR effects that Taylor and Fawcett (2011) were testing for might have been masked (the 8 ms overall IOR effect they observed in their discrimination task was only marginally significant and did not interact with

memory instruction). Thus, a more controlled test of the effects of memory instruction on motoric and visual forms of IOR is needed, and our understanding of the nature of this interaction hinges upon such a test.

The present experiments directly assessed whether the F>R IOR difference represents a selective modulation of the motoric form of IOR, as hypothesized by Taylor and Fawcett (2011) and supported by Thompson et al. (2014), or whether the explicit restriction of eye movements will reveal modulation of visual IOR as well. If, under controlled conditions and careful eye movement monitoring, we observe an interaction between memory instruction and visual IOR, it will challenge the previous conclusions about the mechanisms and implications of the F>R IOR difference. Participants completed a DF cueing paradigm similar to that used in previous investigations of IOR in directed forgetting. On each trial, a word was presented to the left or right of a central fixation and was followed by an auditory R or F memory instruction. After a relatively long SOA relative to the word, a target appeared to the left or right. In Experiment 1, participants were required to maintain fixation at centre until making a saccade to the target. In Experiment 2, participants were required to maintain fixation at centre throughout the entire trial, and make a manual spatially compatible localization response to the target. Participants' eye movements were monitored with an eye tracker in both experiments. This ensured that the participants were adhering to the fixation/saccade requirements of their condition. Because the oculomotor system should be engaged in Experiment 1, any IOR observed in that experiment should be motoric in nature. IOR in Experiment 2 should be visual in nature since participants

are required to suppress the oculomotor system in this experiment (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica, et al., 2010; Hilchey, et al., 2012). Thus, if the interaction of memory instructions and IOR is due to selective modulation of the motoric flavor of IOR, the F>R IOR pattern should be observed in Experiment 1 only. If, however, memory instructions also interact with the visual flavor of IOR, the F>R IOR pattern should be observed in Experiment 2 as well.

### Experiment 1

In Experiment 1, participants were presented with study words one at a time to the left or right of central fixation, each followed by an auditory R or F memory instruction, and then by a target in the same or opposite location as the word. Participants maintained fixation until the target appeared, at which point they moved their eyes to the target. Because the oculomotor system was activated by this requirement to fixate the target, IOR in this experiment should be motoric in nature (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica et al., 2010; Hilchey et al., 2012). To reiterate our predictions: If memory instruction interacts with motoric IOR as it has in previous DF cueing experiments, the F>R IOR pattern should occur in this experiment.

### Method

#### *Participants*

Twenty-nine participants were recruited from the undergraduate subject pool at Dalhousie University, and received one credit point for participating. All



participants reported normal or corrected-to-normal vision and a good understanding of the English language. The experiment was approved by the Human Research Ethics board at Dalhousie University, and thus meets the ethical standards set forth in the Tri-Council Policy Statement.

### *Materials*

The experiment used SR Research Experiment Builder Version 1.10.1 on an Intel Core 2 computer running Microsoft Windows XP Professional Version 2002. Stimuli were presented on a 32" 1366x768 resolution Phillips LCD monitor (Model ID: BDL3231C/00). Participants viewed the monitor from a distance of approximately 55cm. Eye position was monitored with an EyeLink II (version 2.21) eye tracking system.

A master word list of 320 nouns was selected from the Paivio, Yuille, and Madigan Word Pool using an online generator (<http://www.math.yorku.ca/SCS/Online/paivio/>). The words had a mean Kucera-Francis word frequency of 47.3 (ranging from 0 – 100,  $SD = 36.7$ ), a mean imagery rating of 5.4 (ranging from 2 – 6.9,  $SD = 1.3$ ), and a mean concreteness rating of 5.4 (ranging from 1.2 – 7,  $SD = 1.8$ ). Words ranged in length from 3 to 6 letters ( $M = 5$ ,  $SD = 0.9$ ). For each participant, Experiment Builder randomized this word list and split it into 4 lists of 20 R words, 4 lists of 20 F words, and a list of 160 Foil words.

Each trial in the study phase began with the presentation of a centrally located fixation stimulus (+; Arial size 18 font) and two circular grey placeholders on a black background. Each placeholder measured 1 degree of visual angle. One

placeholder was centered 3.5 degrees to the right of fixation, and the other was centered 3.5 degrees to the left. Words were presented in Arial bold, size 14 font in yellow text, replacing one of the grey placeholders. Yellow circles (of the same size and eccentricity as the grey placeholders) served as targets. In studies that have used a similar paradigm, the cue and target were also both the same colour, but black on a white background instead of yellow on a black background (e.g., Taylor, 2005; Taylor & Fawcett, 2011). Our use of yellow for both the word and target was motivated by the fact that pilot testing showed yellow to be more visible on the background than white – an important consideration when peripheral words must be read while the eyes remain fixed at center. We have no reason to believe that having the word and target both in yellow, rather than both in black, would have any impact on our findings. An inter-trial fixation stimulus was visible in the center of the screen between trials, and was used for drift correction before each trial. This stimulus was a white circle measuring 1 degree with a .4 degree black circle in its centre.

Two auditory tones, one relatively high-pitched (1170 Hz) and one relatively low-pitched (260 Hz), were used as memory instructions. The assignment of memory instruction to tone was counterbalanced such that half of the participants were told that the high-pitched tone was an R instruction and the low-pitched tone was an F instruction, while the other half of the participants were told the opposite (low tone = R, high tone = F).

### *Procedure*

Participants were given verbal instructions detailing the task along with a visual depiction of the trial progression in the study phase. Participants were informed that they were to do their best to follow the memory instruction for each word, and that they were to respond to all targets as quickly and as accurately as possible. Participants were told that the study phase would be followed by a memory test, but they were not told that they would be tested for their memory of F items.

*Study Phase.* There were 20 R items and 20 F items for each type of trial for a total of 160 trials in the study phase. A depiction of a trial is presented in Figure 1. Each trial was initiated by the participant by depressing the space bar while maintaining fixation on the inter-trial fixation stimulus. This button press initiated a drift correction before each trial, and then initiated the trial once drift correction was complete. Upon initiation of the trial, a fixation cross (“+”) replaced the inter-trial fixation stimulus, and two circular grey placeholders (one to the right and one to the left of fixation) appeared. A word replaced one of the placeholders 500ms after the start of the trial. The word was equally likely to appear in the place of the right or left placeholder, and remained visible for 400ms. The placeholder reappeared upon word disappearance. An auditory R or F memory instruction (high- or low-pitched tone) was presented 200ms after the disappearance of the word, and lasted 400ms. A target (yellow circle) replaced one of the placeholders 200ms after the end of the memory instruction. The target was equally likely to appear in the place of the right or left placeholder, and remained visible for 1000ms. Participants were given 2000ms from the onset of the target to make a response. RT

and accuracy were measured. Participants were told to maintain fixation at centre until the target appeared, at which point they should move their eyes from fixation to the target (i.e., make a saccade to the target location) as fast as they could. If any erroneous eye movements (saccades of more than 2.5 degrees away from central fixation<sup>1</sup>) were detected before the target appeared, the trial in progress was aborted. Participants were tested for their memory of words presented on aborted trials, but these words were excluded from the analyses of results.

*Recognition Phase.* After all study trials had been presented, participants completed a yes/no recognition task. All R and F items from the study phase were presented, along with an equal number of foil items. Thus, 160 study words plus 160 unstudied foil words were presented randomly, making a total of 320 trials in the recognition phase. Words were presented centrally on the computer monitor one at a time. Participants were to indicate whether they recognized the word during the study phase regardless of the memory instruction they received at study. If they recognized the word, they were told to press the 'y' button, and if they did not, they were told to press the 'n' button. After all study and foil words had been presented, participants were debriefed and had any questions answered by the experimenter.

## Results

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<sup>1</sup> This eccentricity is similar to what has been used in other studies of inhibition of return (see, e.g., Hilchey et al., 2012).

*Proportion of Retained Study Trials.* Study trials were retained for analysis only if participants refrained from making eye movements before target onset. To determine whether study trials were retained differentially across conditions, a 2 (Word-Target Location: same, different) x 2 (Memory Instruction: R, F) repeated measures Analysis of Variance (ANOVA) was conducted with the proportion of retained trials as the dependent measure. There were no significant effects or interactions (all  $F_s < 1$ ). Thus, participants' ability to follow fixation instructions was not influenced by the type of trial that was presented (see Table 1 for descriptive statistics).

*Recognition accuracy.* Although words from aborted study trials were tested during the recognition phase, they were excluded from the calculations of recognition accuracy. The data from the recognition test were analyzed using a one-way repeated measures Analysis of Variance (ANOVA) with Word Type (R, F, foil) as the independent variable, and the proportion of 'yes' responses as the dependent variable. There was a significant main effect of Word Type ( $F(2, 56) = 62.847, MSe = .011, p < .001$ ) such that R items ( $M = .51$ ) were recognized at a higher rate than F items ( $M = .37; t(28) = 6.475, p < .001$ ). This is the expected DF effect (better memory for R than F items). Both R and F items were recognized at a higher rate than foil words ( $M = .20; t(28) = 9.167, p < .001$  and  $t(28) = 6.474, p < .001$ , respectively). These results confirm that participants used the memory instructions as intended at study.

*Saccadic RTs.* Given that participants used the memory instructions as intended, the key question was whether these instructions interacted with the IOR effect measured by saccadic RTs to targets presented at study. See Figure 2 for descriptive statistics. A 2 (Word-Target Location: same, different) x 2 (Memory Instruction: R, F) repeated measures ANOVA was conducted on saccadic RTs to the targets. There was a significant main effect of Word-Target Location ( $F(1, 28) = 36.590, MSe = 1366.332, p < .001$ ) with slower RTs to targets in the same location as the previous word compared to the other location (an IOR effect). There was also a significant main effect of Memory Instruction ( $F(1, 28) = 12.157, MSe = 760.716, p = .002$ ) with slower RTs after F compared to R instructions. Critically, there was a significant Word-Target Location x Memory Instruction interaction ( $F(1, 28) = 4.510, MSe = 826.604, p = .043$ ). The interaction was due to the fact that the magnitude of IOR (same RT – different RT) was greater after F ( $M = 52.871$  ms) than R ( $M = 30.169$  ms) instructions.

Analogous analyses on accuracy of the target response yielded no significant effects (all  $F_s < 1$ ).

## Discussion

The data from the yes-no recognition test revealed a directed forgetting effect, indicating compliance with the R and F memory instructions. Given that this was the case, the question of main interest was whether these memory instructions would interact with the motoric flavor of IOR. Participants responded to a target by making a saccade to its location. We observed the  $F > R$  IOR pattern in the saccadic

RTs, demonstrating an interaction of memory instruction with the motoric flavor of IOR. This is consistent with the results of Taylor and Fawcett (2011; see also Thompson et al., 2014), who concluded that memory instruction interacts selectively with the motoric flavor of IOR.

To fully test Taylor and Fawcett's (2011) conclusions about the F>R IOR difference, it is necessary to explicitly test whether memory instruction also interacts with the visual flavor of IOR. This was done in Experiment 2.

## Experiment 2

In Experiment 2, participants were presented with study words one at a time to the left or right of central fixation, each followed by an auditory R or F memory instruction, and then by a target in the same or opposite location as the word. Participants maintained fixation throughout the entire trial, and localized the target with a manual button-press. Because the oculomotor system was suppressed, IOR in this condition should be visual in nature (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica et al., 2010; Hilchey et al., 2012). To reiterate our predictions: If memory instruction selectively interacts with motoric IOR, the F>R IOR pattern should not occur in this experiment; if memory instruction also interacts with visual IOR, the F>R IOR pattern should occur here.

## Method

### *Participants*

Twenty-seven<sup>2</sup> participants were recruited from the undergraduate subject pool at Dalhousie University, and received one credit point for participating. All participants reported normal or corrected-to-normal vision and a good understanding of the English language. The experiment was approved by the Human Research Ethics board at Dalhousie University, and thus meets the ethical standards set forth in the Tri-Council Policy Statement.

### *Materials*

The materials were the same as Experiment 1, but included the use of a Universal Serial Bus keyboard to record manual responses.

### *Procedure*

The procedure was identical to Experiment 1, with the exception of the response required to the target. Instead of making a saccade to the target, participants were told to maintain fixation at centre throughout the entire trial. When the target appeared on the left, they pressed the 'f' key, and when it appeared on the right, they pressed the 'j' key. Study trials were aborted if erroneous eye movements were made at any time during the trial.

## Results

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<sup>2</sup> Note that Experiment 2 recruited 2 fewer participants than Experiment 1. This was due to variations in participant volunteer rates between experiments. To ensure that the larger sample size in Experiment 1 ( $n=29$ ) versus Experiment 2 ( $n=27$ ) did not impact our conclusions, we repeated the analysis of Experiment 1 data after excluding the last 2 participants ( $n=27$ ); the pattern of results was unchanged.



*Proportion of Retained Study Trials.* Study trials were retained for analysis only if participants refrained from making eye movements after the start of the trial. To determine whether study trials were retained differentially across conditions a 2 (Word-Target Location: same, different) x 2 (Memory Instruction: R, F) repeated measures ANOVA was conducted with the proportion of retained trials as the dependent measure. There were no significant effects or interactions (all  $F$ s < 1). Thus, participants' ability to follow fixation instructions was not influenced by the type of trial that was presented.

*Recognition accuracy.* Although words from aborted study trials were tested during the recognition phase, they were excluded from the calculations of recognition accuracy. The data from the recognition test were analyzed using a one-way repeated measures Analysis of Variance (ANOVA) with Word Type (R, F, foil) as the independent variable, and the proportion of 'yes' responses as the dependent variable. There was a significant main effect of Word Type ( $F(2, 52) = 79.467$ ,  $MSe = .006$ ,  $p < .001$ ) such that R items ( $M = .45$ ) were recognized at a higher rate than F items ( $M = .33$ ;  $t(26) = 6.063$ ,  $p < .001$ ). This is the expected DF effect (better memory for R than F items). Both R and F items were recognized at a higher rate than foil words ( $M = .18$ ;  $t(26) = 10.499$ ,  $p < .001$  and  $t(26) = 8.120$ ,  $p < .001$ , respectively). These results confirm that participants used the memory instructions as intended at study.

*Manual RTs.* Given that participants used the memory instructions as intended, the key question was whether these instructions interacted with the IOR

effect measured by manual RTs to targets presented at study. See Figure 3 for descriptive statistics. A 2 (Word-Target Location: same, different) x 2 (Memory Instruction: R, F) repeated measures ANOVA was conducted on the manual RTs to the targets. There was a significant main effect of Word-Target Location ( $F(1, 26) = 19.537, MSe = 655.255, p < .001$ ) with slower RTs to targets in the same location as the previous word compared to the other location (an IOR effect). The main effect of Memory Instruction was not significant ( $F < 1$ ). Finally, there was a significant Word-Target Location x Memory Instruction interaction ( $F(1, 26) = 4.744, MSe = 263.426, p = .039$ ). The interaction was due to the fact that the magnitude of IOR (same RT – different RT) was greater after F ( $M = 28.578$  ms) than R ( $M = 14.971$  ms) instructions.

Analogous analyses on accuracy of the target response yielded no significant effects (all  $F_s < 1$ ).

## Discussion

The data from the yes-no recognition test revealed a directed forgetting effect, indicating compliance with the R and F memory instructions. Given that this was the case, the question of main interest was whether these memory instructions would interact with the visual flavor of IOR. We observed the F>R IOR pattern in the analysis of manual RTs to the study trial targets, demonstrating an interaction of memory instruction with the visual form of IOR. This is inconsistent with the results of Taylor and Fawcett (2011; see also Thompson et al., 2014), who concluded that memory instruction interacts selectively with the motoric flavor of IOR.

While the results of the present experiment are inconsistent with Taylor and Fawcett (2011), this is perhaps not surprising given the potential confound we outlined above. Since participants were making saccades to each word in Taylor and Fawcett (2011), the visual form of IOR that might be expected to emerge in their perceptual discrimination task would have been masked (Chica et al., 2010). However, we thought it prudent to replicate and extend the results of the present experiment by testing for an interaction of memory instruction and visual IOR using the same perceptual discrimination response used by Taylor and Fawcett (2011), while restricting eye movements as in the present experiment. This would give us more confidence in our conclusion that memory instruction interacts with both forms of IOR.

### Experiment 3

The results of Experiment 2 conflict with a previous conclusion from Taylor and Fawcett (2011). In one of their experiments, participants were presented with a word to the left or right, followed by an auditory R or F instruction, then a triangle to the left or right. Participants were required to indicate with a button-press whether the triangle was upright or inverted. Because Taylor and Fawcett (2011) found no significant interaction between memory instruction and IOR for this perceptual discrimination task, they concluded that memory instruction interacts only with the motoric form of IOR, and not with the visual form. However, this conclusion was based on the results of experiments that neither restricted nor monitored eye movements. And, as noted previously, visual IOR does not occur

when the eyes are unrestrained (Chica et al., 2010). This suggests that the lack of eye movement monitoring likely undermined Taylor and Fawcett's (2011) ability to find an interaction of memory instruction with the visual form of IOR. Perhaps an F instruction leads not only to a bias against responding to targets that arise at the location of the previous mis-information but, in the absence of eye movements, also to a perceptual processing deficit for targets presented at that location. If the conclusions of Experiment 2 are correct and memory instructions do interact with visual IOR, then prohibiting and monitoring eye movements in a replication of Taylor and Fawcett's (2011) perceptual discrimination task should produce the F>R IOR pattern that Taylor and Fawcett (2011) could not. To test this, Experiment 3 presented participants with a word to the left or right, followed by an auditory R or F instruction, and then a triangular target to the left or right. Participants were required to discriminate between upright and inverted triangles with a manual button press while maintaining fixation at centre throughout the trial. Eye movement monitoring ensured that participants complied with the instruction to refrain from making movements.

## Method

### *Participants*

Thirty-five<sup>3</sup> participants were recruited from the undergraduate subject pool at Dalhousie University, and received one credit point for participating. All

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<sup>3</sup> Note that the sample size for Experiment 3 was greater than both Experiments 1 and 2. This was motivated by the fact that Experiment 3 was an attempt to replicate

participants reported normal or corrected-to-normal vision and a good understanding of the English language. The experiment was approved by the Human Research Ethics board at Dalhousie University, and thus meets the ethical standards set forth in the Tri-Council Policy Statement.

### *Materials*

Materials used were identical to those used in Experiment 1 and 2 with the exception of the targets. Yellow triangles (of the same size and eccentricity as the grey placeholders) served as targets.

### *Procedure*

The procedure used was identical to Experiment 2 with the following exceptions. A triangular target was presented on each trial instead of a circular target. When the target appeared, participants were required to press the 'f' key with the index finger of their left hand if the triangle was upright (i.e., pointing upwards), or the 'j' key with the index finger of their right hand if the triangle was inverted (i.e., pointing downwards).

## Results

*Proportion of Retained Study Trials.* Study trials were retained for analysis only if participants refrained from making eye movements after the start of the trial. To determine whether study trials were retained differentially across conditions a 2

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Taylor and Fawcett's (2011) discrimination experiment which, for them, consisted of a null result. Given this, we wished to ensure that we had enough power to observe a potentially small effect.

(Word-Target Location: same, different) x 2 (Memory Instruction: R, F) repeated measures ANOVA was conducted with the proportion of retained trials as the dependent measure. There was a significant main effect of Word-Target Location ( $F(1, 34) = 5.172, MSe = .003, p = .029$ ), with a higher proportion of retained trials when the target appeared in the same compared to the different location as the word. No other effects were significant (all  $F_s < 1$ ).

*Recognition accuracy.* Although words from aborted study trials were tested during the recognition phase, they were excluded from the calculations of recognition accuracy. The data from the recognition test were analyzed using a one-way repeated measures Analysis of Variance (ANOVA) with Word Type (R, F, foil) as the independent variable, and the proportion of 'yes' responses as the dependent variable. There was a significant main effect of Word Type ( $F(2, 68) = 91.668, MSe = .010, p < .001$ ) such that R items ( $M = .46$ ) were recognized at a higher rate than F items ( $M = .33; t(34) = 5.547, p < .001$ ). This is the expected DF effect (better memory for R than F items). Both R and F items were recognized at a higher rate than foil words ( $M = .13; t(34) = 11.583, p < .001$  and  $t(34) = 9.492, p < .001$ , respectively). These results confirm that participants used the memory instructions as intended at study.

*Discrimination RTs.* Given that participants used the memory instructions as intended, the key question was whether these instructions interacted with the IOR effect measured by RTs to discriminate the target arrow on study trials. See Figure 4 for descriptive statistics. A 2 (Word-Target Location: same, different) x 2 (Memory

Instruction: R, F) repeated measures ANOVA was conducted on the discrimination RTs. There was a significant main effect of Word-Target Location ( $F(1, 34) = 4.921$ ,  $MSe = 1224.310$ ,  $p < .033$ ) with slower RTs to targets in the same location as the previous word compared to the other location (an IOR effect). There was also a significant main effect of Memory Instruction ( $F(1, 34) = 11.157$ ,  $MSe = 1505.005$ ,  $p = .002$ ) with slower RTs after R compared to F instructions. Finally, there was a significant Word-Target Location x Memory Instruction interaction ( $F(1, 34) = 6.792$ ,  $MSe = 1032.661$ ,  $p = .013$ ). The interaction was due to the fact that the magnitude of IOR (same RT – different RT) was greater after F ( $M = 27.277$  ms) than R ( $M = -1.035$  ms) instructions.

Analogous analyses on accuracy of the target response yielded no significant effects (all  $F_s < 1$ ).

### Discussion

The results from the yes-no recognition test confirmed a directed forgetting effect, suggesting that participants complied with the R and F instructions. Given that this was the case, the critical question was whether instituting eye movement monitoring in a replication of Taylor and Fawcett's (2011) perceptual discrimination task would reveal the interaction of memory instruction and visual IOR that Taylor and Fawcett discounted. Indeed, it did. Experiment 3 revealed the F>R IOR pattern for the same perceptual discrimination task employed by Taylor and Fawcett (2011). In so doing, the results of Experiment 3 bolstered the

conclusion drawn from the results of Experiments 1 and 2: Memory instruction interacts not only with the motoric form of IOR, but also with the visual form.

Before proceeding to the General Discussion, it is worth noting that in Experiment 3, the larger IOR effect for F than R trials reflected a significant IOR effect for the former and not for the latter condition. This is consistent with previous investigations of IOR and directed forgetting, where the trend is that in some cases the IOR effect is not significant after R instructions, but even in the cases where significant IOR is observed after R instructions, the magnitude of IOR is greater after F compared to R instructions. That is, the increased magnitude of IOR after F instructions is always observed, and this is sometimes accompanied by a non-significant IOR effect after R items (Taylor, 2005; Taylor & Fawcett, 2011; Thompson et al., 2014). This relative increase in magnitude of IOR after F instructions and decrease after R instructions has been made in comparison to a no-memory control condition (Taylor & Fawcett, 2011). The decreased magnitude of IOR after R instructions may be due to individual differences in study strategies (perhaps explaining its inconsistent appearance), and likely indicates attentional dwelling on R-items to aid in elaborative encoding – this would result in a delay in the appearance of IOR, which is caused by the onset of the word, but is masked by facilitatory effects until attention is withdrawn (Danziger & Kingstone, 1999).

### General Discussion

IOR can be conceived of as a mechanism that facilitates visual search for novelty (Klein & MacInnes, 1999; Klein, 2000; MacInnes & Klein, 2003). After



attention is captured by a particular stimulus, re-inspection of that location is prevented in one of two ways depending on the state of the oculomotor system (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica et al., 2010; Hilchey et al., 2012). When the oculomotor system is active, IOR reflects a motoric bias against making responses toward the cued location. When the oculomotor system is inactive or suppressed, IOR reflects a perceptual processing deficit at the stimulus location.

We observed effects of memory instruction on both of these forms of IOR. It seems unlikely that memory instruction has two entirely independent effects, one that interacts only with a motor response bias and one that interacts only with perceptual processing. Instead, it is more parsimonious to assume that despite the fact that motoric and visual IOR represent different behavioural manifestations of the after-effects of peripheral visual stimulation (Taylor & Klein, 2000; Hunt & Kingstone, 2003; Chica et al., 2010; Hilchey et al., 2012), they must have upstream processing in common, and that it is this common upstream processing that interacts with the memory instruction.

Most research on the two forms of IOR focuses on the mechanisms that differentiate them. However, there may be some commonalities between them. For example, in an rTMS study, Bourgeois et al. (2013) found that disruption of the intra-parietal sulcus (IPS) disrupted both motoric and visual IOR for left-sided targets. Thus, the IPS may represent a neural correlate of both motoric and visual IOR. In attention research, the IPS is known as the seat of a spatial salience map

where the salience of environmental stimuli is represented and can be modified based on experience (Silver & Kastner, 2009; van Koningsbruggen, Gabay, Sapir, Henik, & Rafal, 2010). In the inhibition of return framework, it is thought that the salience of a cued location in the IPS is diminished/inhibited to allow orienting to new spatial locations, causing increased RTs to targets presented in cued locations (Sapir, Hayes, Henik, Danziger, & Rafal, 2004; Vivas, Humphreys, & Fuentes, 2006). In accordance with the idea that this area could be upstream of both the motoric and visual forms of IOR, the IPS has connections to the superior colliculus (SC; known to be involved in motoric IOR; Robinson, Bowman, & Kurtzman, 1995; Anderson & Rees, 2011; Dorris, Klein, Everling, & Munoz, 2002; Bourgeois et al., 2012; Bourgeois et al., 2013). Not only this, but the dorsal parieto-frontal network that encompasses the IPS is also tightly linked with the ventral parieto-frontal network that encompasses the temporo-parietal junction (TPJ; known to be involved in visual IOR; Asplund, Todd, Snyder, & Marois, 2010; Bourgeois et al., 2012 & 2013). Interestingly, there is research suggesting that the salience map in the IPS has much broader applications than mapping the salience of environmental spatial locations. It is thought to be involved with guiding top-down attention not only spatially, but also with respect to particular target features, semantic associations, and even guides retrieval of target memories (Ciaramelli et al., 2008; Cabeza, 2008; Silver & Kastner, 2009). Although highly speculative, this introduces the intriguing possibility that memory instructions interact with motoric and and visual IOR effects by altering representations within the IPS saliency map. Essentially, locations

that contained a to-be-forgotten item become relatively less salient than those that contained a to-be-remembered item.

While fMRI research on directed forgetting focuses on frontal and medial temporal lobe activation, there is often parietal activation associated with instantiating an instruction to forget at study (e.g., Wylie et al., 2008; Nowicka et al., 2011; Saletin et al., 2011; Bastin et al. 2012). In addition, electrophysiological investigations of directed forgetting have consistently shown that R instructions are associated with a parietally distributed positivity that is absent after F instructions (Ullsperger, Mecklinger, & Muller, 2000; Hauswald, Schulz, Iordanov, & Kissler, 2011; Paz-Caballero, Menor, & Jimenez, 2004; Hsieh, Hung, Tzeng, Lee, & Cheng, 2009; van Hoof & Ford, 2011; Lin, Kuo, Liu, Han, & Cheng, 2013). This could represent parietal inhibition after F, but not R instructions. When combined with an IOR cueing paradigm, this inhibition after F items may be additive with that observed due to IOR. Finally, parietal areas including the IPS have been found to be associated with the suppression of unwanted memories in other experimental paradigms such as think/no-think (Anderson, Ochsner, Kuhl, Cooper, Robertson, et al., 2004). So, while the present results certainly are not able to directly support the hypothesis that activation in the IPS in particular may be influenced by memory instructions, this is one possibility that is consistent with the existing IOR and directed forgetting literatures.

Collectively, the research on IOR in directed forgetting has taught us much about the cognitive consequences of instantiating an intention to forget. We now

have a substantial amount of evidence that attention is more readily withdrawn after F compared to R instructions (Taylor, 2005; Fawcett & Taylor, 2010; Taylor & Fawcett, 2011; Thompson et al., 2014; the present experiments). This differential withdrawal of attention helps direct cognitive resources away from unwanted information and toward relevant information. Withdrawing attention is a cognitively demanding process, which results in reduced availability of cognitive resources following F compared to R instructions (Cheng et al., 2012; Fawcett & Taylor, 2008). We know that, while there is conflicting evidence regarding whether the F>R IOR difference is related to the magnitude of the directed forgetting effect (Fawcett & Taylor, 2010; Taylor & Fawcett, 2011; Thompson et al., 2014), successful instantiation of an F instruction *is* related to the availability of cognitive resources. Forgetting is *more* successful under highly demanding task conditions (Lee & Lee, 2011; Lee, 2012). Thus, the differential withdrawal of attention may be directly beneficial for successful intentional forgetting by redirecting attention away from unwanted information. It may also indirectly benefit successful intentional forgetting by occupying cognitive resources.

Not only does an F instruction cause attention to be differentially withdrawn, but it also has lasting and wide ranging consequences on subsequent information processing. The present experiment has shown that memory instruction interacts with IOR in such a way that enhances both a bias against responding to the source of the F item, and also perceptual impairments at that source. IOR has been conceptualized as a mechanism that facilitates visual search by encouraging the inspection of novel, un-inspected locations (Klein & MacInnes, 1999; Klein, 2000;

MacInnes & Klein, 2003). In this case, a location is inspected, and found to be irrelevant, so processing and responses are directed away from that location to avoid the constant re-inspection of a known irrelevant source. The magnification of this difference by an F instruction is a logical extension. Previous research has suggested that instantiating an F instruction results not only in decreased memory for F items, but also in impoverished encoding of contextual/episodic information presented in close temporal proximity to the F item (Fawcett & Taylor, 2012; Hourihan, Goldberg, & Taylor, 2007). Fawcett and Taylor (2012) showed decreased memory for probe words presented after F compared to R instructions, suggesting that incidental memory for information presented soon after an F instruction is decreased. Hourihan, Goldberg, and Taylor (2007) showed that presenting items in the same spatial location at study and test benefitted memory performance only for F items, but not R items. This suggests that encoding of contextual characteristics (such as spatial location) was already strong for R items, but the weak encoding of such details for F items lead to a significant improvement on memory performance with the addition of such contextual cues at test. The notion that an F instruction disrupts episodic encoding of the event is also supported by fMRI studies of item-method directed forgetting, where instantiating an F instruction has been associated with frontal and medial temporal activation (Wylie et al., 2008; Nowicka et al., 2011; Saletin et al., 2011; Bastin et al., 2012) The F>R IOR difference represents a mechanism by which this disruption of episodic encoding occurs. We have shown that an F instructions limits the degree to which contextual elements are able to capture attention by modulating perceptual processing of the event and/or motor

output (visual and motoric IOR). This would result in impoverished encoding of the event, and therefore reduced memory strength for F items compared to R items – the DF effect.

To conclude, we have shown that instantiating an instruction to forget increases the magnitude of IOR, leading to both a bias against responding to the F item source and perceptual decrements at the F item location, depending on the state of the oculomotor system. These consequences of instantiating an instruction to forget are adaptive insofar as they promote the encoding of valid and relevant observations about the world, and prevent the encoding of invalid, irrelevant observations.

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*Table 1.* Descriptive statistics of the proportion of retained study trials per condition in Experiment 1. Means are reported, with Standard Deviations in parentheses.

<b>Memory Instruction</b>	<b>Word-Target Location</b>	
	<b>Same</b>	<b>Different</b>
<b>Remember</b>	.59 (.12)	.60 (.14)
<b>Forget</b>	.57 (.14)	.60 (.13)

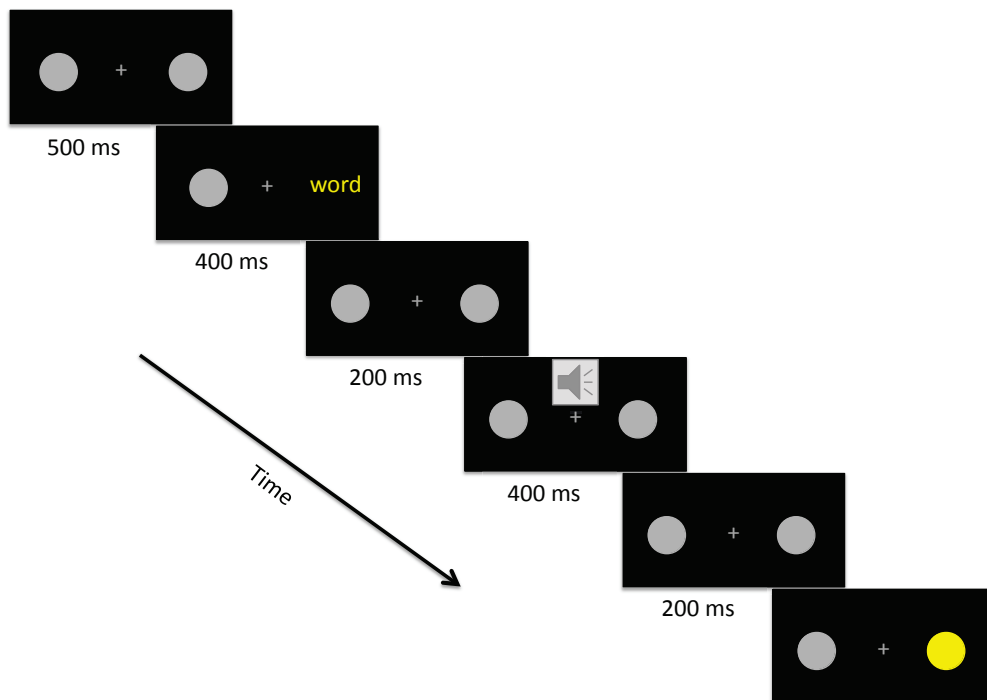


*Table 2.* Descriptive statistics of the proportion of retained study trials per condition in Experiment 2. Means are reported, with Standard Deviations in parentheses.

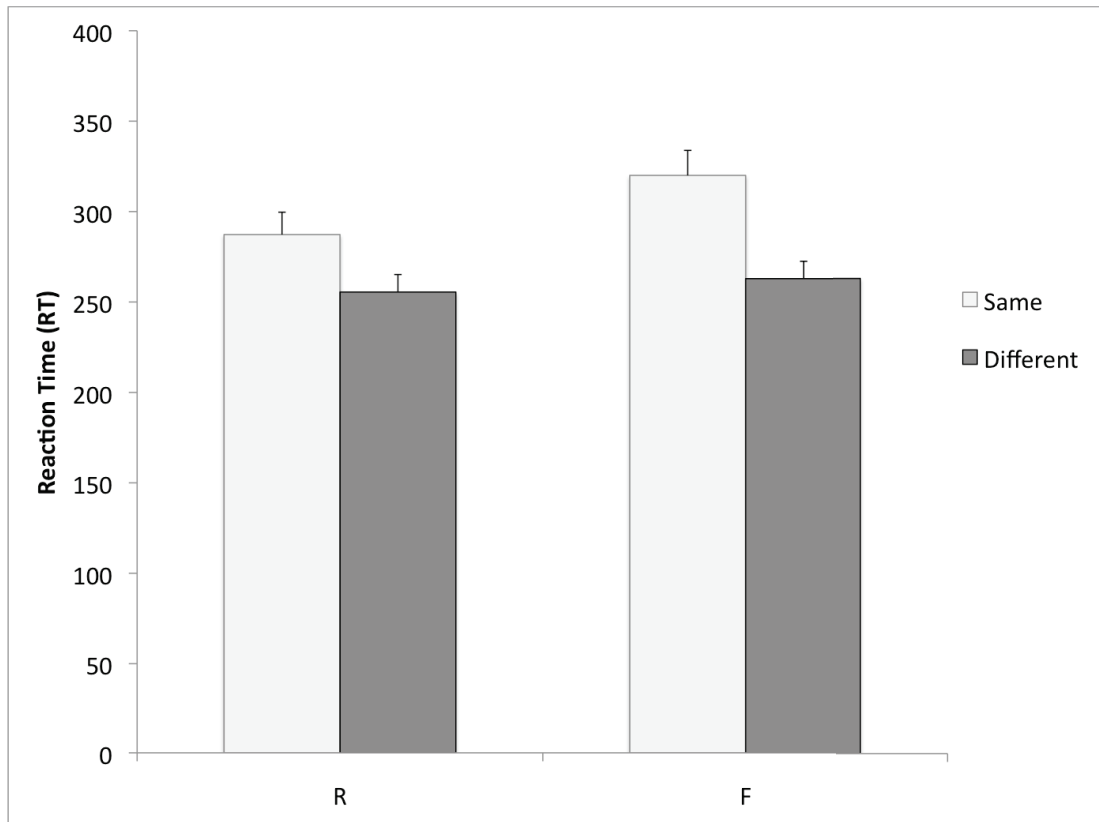
<b>Memory Instruction</b>	<b>Word-Target Location</b>	
	<b>Same</b>	<b>Different</b>
<b>Remember</b>	.71 (.14)	.69 (.16)
<b>Forget</b>	.69 (.15)	.70 (.13)

*Table 3.* Descriptive statistics of the proportion of retained study trials per condition in Experiment 3. Means are reported, with Standard Deviations in parentheses.

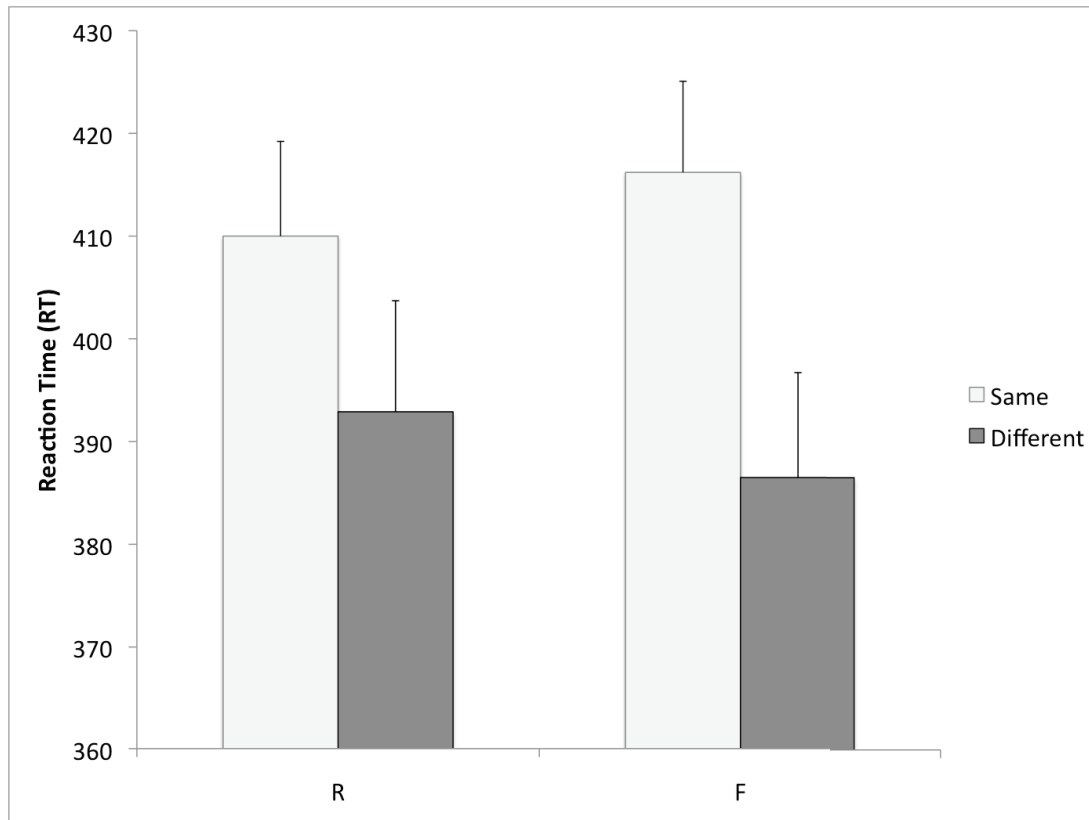
<b>Memory Instruction</b>	<b>Word-Target Location</b>	
	<b>Same</b>	<b>Different</b>
<b>Remember</b>	.79 (.14)	.77 (.12)
<b>Forget</b>	.80 (.10)	.78 (.13)



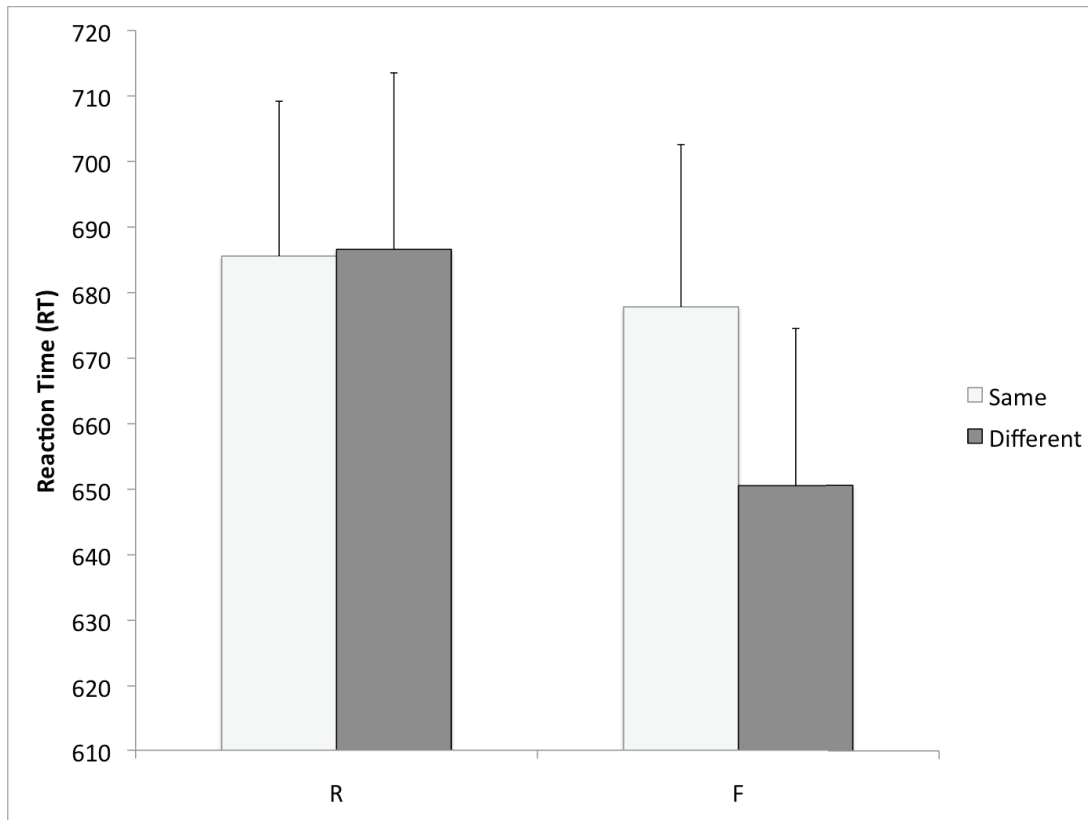
*Figure 1.* Progression of a trial in Experiments 1 and 2.



*Figure 2.* Mean RT in ms after R and F memory instructions to targets appearing in the same and different locations compared to the word in Experiment 1. Error bars are standard error.



*Figure 3.* Mean RT in ms after R and F memory instructions to targets appearing in the same and different locations compared to the word in Experiment 2. Error bars are standard error.



*Figure 4.* Mean RT in ms after R and F memory instructions to targets appearing in the same and different locations compared to the word in Experiment 3. Error bars are standard error.