EXPLORING THE ROLE OF ATTENTIONAL WITHDRAWAL IN ITEM-METHOD DIRECTED FORGETTING THROUGH VISUAL SEARCH

by

Ryan Lewis

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

DEDICATION PAGE

For my Ma, Da and dearest friends

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ABSTRACT

We embedded a serial and pop-out visual search into the study phase of an item-method directed forgetting paradigm to assess attentional availability following instructions to remember (R) or forget (F). Study words were presented to the left or right of a central fixation (Experiments 1-2) or at center (Experiments 3-5), followed by a visual (Experiments 1-4) or auditory (Experiment 5) memory instruction, and then by the search display. Although the evidence did not support a differential withdrawal of attention following F compared to R instructions, Experiment 5 replicated slower response times to visual targets that followed F compared to R instructions (e.g. Fawcett and Taylor, 2008; 2012) - consistent with the view that intentional forgetting engages an active cognitive process. We speculate that this active process might be a non-attentional inhibitory mechanism that is employed to further reduce the encoding of F items alongside selective rehearsal of R over F items.

LIST OF ABBREVIATIONS USED

Abbreviation	**Meaning**
ANOVA	Analysis of Variance
DF	Directed Forgetting
ERP	Event-Related Potential
F	Forget
F>R	Greater forget compared to remember
FA	False Alarms
FR	Frame Rate
fMRI	Functional-Magnetic Resonance Imaging
IOR	Inhibition of Return
M	Mean
ms	Milliseconds
R	Remember
RT	Response Time
RTs	Response Times
SE	Standard Error

SD	Standard Deviation
SOA	Stimulus Onset Asynchrony

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Chapter 1: Introduction

Long-term memory is a powerful part of human cognition that directly influences our sense of self and ability to function in daily life. It allows us to store details of important life events, new knowledge about a favorite subject, and where we last placed our house keys… sometimes. Indeed, forgetting is commonly cast in a negative light, being seen as a failure of proper brain functioning. Though it is undoubtedly true that forgetting can be an annoyance, our ability to forget irrelevant or unwanted information is essential for healthy cognitive functioning (Bjork, 1970). When an individual attempts to forget with purpose, we call it intentional or directed forgetting, which is seen as a goal-directed, adaptive cognitive process used to prevent memory encoding, consolidation, or retrieval of undesired or irrelevant information (Basden & Basden, 1998; Bjork, 1989). Intentional forgetting is distinguished from the more commonly known unintentional forgetting, which is a failure to remember information due to issues in encoding, consolidation, or retrieval.

Intentional forgetting is studied in laboratory settings using directed forgetting (DF) paradigms. In DF paradigms, participants are given items of information during a study phase. Studied items are generally words but other stimuli such as pictures (Scotti & Maxcey, 2022) and even video clips (Fawcett, Taylor, & Nadel, 2013) have been used instead. Following the presentation of one or more study items, an instruction is given to either remember (R) or to forget (F) the items that preceded. A memory test is then used to assess participants' success in instantiating the memory instructions. This is accomplished by instructing participants to recall or recognize both R and F items to the best of their ability regardless of the previous instruction given. A DF effect occurs when significantly more R items are recalled and/or recognized than F items.

Conventional DF paradigms fall into two types: item-method or list-method. The item-method DF paradigm presents study items one at a time, each followed by an instruction to remember or forget (Basden & Basden, 1998). DF effects occur in the item-method due to the selective rehearsal of R items over F items which leads to a stronger encoding of R items compared to F items, the latter of which receive only minimal processing prior to the memory instruction (Baden & Basden, 1998; Hockley, Ahmad, & Nicholson, 2016). In contrast, the list-method paradigm separates the presentation of items into two lists that receive either R or F instructions after all items in a list are presented (Basden & Basden, 1998). DF effects in the list-method paradigm are thought to be driven by changes in the mental context based on the memory instruction, with F lists contextually differentiated from R lists at retrieval (Sahakyan & Kelley, 2002). Interestingly, only tests of recall elicit the DF effect in the list-method paradigm (Basden & Basden, 1998): attempts to use recognition tests in list-method experiments (Elmes, Adam, & Roediger, 1970), or to present a recall test following an initial recognition test (Bjork, 1989) fail to reveal a DF effect. In contrast, both tests of recall and recognition reveal DF effects in the item-method DF paradigm. This discrepancy underscores that these two paradigms differ in the underlying mechanism that accomplishes forgetting: list-method DF occurs due to disrupted retrieval whereas item-method DF occurs due to disrupted encoding of F items. Of primary interest for this thesis is the item-method directed forgetting paradigm and the role attention might play in limiting unwanted encoding of F items.

1.1 Item-Method Directed Forgetting

Item-method DF is widely agreed to be the result of R items receiving selective elaborative rehearsal whereas F items are omitted from this deeper encoding strategy (Bjork & Woodward, 1973; Macleod 1998; Sahakyan & Foster, 2009; Tan, Hockley, Harrison, & Wilson, 2020). Early studies of item-method DF implied that this selective elaborative rehearsal of R over F items is, in part, a consequence of passive decay of the F item memory trace over time following the suspension of maintenance rehearsal upon F instruction presentation (Bjork & Woodward, 1973; Woodward, Bjork, & Jongeward, 1973; MacLeod, 1975). As a result of this decay of the unrehearsed F item trace, participants are slower to endorse having seen F items compared to R items and less able to recall episodic details (Tulving, 1985). However, not all agree that intentional forgetting is accomplished in this passive manner. Evidence from contemporary studies suggest that the exclusion of F items from post-instruction elaborative rehearsal may be due to a more active cognitive process than first believed.

One of the first proposals of DF as an active process comes from the Attentional Inhibition Hypothesis (Zacks, Radvansky, & Hasher, 1996). When compared to younger adults, Zacks and colleagues showed that older adults recalled more F items and fewer R items in an immediate test of memory, with overall lower performance on final tests of recall and recognition. This difference in the magnitude of the DF effect between age groups was attributed to older adults having a diminished ability to engage inhibitory mechanisms because of aged-related cognitive decline that prevented them from successfully instantiating the F instruction. Under this framework, intentional forgetting was conceived as a form of cognitive control that inhibits attention from refreshing a study item representation held in working memory. Inhibiting the F items segregates them from R items, effectively lowering the chance of encoding the F items into long-term memory (Zacks et al., 1996). Although the notion of attentional inhibition as a mechanism for item-method DF has fallen out of favour and is not required to explain the data (see Macleod, Dodd & Sheard, 2003), it is nevertheless the case that selective rehearsal is thought to rely on an active rather than a passive process to prevent unwanted rehearsal of F items – which is consistent with modern views of working memory updating (Ecker, Lewandowsky, & Oberauer, 2014; Ecker, Oberauer, & Lewandowsky, 2014b; Lewis-Peacock, Kessler, & Oberauer, 2018).

To lend credence to this idea of intentional forgetting being an active cognitive process, neuroimaging studies have examined activity during item-method directed forgetting. Event-related Functional Magnetic Resonance Imaging (fMRI) compared brain activity for intentional and unintentional forgetting and remembering (Wylie, Foxe, & Taylor, 2008). Compared to unintentional forgetting (i.e., failed recall of an R item), intentional forgetting showed unique activity in frontal areas associated with cognitive control and memory formation, along with differential activity in parietal regions, related to sensory processing. Studies using Event Related Potentials (ERP) have also found a unique signature of intentional forgetting shortly after the onset of the memory instruction leading to activation in frontal and parietal brain areas which implicates a cognitively active process (Cheng, Liu, Lee, Hung, & Tzeng, 2012; Rizio and Dennis, 2013; van Hoof & Ford, 2011).

In behavioural studies designed to assess the relative cognitive demands of remembering and forgetting, Fawcett and Taylor (2008) embedded a visual probe detection task within the study phase of an item-method directed paradigm at onsets of 1400 milliseconds (ms), 1800ms, and 2600ms after the study word or after an auditory memory instruction. Participants responded to the appearance of the probe by pressing the space bar on a keyboard as quickly as possible. F instructions induced slower response times (RTs) when probe onsets occurred 1400ms and 1800ms post memory instruction, with probe RTs on R and F trials becoming equivalent by 2600ms (Fawcett and Taylor, 2008). Additional analysis also found that this slowing following F compared to R instructions was more pronounced when instructions to forget were successful versus unsuccessful. The authors argued that slower probe RTs following F compared to R instructions were consistent with the supposition of intentional forgetting being an active cognitive process that – at least in the initial implementation – is even more cognitively demanding than remembering (Fawcett & Taylor, 2008; Lee, 2011; Taylor & Fawcett, 2011; although see Tan et al, 2020). The nature of this active process may be related to a differential allocation of attention following F compared to R instructions (Fawcett & Taylor, 2010).

1.2 Directed Forgetting and Attentional Withdrawal

One means of assessing the dynamics of attention is the Posner (or spatial) cueing task (Posner, 1980; Posner & Cohen, 1984). In the version of this paradigm that measures exogenous attention, participants are presented with a central fixation point flanked by a box to the left and right. A visual cue then appears in one of the peripheral boxes and is intended to capture attention at one of the boxes in which a visual target can appear after a variable stimulus onset asynchrony (SOA). Exogenous visual cues are uninformative of where the subsequent target will appear, coinciding with the target location on only half of the trials. At relatively short SOAs, attention is still at the cued location – even though the target is no more likely at the cued location than at the uncued location. Consequently, mean RTs are faster to targets that appear in cued locations compared to un-cued locations (Posner, 1980; Posner & Cohen, 1984).

In contrast, when the SOA between cues and target probes is particularly long, RTs become slower at the cued location compared to the non-cued location, a result referred to as Inhibition of Return (IOR) (Posner & Cohen, 1984). IOR has been described as a facilitator for guiding attention towards novel locations when searching for a target (Klein, 1988; 2000; Klein & MacInnis, 1999; Wang & Klein, 2010). Although originally thought to be due to the inhibited return of attention to the cued location (Posner and Cohen, 1984), the reduction in the visuo-spatial saliency of previously attended location (Klein & and Ivanoff, 2008) more likely co-occurs with the initial cue onset. IOR effects thus remain obscured until attentional facilitation decays or until attention is actively removed (Klein, 2000).

Given that IOR can be revealed when unmasked by the removal of attention, Taylor (2005) embedded a Posner cueing paradigm within an item-method directed forgetting paradigm to assess whether attention is withdrawn more readily following F instructions than following R instructions. A peripherally presented study word served as an exogenous visual cue, appearing with equal probability to the left or right of central fixation. Following a memory instruction, a visual target appeared in one of the same two possible locations as the study word. Participants then made key responses to report the location of the target. IOR effects were larger following F compared to R instructions (Taylor, 2005; see also Taylor & Fawcett, 2011). Larger IOR following F instructions is a robust finding (Taylor & Fawcett 2011; Thompson, Hamm, & Taylor, 2014; Thompson & Taylor, 2015), that has been interpreted as evidence for an active withdrawal of attention from study items on F compared to R trials.

Eye-tracking data has provided additional support for a withdrawal of attention following F instructions. Lee (2018) showed that when presented with an auditory instruction to forget or ignore an item, participants spent less time viewing the item location compared to R item location, both when the study word remained on screen and when it disappeared before the memory instruction. Furthermore, participants had larger pupil diameters when presented with R instructions compared to F instructions (Lee, 2018). The bias against viewing an F item location is seen as an indication that participants divert spatial attention away from a study item location while their increased pupil size on R compared to F trials is interpreted as evidence of greater cognitive effort involved in elaborative encoding (Lee, 2018).

Conditions of higher mental load such as larger item rehearsal sets or dividing attention with another task increase the success of instantiating an F instruction in item-method DF compared to conditions of lower mental load (Lee, 2012; Lee & Lee, 2011). Increasing the perceptual load fails to elicit a similar effect (Taylor & Ivanoff, 2021). In the case where increased cognitive load increases the magnitude of the DF effect, an attentional withdrawal following F instructions could be a useful mechanism for limiting unwanted F item processing. Presumably, under high load conditions, a withdrawal of attention from unwanted F item processing not only magnifies the DF effect but makes these limited-capacity resources more available for a secondary task (see also Taylor, 2018). That said, however, recent work indicates that instructing participants to maintain or remove their gaze from F and R items does not alter the magnitude of the DF effect (Foster & Harriman, 2022) nor does capturing or directing attention through a visual cue presented before a study item (Taylor & Hamm, 2016, Rubinfeld, Taylor, & Hamm, 2019; Taylor & Hamm, 2021). Thus, the relationship between DF and alterations in the spatial allocation of attention is not entirely clear.

Although previous studies have suggested an effect of memory instructions on the availability of attentional resources and their deployment in space and time (e.g. Fawcett & Taylor, 2008; Lee, 2018; Taylor 2018), it is possible that another process could be at play. Indeed, though the interpretation of larger IOR effects following F instructions than following R instructions being due to attentional withdrawal is intriguing, IOR is revealed in locations where attention is *not* currently deployed, rather than in locations where it is. Slower probe detection and identification following F instructions than following R instructions (e.g., Fawcett & Taylor, 2008; Thompson, Hamm, & Taylor 2014) *could* be due to a withdrawal of attentional resources, but without a direct assessment of attention that controls for non-attentional factors, we cannot be certain that this is the case.

To fully illuminate the interactions of attentional resources with memory instructions, it is necessary to construct a paradigm that assesses attention directly by determining its availability for use in a secondary, attentionally demanding task. At the same time, it is necessary to ensure that attentional availability following R and F instructions can be compared directly, without any contaminating effects from other processes that might otherwise differ between R and F trials. For example, Tan and colleagues (2020) have suggested that differences in post-R and post-F probe and target RTs might not reflect differences in the availability of attentional resources per se, but the influence of other cognitive processes — for example, switching from maintenance rehearsal to prior-trial R item retrieval and cumulative rehearsal — that are either not engaged on R trials or that are engaged differently than on F trials. This suggests the need to create a paradigm that can measure differences in attentional availability following R and F instructions, while holding constant any other processing differences that might otherwise occur during the post-instruction interval. The present study accomplishes this by using the task of visual search to assess attentional deployment following memory instructions in an item-method DF task.

1.3 Directed Forgetting and Visual Search

Visual search refers to the goal-driven task of locating an object of interest (i.e. a target) from amongst other objects (i.e. distractors) in the visual field. Such a task is common in daily life from searching a cupboard for ingredients to picking out a friend from a crowd at a social gathering. Due to its importance, extensive research has been conducted into the influences that lead to successful search. Feature Integration Theory (FIT) conceptualized the search process as beginning with pre-attentive processing whereby basic features of objects in a scene are initially held in unbound states in the visual system (Treisman & Gelade, 1980). Basic features are then bound through focused attention to specific objects in space represented in a mental map, starting with objects comprised of the most salient features (Treisman & Gelade, 1980). FIT proposes a dichotomous view of visual search as being either parallel or serial. Parallel (or pop-out) searches were defined as those that could be completed entirely through pre-attentive processing due to the target possessing uniquely salient features relative to nearby distractors. A target under these circumstances, such as a red circle among an array of blue squares, appears to “pop-out” of a search display. Visual searches where the target features more closely resemble surrounding distractors require a deployment of focused attention in a serial, item-by-item manner (Treisman & Gelade, 1980).

FIT has fallen out of favour as an explanation for visual search as its predictions fell short with further study. However, its conceptualization of parallel and serial processing during search has continued to influence contemporary models. The Guided Search (GS) model (Wolfe, 1994) of visual search emerged as a response to the inconsistencies in FIT and has since undergone several revisions in the past decades (Wolfe, 2007; 2021). GS suggests that both parallel and serial search occur simultaneously rather than separately. Both bottom-up processing of visual input and top-down influences come together to form a mental priority map for attentional deployment. Due to attention being limited in its capacity, items or locations are passed through a selective bottleneck. This selection process is “guided” by the priority map, starting with the most salient item in a display (Wolfe, 2021). In the initial processing stages, attention may be guided entirely by bottom-up saliency even when an item is a clear distractor (Theeuwes, 2010; Lagroix, Yanko & Spalek, 2018). The priority map changes to guidance based on top-down influences on task goals and representations of the target held in memory. Items that make it through the bottleneck are stored as representations in working memory where they can be assessed as to whether they match the target template held in long-term memory and working memory. Acceptance/rejection of items is guided through an asynchronous diffusion process, where evidence is accumulated for each item until it reaches a threshold for a decision (Ratcliff, Smith, Brown, & McKoon, 2016). Another diffuser concurrently accumulates toward the ceasing of search based on whether the target is successfully located or if enough evidence points to the target being absent (Wolfe, 2021). Thus pop-out searches are those in which the target is the most visually salient item, allowing rapid identification without attentional demands. Displays that lack this strong bottom-up saliency have relatively greater top-down influence on the priority map. Consequently, increasing the number of distractor items in pop-search leads to very little change in search RT, whereas serial search RT tends to increase at a linear rate with each additional item (Buetti, Xu, & Lleras, 2019).

Using this serial/pop-out search distinction, we can create two visual search tasks that either demand the deployment of attention or that do not require focused attention. To this end, the present study embeds serial and pop-out visual search displays into an item-method DF paradigm following instructions to remember or forget. From the visual search literature, we can predict that serial search demands the deployment of attention resources in and so will always have slower RT than pop-out search. Should F instructions lead to a withdrawal of attention that makes limited capacity resources relatively unavailable, this should increase the time needed to perform this attention-demanding serial search but have relatively little influence on the time needed to perform pop-out search (because pop-out search does not depend on focused attention). Accordingly, we expect a *magnification* of this serial>pop-out RT difference on F trials compared to R trials.

For each level of memory instruction (i.e., R trials or F trials), assessing this serial>pop-out RT difference allows us to measure directly the relative availability of attention while holding constant all other trial parameters: indeed, the only thing that distinguishes search trials is whether the target is presented amongst distractors that prompt an attention-demanding serial search or amongst distractors that allow for a less demanding pop-out search. By using this serial>pop-out RT difference to compare F trials to R trials, we are able to isolate differences in attentional availability in the post-instruction interval, while controlling for all other processes that might otherwise occur (i.e., because such processes — e.g., stopping maintenance rehearsal, retrieving and cumulatively rehearsing preceding-trial R items — would presumably be initiated by the instruction itself and therefore occur regardless of whether the subsequent target requires serial or pop-out search).[1].

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[1] One other known study embedded a visual search into a DF paradigm, but its design substantially differed from previously discussed item-method DF, due to using simple shapes as both memory objects and stimuli in search tasks (Sasin, Morey, & Nieuwenstein, 2017). Furthermore, a recognition test was presented at the end of each *trial* and only when R instructions were given, meaning participants did not need to hold R items in long-term rehearsal for a post-study phase test. Thus, our present study is the first to use visual search to assess attentional availability following memory instructions in an item-method DF paradigm

In five experiments, we presented participants with an item-method DF paradigm in which a visual search task followed the instruction to remember or forget. This visual search task required participants to report the orientation of a target letter “E” as either normal or mirror reversed. On serial trials, this target was embedded amongst normal and mirror-reversed letter “F” distractors; on pop-out trials, this target was embedded amongst “O” distractors. We were primarily interested in knowing whether the serial>pop-out RT difference that otherwise distinguishes these two search types would be magnified on F compared to R trials, as would be predicted by the view that attention is withdrawn following an instruction to forget. However, to allow for the possibility that this attentional withdrawal might be location-specific (i.e., withdrawn from the location of the F item representation held in working memory; e.g., see Taylor, 2005), Experiments 1 and 2 also manipulated the location of the target relative to the study word (same, different). Experiments 3 and 4 eliminated this manipulation of location. Experiment 5 altered the stimulus timing parameters and the modality of the memory instruction. To anticipate our results, all of our experiments replicated the expected memory (R>F) and search (serial slower than pop-out) findings. However, none of these experiments provided evidence of the critical interaction of memory instruction and visual search type in measures of search RT.

Chapter 2: Experiment 1

Experiment 1 embeds two visual search tasks (serial and pop-out) within the study phase of an item method-directed forgetting task. Study words are presented to the left and right of a central fixation stimulus followed by instructions to remember or forget an item and then by a visual search display requiring serial or pop-out search. The search target appears in either the same location as the study word or in a different location. For both search types, the search target is a normal or mirror-reversed letter ‘F’ that appears above, below, left, or right of the central fixation stimulus. Participants are required to make a speeded button-press to report the orientation of this target. On serial trials, the target is presented amongst normal and mirror-reversed letter Es; on pop-out trials, the target is presented amongst letter Os. After all study trials have been presented, a yes-no recognition test is used to assess memory of R and F items.

Performance on the recognition test will be used to confirm a DF effect, with better recognition for R items compared to F items. Serial search is more demanding on attention than pop-out and should therefore result in a serial > pop-out difference on search RTs in the study phase. We hypothesized that if intentional forgetting makes limited capacity attentional resources relatively less available compared to remembering, this should influence serial search more than pop-out, such that there will be a magnification of the RT difference between serial and pop-out searches on F compared to R trials. This would be reflected in a two-way interaction between Memory Instruction and Search Type. Moreover, if the withdrawal of attention on F compared to R trials is specific to the study item location, this magnification of the serial versus pop-out difference on F compared to R trials should occur only when the search target appears at the same location as the study word rather than a different location. This would be reflected in a three-way interaction between Memory Instruction, Search Type, and Word-Target Location.

2.1 Methods

2.1.1 Participants

A total of 71 undergraduate students enrolled at Dalhousie University participated in the experiment in exchange for course credit awarded through the SONA-systems interface. Participants completed the experiment online through Pavlovia with the experiment lasting no more than an hour. Participants were asked to take part in the study only if they had normal or corrected-to-normal vision, had not previously taken part in DF research, and could complete the study on a computer that had reliable internet access and a physical keyboard.

2.1.2 Materials and Apparatus

PsychoPy 3.0 Builder interface (Peirce, Hirst, & MacAskill, 2022) was customized with additional Python code and then used to generate Javascript that was used to control stimulus presentation and to record key presses and RT. The experiment was preceded by a consent form with a gray background and white text. All experimental stimuli were presented on a black background. The central fixation stimulus used consisted of a white cross. Study and recognition test words were presented in white text. The R instructions were given via a string of 3 green diamonds (<><><>) and F instructions via a string of 3 red Xs (><><><).

For the memory task, a pool of 576 nouns were generated using the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1987). From this pool, 128 words were selected to appear in the study phase with 64 designated as R items and 64 as F items. The selection of the study words from the word pool and their order of presentation was randomized for every participant. During the test phase, an additional 128 words were randomly selected to serve as unstudied foils.

For the visual search task, a target letter F was presented in either normal or mirror-reversed orientation in an 8-item circular display centered around fixation, with the 7 non-target locations occupied by distractor letters. The distractors were either Es in normal and mirror-reversed orientations in serial search or letter Os in pop-out search. All eight stimulus locations in the search array were equally spaced around an invisible circle centered on the fixation stimulus. The radius of the circle was set to 0.4 height units[2] (hu) in PsychoPy with stimuli occupying positions at 0, 45, 90, 135, 180, 225, 270, and 315 degrees of angle. All letter stimuli used in the visual search tasks were colored orange.

2.1.3 Procedure

Participants were instructed on the tasks required for the experiment through on-screen text. Participants were told the meaning of the visually presented memory instructions and that they would be given a memory test following the study phase. They were also told that they would complete a speeded target task requiring them to report the orientation of a letter F among distractor letters as being normal or mirror-reversed and that key responses would be timed and recorded. Participants were not explicitly told

[2] Height units are measured as a proportion of the size of the window.

Experiments 1 & 2: Peripheral Word

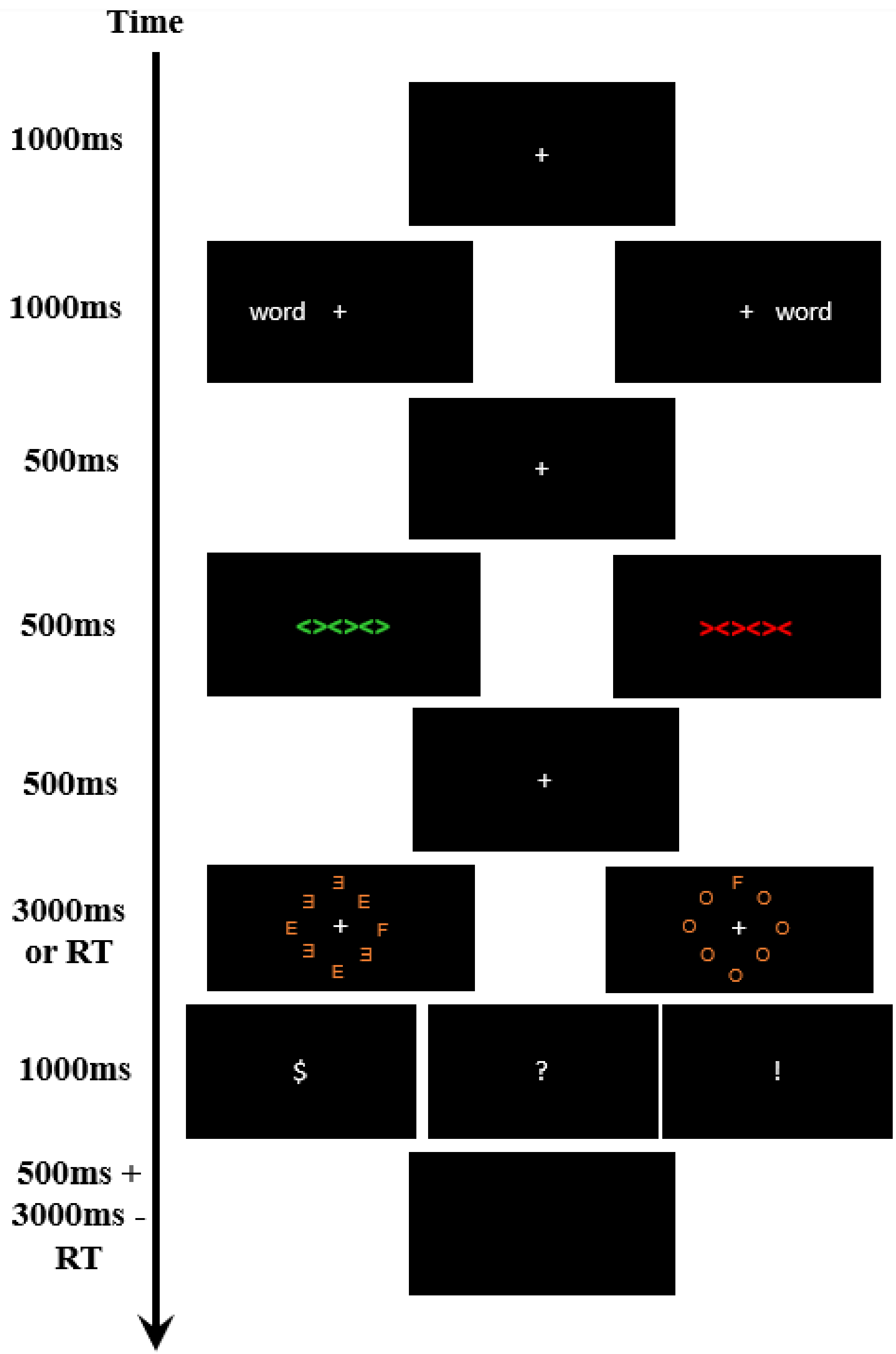

Figure 1. Graphical depiction of the progression of study phase trials for Experiments 1 and 2.

until after they completed the study phase that the memory task would include F items.

Practice trials

Before the study trials, participants completed a set of 10 practice trials that were drawn randomly from study phase conditions to familiarize participants with responding to the visual search tasks and the general presentation of the study trials. These practice trials were identical to the study trials, except that the word '*word'* appeared on each practice trial instead of a new word each time and participants were therefore not required to follow the memory instructions.

Study trials

The study phase procedure is summarized in **Figure 1.** Each study trial began with the presentation of a central fixation cross for 1000ms. Then, a study word appeared to the left of fixation on a random half of trials and the right on the other half and remained visible for 1000ms. Following a 500ms delay, the fixation stimulus was replaced with equal probability by either an R (green <><><>) or F (red ><><><) instruction, that remained visible for 500ms before being replaced by the fixation stimulus. After another 500ms delay, the visual search display appeared, consisting of a normal or mirror-reversed target F placed among 7 letter Os in the pop-out search condition or among 7 letter Es that were displayed in randomized normal and mirror-reversed orientation in the serial search condition. Serial and pop-out search displays appeared in a randomized order on an equal number of trials, with both orientations of the F target (normal and mirror-reversed) appearing an equal number of times for each type of visual search. The F target appeared randomly in one of four locations (directly left, right, above, or below fixation)[3] with equal probability. Participants were required to respond with a press of ‘n’ or ‘m’ on the keyboard if the F target was in normal or mirror-reversed orientation, respectively. Participants were told to place their right index finger on the ‘n’ key and their right middle finger on the ‘m’ key during the study phase trials. Valid responses (i.e. ‘n’ or ‘m’) to the search task were required to be given within 3000ms before the search timed out. Visual feedback was presented for 1000ms in place of the fixation stimulus, to indicate whether the response was correct ($), incorrect (!), or timed out (?). The study trial ended with a blank interval whose duration was set to ensure the total trial duration was always fixed at 8000ms. A total of 128 study trials were run per participant.

Test trials

After all words were presented in the study phase, participants were given a yes-no recognition test, on which a total of 256 words was presented one at a time in a randomized order: 64 R items from the study phase, 64 F items from the study phase, and 128 unstudied foil words. Participants were instructed to respond “y” (yes) to all words that they recognized from the study phase and “n” (no) to those they did not,

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[3] Study words only appeared in two locations to reduce the number of study and test phase trials. To counterbalance four study word locations, a total of 256 study trials would have been necessary requiring the rehearsal of 128 R items. This was deemed to be too demanding of participants. Thus, two study word locations still allowed for the assessment of word-target location on RT while cutting the rehearsal set by half. At the same time, we chose to use four target locations to ensure participants had greater uncertainty as to where the search target would appear in the display. Leaving only two locations would have undermined the demandingness of the task.

regardless of the memory instruction. A visual reminder of the meaning of the "y" and "n" key presses remained visible during all test trials and participants were given unlimited time to make a response. Once the test phase concluded, participants received a written debriefing and were encouraged to follow up with the experimenter through e-mail should they have any questions about the study.

2.2 Results

The study was conducted as a 2 (Memory instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Study Word Location: left, right) × 4 (Search Target Location: left, right, above, below) × 2 (target orientation: normal, mirror reversed) within-subjects design. For, analysis the design was reconceptualized as a 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) within-subjects design. Of the 71 participants that completed Experiment 1, 8 participants were removed upon request that their data not be included in analysis, opting to be observers rather than participants of the study. Data from participants whose average search accuracies were below 50% and for whom False Alarm (FA) rates on the recognition test were >2 standard deviations above the mean of all participants were excluded. Data from 2 participants met the exclusionary criteria, leaving a final sample size of 61 participants for analysis. To complete the online study, 38 participants used an Intel Macintosh computer, and 23 participants used a Windows 32-bit machine. The frame rates (FR) of the participants' operating systems are provided in **Table 1**.

Table 1. The number (N) of participants who performed Experiment 1 under recorded frame rates (FRs) for each operating system. All FRs are reported in Hz.

Operating System	FR	N
Intel Macintosh	60	38
Windows 32-bit	60	23
	74	1
	122	1
	144	1

2.2.1 Recognition Test Performance

Recognition test performance was calculated as a proportion of yes versus no responses. This represents hits for remember and forget items and false alarms for foil words. Recognition test data are summarized in **Table 2.** A one-way repeated measures analysis of variance (ANOVA) compared accuracy for R, F, and foil items. A significant difference was found between the three word types in accuracy on the yes-no recognition test, $F(2, 120) = 100$, $p < .001$, $\eta^2_p = .63$. Confirming a DF effect, recognition hits were higher for R words and than F words, $t(60) = 6.94$, $p < .001$, $d = 0.88$. Forget hits were also significantly higher than foil false alarms (FAs), $t(60) = 10.71$, $p < .001$, $d = 1.37$. See **Appendix A** for an analysis of recognition performance for R and F items with respect to search type and word-target location.

Table 2. The mean proportions of 'yes' responses on the yes-no recognition test for remember, forget and foil words in Experiment 1. SE refers to the Standard Error of the mean.

Memory Instruction	M	SE
Remember	0.59	0.022
Forget	0.43	0.020
Foil	0.23	0.022

2.2.2 Visual Search Response Times

When calculating mean RT for correct search trials, means and standard deviations (SDs) for serial and pop-out search RT were first calculated for each participant. Pop-out search trials which were +/- 2 SDs above or below the participant's average pop-out search RT were excluded from analysis as errors. Likewise, serial search trials which were +/- 2 SDs above or below the participant's average serial search RT were excluded from analysis as errors – being seen as an indication of anticipatory responses or inattentiveness to the search task. Applying these restrictions led to an average of 6% of pop-out trials and 6% of serial trials excluded from the calculations of mean visual RT. On the remaining trials, only those on which the orientation of the search target was accurately identified were included in the calculation of mean search RT.

A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) repeated-measures ANOVA was conducted on mean RT. Visual search RTs are summarized in **Figure 2.** Memory Instructions had no significant main effect on RT, $F(1, 60) = 1.76$, $MSe = 11020$, $p = .19$, $\eta^2_p = .028$. There was, however, a main effect of Search Type, $F(1, 60) = 232.94$, $MSe = 41554$, $p < .001$, $\eta^2_p = .80$, with overall slower RT on serial search trials ($M = 1166$ms, $SE = 37.1$) than pop-out search trials ($M = 884$ms, $SE = 27.0$). There was no significant main effect of Word-Target Location, $F(1, 60) = 3.27$, $MSe = 11005$, $p = .08$, $\eta^2_p = .05$.

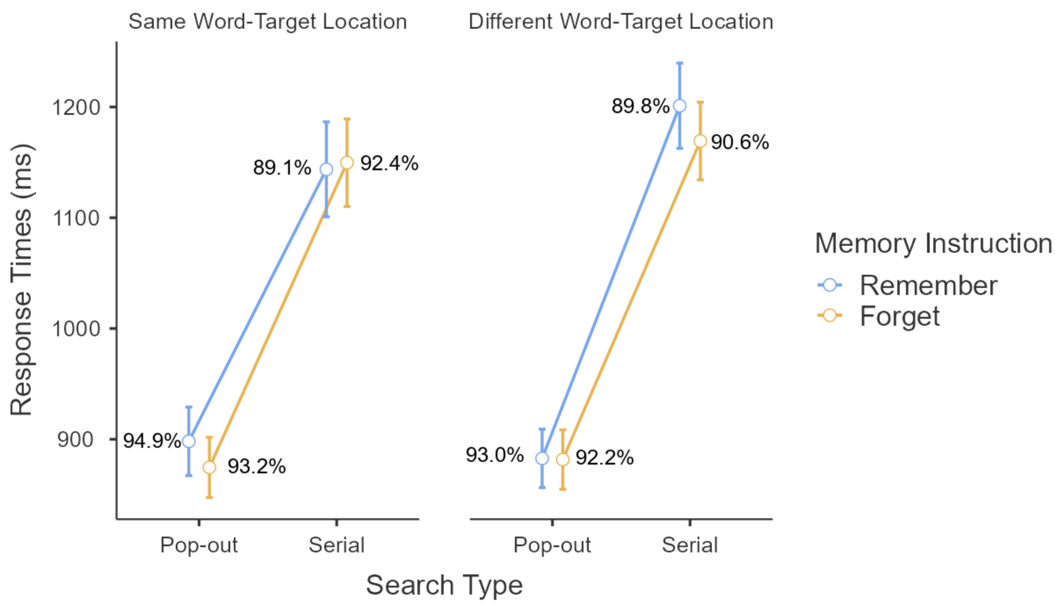

Figure 2. Mean search target RT in milliseconds on serial and pop out searches after R and F instructions for Experiment 1. Trial targets appearing in the same location are depicted on the left and trials appearing in a different location on the right. Error bars represent one standard error of the mean. Percentages represent search accuracy for the adjacent condition.

The critical two-way interaction between Memory Instruction and Search Type was not significant, $F(1, 60) = 0.002$, $MSe = 5975$, $p = .97$, $\eta^2_p = .00$, nor were the two-way interactions between Memory Instruction and Word-Target Location, $F(1, 55) = 0.38$, $MSe = 10135$, $p = .54$, $\eta^2_p = .006$. There was, however, a significant interaction between Search Type and Word-Target Location, $F(1, 60) = 8.27$, $MSe = 11026$, $p <. 01$, $\eta^2_p = .12$, with overall faster RTs on Serial searches when the target appeared in the same location as the study word ($M = 1147$ms, $SE = 39.6$) compared to when the target appeared in a different location ($M = 1186$ms, $SE = 36.1$), $t(60) = 2.52$, $p < .05$, $d = 0.20$.

There was a significant 3-way interaction between Memory Instruction, Search Type and Word-Target Location, $F(1, 60) = 4.32$, $MSe = 6413$, $p <. 05$, $\eta^2_p = .07$, but this was not in the expected direction. Whereas we predicted that serial > pop-out search

RT might be magnified for F compared to R trials, particularly when the search target appeared in the same location as the study item rather than a different location, this is not what we found. To better understand this three-way interaction, we calculated on a participant-by-participant basis the difference in serial versus pop-out search RT for R and F trials, separately for same and different word-target locations. Paired sample t-tests were used to compare this serial versus pop-out RT difference on R versus F trials. When the search target appeared in the same location as the study word, the serial>pop-out search difference was not distinguishable on R compared to F trials, $t(60) = 1.21$, $p = .23$, $d = 0.16$. In other words, contrary to our prediction, we did not find the serial>pop-out difference to be significantly larger on F ($M = 275$ms, $SE = 25$) compared to R trials (M = 245ms, $SE = 26$) as would have been expected if F instructions caused a location-based withdrawal of attention. Instead, we found an unexpected significant, albeit small, effect of memory instruction (R, F) on the serial>pop-out difference when the search target appeared in a different location than the study word, $t(60) = 2.09$, $p < .05$, $d = 0.27$. This effect reflected a *smaller* serial>pop-out difference on F trials, ($M = 288$ms, $SE = 19$) compared to R trials ($M = 318$ms, $SE = 18$).

2.2.3 Visual Search Accuracy

Search accuracy was calculated as a percentage of correctly identified search targets on trials with RTs that were within +/- 2 SDs of the serial search and pop-out search means for each participant. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) repeated-measures ANOVA was conducted on search accuracy, which is summarized as percentages in **Figure 2.** There was no significant main effect of Memory Instruction on search accuracy, $F(1, 60) = 0.66$, $MSe = 33.9$, $p = .42$, $\eta^2_p = .01$. Countering any concerns about speed-accuracy trade-offs in search performance, there was a significant main effect of Search Type, $F(1, 60) = 7.64$, $MSe = 129.8$, $p < .01$, $\eta^2_p = .11$, with overall lower accuracy on the slower serial search trials ($M = 90.5$, $SE = 1.6$) than the faster pop-out search trials ($M = 93.3$, $SE = 1.2$). There was no significant main effect of Word-Target Location, $F(1, 60) = 3.01$, $MSe = 40.78$, $p = .09$, $\eta^2_p = .05$.

There was a significant two-way interaction between Memory Instruction and Search Type, $F(1,60) = 6.80$, $MSe = 49.2$, $p < .05$, $\eta^2_p = 0.10$. Serial search accuracy was higher on F trials ($M = 91.5$, $SE = 1.6$) compared to R trials ($M = 89.4$, $SE = 1.8$), $t(60) = 2.19$, $p < .05$, $d = .32$. There were no significant two-way interactions between Memory Instruction and Word-Target Location, $F(1, 60) = 0.48$, $MSe = 39.6$, $p = .49$, $\eta^2_p = .008$, nor between Search Type and Word-Target Location, $F(1, 60) = 0.61$, $MSe = 36.2$, $p = .44$, $\eta^2_p = .01$. There was also no significant three-way interaction between Memory Instruction, Search Type, and Word-Target Location, $F(1, 60) = 1.53$, $MSe = 51.3$, p = .22, $\eta^2_p = .03$.

2.3 Discussion

The recognition test showed a classic DF effect, with a higher proportion of R item hits compared to F item hits. The mean RT for serial searches were slower than for pop-out searches. These findings make us confident that participants correctly followed memory instructions and that our serial search was in fact more attentionally demanding than our pop-out search. Nevertheless, when we tested for interactions between memory instruction, search type, and word-target location in RT, we did not confirm our predictions. We hypothesized that if attention is withdrawn following an F instruction, an attention-demanding serial search would be particularly influenced by the relative unavailability of attention resources. We expected this to magnify the serial>pop-out difference in RTs on F trials compared to R trials. To the extent that the attentional withdrawal was based on item location, we reasoned that this magnification might occur when the search target appeared in the same location as the study item but not when the locations differed.

However, we did not observe the critical interaction between memory instruction and search type and, while there was a three-way interaction of memory instruction, search type and word-target location, it was not in the predicted direction. Rather, the three-way interaction revealed a magnified serial>pop-out difference on R compared to F trials where the study word and search target locations differed but *not* when they were the same. Effectively, this result is the *opposite* of what was predicted by our hypothesis of attentional withdrawal from an F item and its location in space.

Before considering these results any further, we thought it worthwhile to conduct an in-person replication of the Experiment 1 procedure. Our reasoning was that participants may be prone to distraction when performing the study in an online environment. Given that the published literature that informed our study used in-person data collection exclusively, we thus wanted to ensure that our online presentation did not affect the validity of the results. Accordingly, we will defer further discussion of Experiment 1 results until after Experiment 2.

Chapter 3: Experiment 2

The interaction we found in Experiment 1 was in the opposite direction of what was hypothesized: the serial>pop-out difference was magnified for R trials compared to F trials when word-target location differed compared to when it was the same, whereas we predicted the serial>pop-out difference to be magnified on F trials compared to R trials when the word-target location was the same compared to when it was different. To determine whether the results of our online presentation of the DF search paradigm were replicable, an in-person version of Experiment 1 was conducted. We hypothesized again that should F instructions lead to a withdrawal of attention from the study item, a magnified difference of RT between serial and pop-out searches should occur following F instructions compared to R instructions. Furthermore, if this withdrawal is location specific, the magnified serial versus RT difference on F compared to R trials should appear when the word-target location is the same rather than different.

3.1 Methods

3.1.1 Participants

A total of 44 undergraduate students enrolled at Dalhousie University participated in the experiment in exchange for course credit awarded through the SONA-systems interface. Participants completed the experiment in-person with the experiment lasting no more than an hour. Participants were asked to take part in the study only if they had normal or corrected-to-normal vision, had not previously taken part in directed forgetting research, and could respond to stimuli quickly with a press on a physical keyboard.

3.1.2 Materials & Procedure

All materials were the same as those used in Experiment 1. The procedure differed only in that an experimenter[4] was present during the reading of instructions, practice trials, and debriefing, allowing participants to ask any clarifying questions throughout the experiment. The rest of the procedure was identical to Experiment 1.

3.2 Results

Data from participants whose search accuracies were below 50% and for whom False Alarm rates on the recognition test were >2 standard deviations above the mean of all participants were excluded. Data from 3 participants met these criteria, leaving a final sample size of 41 participants for analysis. To complete the in-person study, participants used an Intel Macintosh computer provided in the lab with an FR of 60 Hz.

3.2.1 Recognition Test Performance

Recognition test performance was calculated as a proportion of yes versus no responses. This represents hits for remember and forget items and false alarms for foil words. Recognition test data are summarized in **Table 3.** A one-way repeated measures

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[4] Experiment 2 data were collected independently by Olivia Eisnor for completion of her undergraduate honours thesis. All reported analyses and discussion of the data in the current thesis were completed separately.

ANOVA compared the proportion of "yes" responses between R, F, and foil words. A significant difference in "yes" responses was found between the three word types on the yes-no recognition test, $F(2,80) = 184$, $p <.001$, $\eta^2_p = .82$. Recognition hits were higher for R words and than F words, $t(40) = 8.22$, $p < .001$, $d = 1.28$. Forget hits were significantly greater than foil false alarms, $t(40) = 12.15$, $p < .001$, $d = 1.90$. See **Appendix B** for an analysis of recognition performance for R and F items with respect to search type and word-target location.

Table 3. The mean proportion of 'yes' responses on the yes-no recognition test for remember, forget, and foil words in Experiment 2.

Memory Instruction	M	SE
Remember	0.64	0.03
Forget	0.41	0.03
Foil	0.12	0.02

3.2.2 Visual Search Response Times

When calculating mean RT for correct search trials, means and SDs for serial and pop-out search RT were first calculated for each participant. Pop-out search trials which were +/- 2 SDs above or below the participant's average pop-out search RT were excluded from analysis as errors. Likewise, serial search trials which were +/- 2 SDs above or below the participant's average serial search RT were excluded from analysis as errors. Applying these restrictions lead to an average of 5% of pop-out trials and 5% of serial trials to be excluded from the calculations of mean visual RT. On the remaining trials, only those on which the orientation of the search target was accurately identified were included in the calculation of mean search RT.

A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2(Word-Target Location: Same, Different) repeated-measures ANOVA was conducted on RT for correctly identified search targets. Visual search RTs are summarized in **Figure 3.** Memory Instructions had no significant main effect on RT, $F(1, 40) = 0.28$, $MSe = 6923$, $p = .60$, $\eta^2_p = .01$. There was no significant main effect of Memory Instruction, $F(1,40) = 0.27$, $MSe = 6923$, $p = .60$, $\eta^2_p = .01$. There was however a significant main effect of Search Type, $F(1,40) = 248.21$, $MSe = 11469$, $p < .001$, $\eta^2_p = .86$, with overall slower RT on serial search trials ($M = 995$ms, $SE = 28$) than on pop-out search trials ($M = 809$ms, $SE = 23$). There was no significant main effect of Word-Target Location, $F(1, 40) = 1.48$, $MSe = 3300$, $p = .23$, $\eta^2_p = .11$.

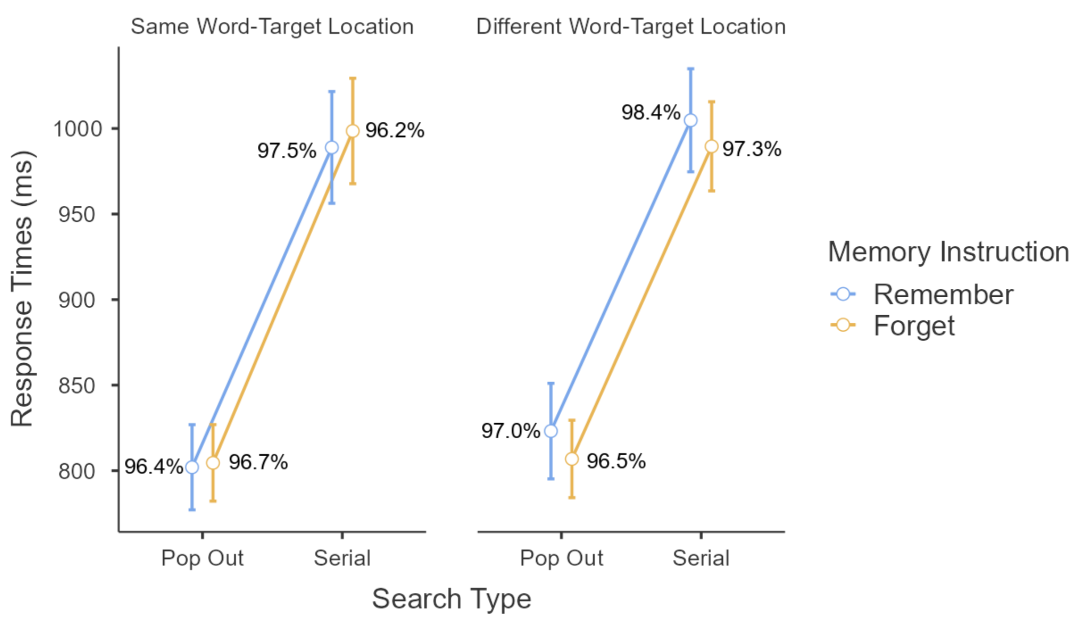

Figure 3. Mean search target RTs in milliseconds for serial and pop out searches after R and F instructions for Experiment 2. Trial targets appearing in the same location are depicted on the left and trials appearing in a different location on the right. Error bars represent one standard error of the mean. Percentages represent mean search accuracies for the adjacent conditions.

There were no significant two-way interactions – not for the critical interaction between Memory Instruction and Search Type interaction, $F(1, 40) = 0.84$, $MSe = 4008$, $p = .77$, $\eta^2_p = .00$, for the interaction between Memory Instruction and Word-Target Location, $F(1, 40) = 3.56$, $MSe = 2749$, $p = .07$, $\eta^2_p = .08$, or for the interaction between Search Type and Word-Target Location, $F(1, 40) = 0.36$, $MSe = 4565$, $p = .55$, $\eta^2_p = .01$. Unlike in Experiment 1, the three-way interaction between Memory Instruction, Search Type, and Word-Target Location was also not significant, $F(1, 40) = 0.04$, $MSe = 4413$, $p = .84$, $\eta^2_p = .00$.

3.2.3 Visual Search Accuracy

Search accuracy was calculated as a percentage of correctly identified search targets on trials with RTs that were within +/- 2 SDs of the serial search and pop-out search means for each participant. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) repeated-measures ANOVA was conducted on search accuracy, which is summarized as percentages in **Figure 3.** There was no significant main effect of Memory Instruction on search accuracy, $F(1, 40) = 0.97$, $MSe = 30.3$, $p = .33$, $\eta^2_p = .02$, no significant main effect of Search Type, $F(1,40) = 0.98$, $MSe = 39.7$, $p = .33$, $\eta^2_p = .02$, and no significant main effect of Word-Target Location, $F(1,40) = 1.29$, $MSe = 22.0$, $p = .26$, $\eta^2_p = .03$.

There were no significant two-way interactions between Memory Instruction and Search Type, $F(1,40) = 1.11$, $MSe = 22.5$, $p = .30$, $\eta^2_p = .03$, between Memory Instruction and Word-Target Location, $F(1,40) = 0.07$, $MSe = 27.2$, $p = .80$, $\eta^2_p = .00$, or between Search Type and Word-Target Location, $F(1,40) = 0.44$, $MSe = 30.0$, $p = .51$,

η^2_p = .01. There was no significant three-way interaction between Memory Instruction, Search Type, and Word-Target Location, $F(1,40) = 0.16$, $MSe = 34.8$, $p = .69$, $\eta^2_p = .00$.

3.3 Discussion

Experiment 2 replicated the methods of Experiment 1 with an experimenter verbally guiding the participant through instructions in an in-person lab setting. This was motivated by concerns that the online format of Experiment 1 might have made participants more prone to distraction and less engaged with this challenging experiment than if they participated in a controlled environment. Concerns over the reliability of the Experiment 1 data were particularly acute, given that Experiment 1 showed a three-way interaction in a direction that was opposite of our predictions (i.e. serial>pop-out search was magnified on R compared to F trials when targets appeared in a different location from the study word rather than in the same location). However, this unexpected — and largely inexplicable — 3-way interaction in Experiment 1 was not replicated in Experiment 2, suggesting that the Experiment 1 finding was neither robust nor meaningful. Indeed, the only significant factor influencing search RT in Experiment 2 was search type, with serial>pop-out RT: There was no evidence that this difference was magnified on F trials compared to R trials, whether the target appeared in the same or a different location relative to the study word (see **Appendix C** for a formal comparison of Experiments 1 and 2).

As a reminder, our hypothesis was that if F instructions lead to a withdrawal of attention from the study item, this should be revealed as a greater serial>pop-out difference in RT following F compared to R instructions. Experiments 1 and 2 tested this critical interaction of memory instruction and search type, while also manipulating word-target location to allow for the possibility that attentional withdrawal might be location-specific. Importantly, however, word-target location did not have a main effect on RT in either experiment and did not enter into a robust, meaningful, or replicable 3-way interaction that would suggest a location-specific withdrawal of attention. Considering this, we decided to simplify the experiment by removing the manipulation of word-target location and, instead, presenting all study words at centre. By maintaining the same number of study trials, this change to a central word presentation allowed us to increase the number of search RTs per cell of the design, while also reducing the performance demands on participants: Whereas in Experiments 1 and 2 participants had to read a peripheral study word, interpret a central memory instruction, and then respond to a peripheral search target, by removing location as a factor, participants could remain focused at centre until the search target was presented. This modification was first run online (Experiment 3) and then replicated in-person (Experiment 4).

Chapter 4: Experiment 3

Our primary interest in incorporating a visual search task into the study trials of an item-method DF paradigm was to determine whether a withdrawal of attention from the study item follows an instruction to forget. We predicted that if such a withdrawal occurs, there would be a greater serial>pop-out RT difference following F compared to R instructions. Experiments 1-2 manipulated whether study items and search targets appeared in the same or different locations to determine whether attentional withdrawal might be location specific. However, the two-way interaction of memory instruction and search type was considered central to our hypothesis, making the spatial components of secondary interest. In any case, there was no strong evidence to suggest that there is a location specific withdrawal of attention following F instructions. Accordingly, Experiment 3 eliminated the manipulation of word-target location by presenting study words at center rather than in locations peripheral to center fixation. Keeping the same number of trials while simplifying the experimental design from 3 factors to 2 factors improves the chance of detecting the critical interaction between memory instruction and search type, should it exist. Furthermore, it allows us to determine whether memory instruction influences the allocation of attention for use in search even when targets never appear at the same location as the study item. We hypothesized that should attention be left relatively less available following F compared to R instructions, the serial>pop-out difference should be magnified.

4.1 Methods

4.1.1 Participants

A total of 72 students enrolled at Dalhousie University participated in the experiment in exchange for course credit awarded through the SONA-systems interface. Participants completed the experiment online through Pavlovia with the experiment lasting no more than an hour. Participants were asked to take part in the study only if they had normal or corrected-to-normal vision, had not previously taken part in directed forgetting research, and could complete the study on a computer that had reliable internet access and a physical keyboard.

4.1.2 Materials & Procedure

All materials and procedures were the same as those used in Experiment 1. The procedure differed only in that the study item appeared at center, replacing the central fixation stimulus rather that appearing to one of two peripheral locations. This removed the possibility for study items and search targets to appear in the same location. The procedure is summarized in **Figure 4.**

4.2 Results

Of the 72 participants who completed Experiment 3, 13 participants were removed upon request that their data not be included in analysis, opting to be observers rather than participants of the study. Data from remaining participants whose average search accuracies were below 50% and for whom FA rates on the recognition test were >2 standard deviations above the mean of all participants were excluded. Data from 2

Experiment 3 & 4: Central Word

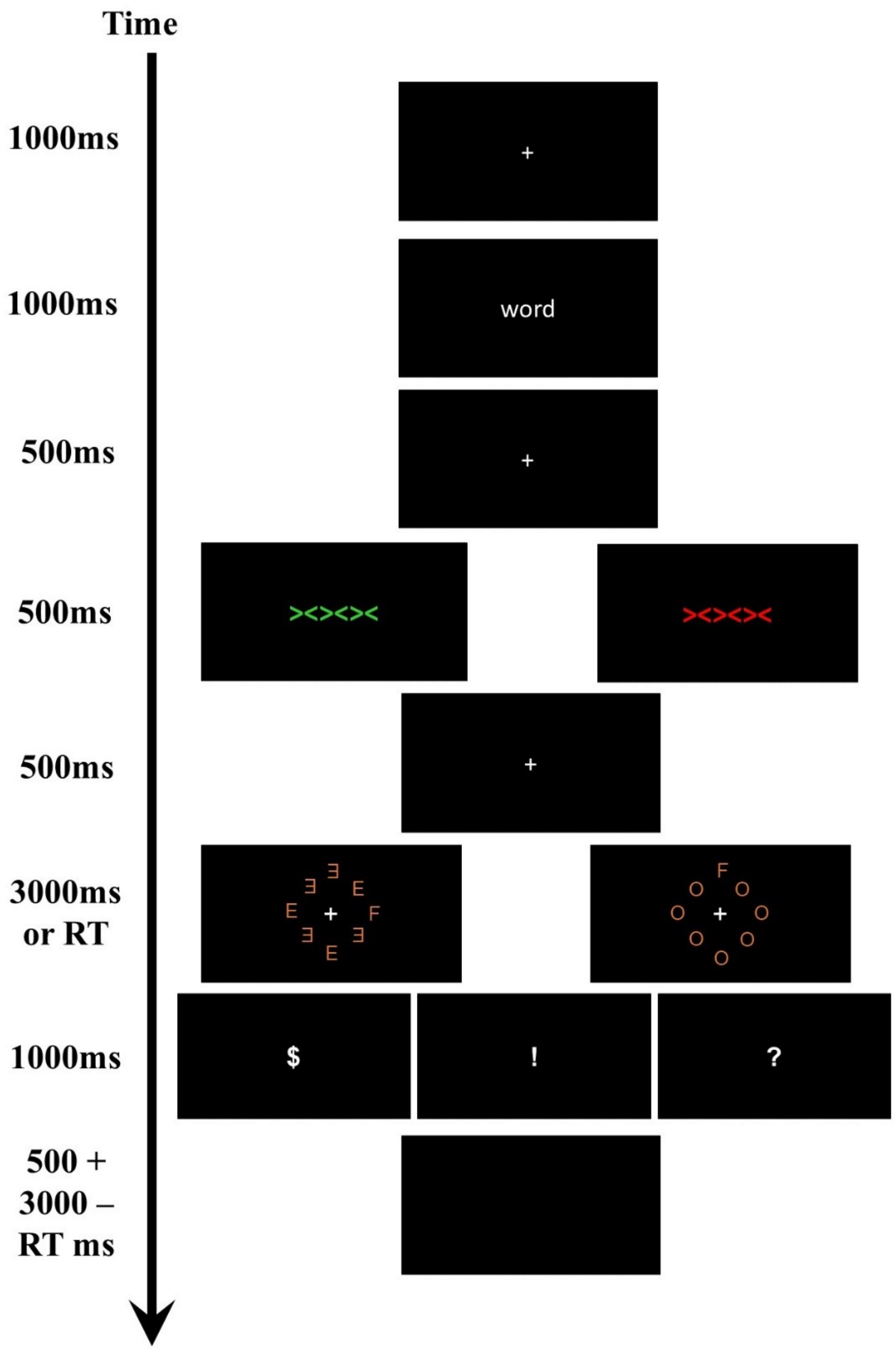

Figure 4. Graphical depiction of the progression of study phase trials for Experiments 3 and 4. Depicted stimuli are not to scale with those used in the experiment.

participants met the exclusionary criteria, leaving a final sample size of 56 participants for analysis. To complete the online study, 29 participants used an Intel Macintosh computer, and 27 participants used a Windows 32-bit machine. The frame rates (FR) of the participants' operating systems are provided in **Table 4**.

Table 4. The number (N) of participants who performed the experiment under recorded FRs for each operating system. All FRs are reported in Hz.

Operating System	FR	N
Intel Macintosh	40	1
	50	1
	60	26
	70	1
Windows 32-bit	40	1
	60	23
	140	2
	165	1

4.2.1 Recognition Test Performance

Recognition test performance was calculated as a proportion of yes versus no responses. This represents hits for remember and forget items and false alarms for foil words. Proportion data are summarized in **Table 5.** A one-way repeated measures ANOVA compared proportion yes responses for R, F, and foil items. A significant difference was found between the three word types in proportion "yes" responses on the yes-no recognition test, $F(2,110) = 181$, $MSe = 0.0134$, $p < .001$, $\eta^2_p = .77$. Recognition hits were higher for R words and than F words, $t(55) = 9.11$, $p < .001$, d = 1.40, consistent with a classic DF effect, and F hits were significantly greater than foil false alarms , $t(55) = 12.54$, $p <. 001$, d = 1.87. See **Appendix D** for an analysis of recognition performance for R and F items with respect to search type.

Table 5. The mean proportion of 'yes' responses on the yes-no recognition test for remember, forget, and foil words in Experiment 2.

Memory Instruction	M	SE
Remember	0.60	0.027
Forget	0.41	0.028
Foil	0.19	0.028

4.2.2 Visual Search Response Times

When calculating mean RT for correct search trials, means and SDs for serial and pop-out search RT were first calculated for each participant. Pop-out search trials that were +/- 2 SDs above or below the participant's average pop-out search RT were excluded from analysis as errors. Likewise, serial search trials that were +/- 2 SDs above or below the participant's average serial search RT were excluded from the analysis as errors. Furthermore, only search trials for which the orientation of the search target was accurately identified were included in the calculation of mean search RT. On the remaining trials, only those on which the orientation of the search target was accurately identified were included in the calculation of mean search RT. Visual search RTs are summarized in **Figure 5.**

A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) repeated-measures ANOVA was conducted on mean RT. There was no significant main effect of Memory Instruction, $F(1,55) = 0.15$, $MSe = 2750$, $p = .90$, $\eta^2_p = .00$. There was however, a significant main effect of Search Type, $F(1,55) = 372.24$, $MSe = 12825$, $p < .001$, $\eta^2_p = .87$, with overall slower RT on serial search trials (M = 1169ms, SE = 32) than on pop-out search trials (M = 877ms, SE = 23). Contrary to our hypothesis, the

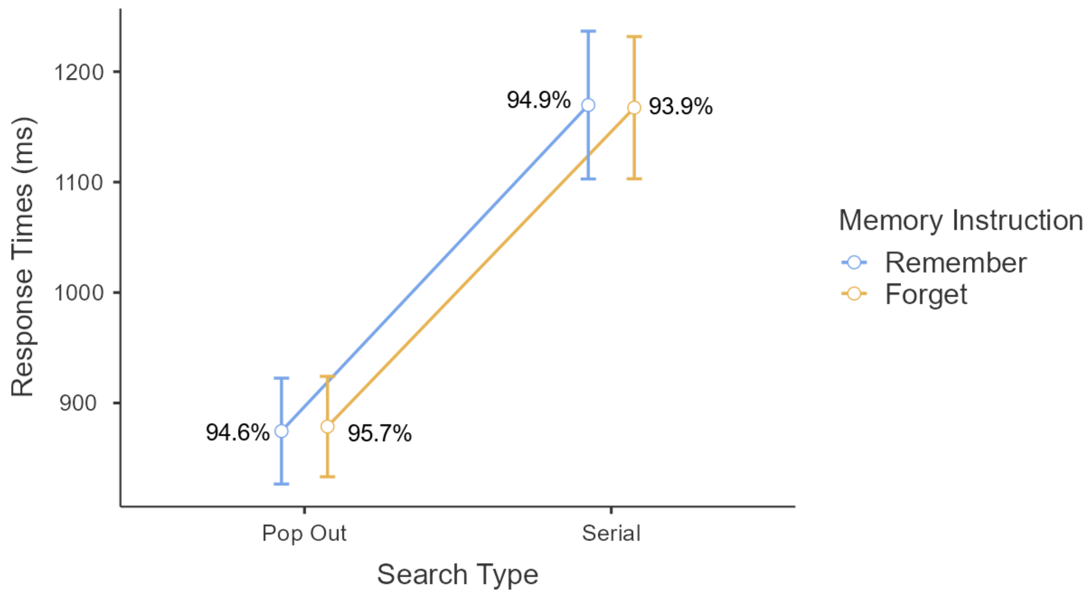

Figure 5. Mean search target RT in milliseconds on serial and pop out searches after R and F instructions for Experiment 3. Error bars represent one standard error of the mean. Percentages represent mean search accuracies for the adjacent conditions.

critical two-way interaction between Memory Instruction and Search Type failed to reach significance, $F(1, 55) = 0.30$, $MSe = 1951$, $p = .59$, $\eta^2_p = .01$.

4.2.3 Search Accuracy

Search accuracy was calculated as a percentage of correctly identified search targets on trials with RT that were within +/- 2 SDs of the serial search and pop-out search means for each participant. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: Same, Different) repeated-measures ANOVA was conducted on search accuracy, which is summarized as percentages in **Figure 5.** There was no significant main effect of Memory Instruction, $F(1,55) = 0.002$, $MSe = 25.65$, $p = 0.97$, $\eta^2_p = .00$, nor a main effect of Search Type, $F(1,55) = 1.17$, $MSe = 28.98$, $p = .28$, $\eta^2_p = .02$. There was also no significant two-way interaction between Memory Instruction and Search Type, $F(1, 55) = 3.12$, $MSe = 17.61$, $p = .08$, $\eta^2_p = .05$.

Discussion

Like the previous experiments, the recognition test showed a classic DF effect, with a higher proportion of R item hits compared to F item hits, as well as a mean RT for serial searches that was slower than for pop-out searches. Once again, we can be sure our serial search was more demanding than our pop-out search and that participants properly followed the memory instructions. Despite having simplified the DF search paradigm procedure by displaying the study word at center rather than to the left or right of center, the critical interaction of Memory Instruction and Search Type still was not significant.

To ensure results remained consistent between an online and in-person format, we decided to replicate Experiment 3 in-person as had been done with Experiments 1 and 2. Accordingly, we will post pone further discussion of Experiment 3 results until after the presentation of the Experiment 4 results.

Chapter 5: Experiment 4

In the same vein as Experiments 1 and 2, we replicated the central word presentation design of Experiment 3 in an in-person lab setting. This allowed us to determine whether there is any evidence of a significant critical interaction between memory instruction and search type an in-person experiment. Once again, we hypothesized that should F instructions lead to a withdrawal of attention from the study item, a magnified serial versus pop-out search RT difference would be revealed following F instructions compared to R instructions.

5.1 Methods

5.1.1 Participants

A total of 44 undergraduate students enrolled at Dalhousie University participated in the experiment in exchange for course credit awarded through the SONA-systems interface. Participants completed the experiment in-person with the experiment lasting no more than an hour. Participants were asked to take part in the study only if they had normal or corrected-to-normal vision, had not previously taken part in directed forgetting research, and could respond to stimuli quickly with a press on a physical keyboard.

5.1.2 Materials & Procedure

All materials were the same as those used in Experiment 3. The procedure differed only in that an experimenter[5] was present during the reading of instructions, practice trials, and debriefing, allowing participants to ask any clarifying questions throughout the experiment. The rest of the procedure was identical to Experiment 3.

5.2 Results

Data from participants whose average search accuracies were below 50% and for whom False Alarm (FA) rates on the recognition test were >2 standard deviations above the mean of all participants were excluded. Data from 3 participants met the exclusionary criteria, leaving a final sample size of 39 participants for analysis. To complete the in-person study, participants used an Intel Macintosh computer provided in the lab with an FR of 60 Hz.

5.2.1 Recognition Test Performance

Recognition test performance was calculated as a proportion of yes versus no responses. This represents hits for remember and forget items and false alarms for foil words. Recognition test data are summarized in **Table 6.** A one-way repeated measures ANOVA compared proportion yes responses for R, F, and foil items. A significant difference was found between the three word types in proportion yes responses on the yes-no recognition test, $F(2, 76) = 100$, $MSe = 0.015$, $p < .001$, $\eta^2_p = .88$. Confirming a

[5] Experiment 4 data were collected independently by Heather LeBlanc for completion of her undergraduate honours thesis. All reported analyses and discussion of the data in the current thesis were completed separately.

Table 6. The mean proportion of ‘yes’ responses on the yes-no recognition test for remember, forget, and foil words in Experiment 4.

Memory Instruction	M	SE
Remember	0.72	0.028
Forget	0.48	0.029
Foil	0.04	0.006

DF effect, recognition hits were higher for R words and than F words, $t(38) = 9.67$, $p < .001$, d = 1.55. Forget hits were also significantly higher than foil false alarms, $t(38) = 13.90$, $p < .001$, d = 2.23. See **Appendix E** for an analysis of recognition performance for R and F items with respect to search type.

5.2.2 Visual Search RT

When calculating mean RT for correct search trials, means and SDs for serial and pop-out search RT were first calculated for each participant. Pop-out search trials which were +/- 2 SDs above or below the participant’s average pop-out search RT were excluded from analysis as errors. Likewise, serial search trials which were +/- 2 SDs above or below the participant’s average serial search RT were excluded from analysis as errors. Applying these restrictions lead to an average of 5% of pop-out trials and 5% of serial trials to be excluded from the calculations of mean visual RT. On the remaining trials, only those on which the orientation of the search target was accurately identified were included in the calculation of mean search RT.

A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) repeated-measures ANOVA on RT for correctly identified search targets. Visual search RTs are summarized in **Figure 6**. There was no significant main effect of Memory Instruction, $F(1,38) = 1.40$, $MSe = 1608$, $p = .24$, $\eta^2_p = .036$. There was however, a

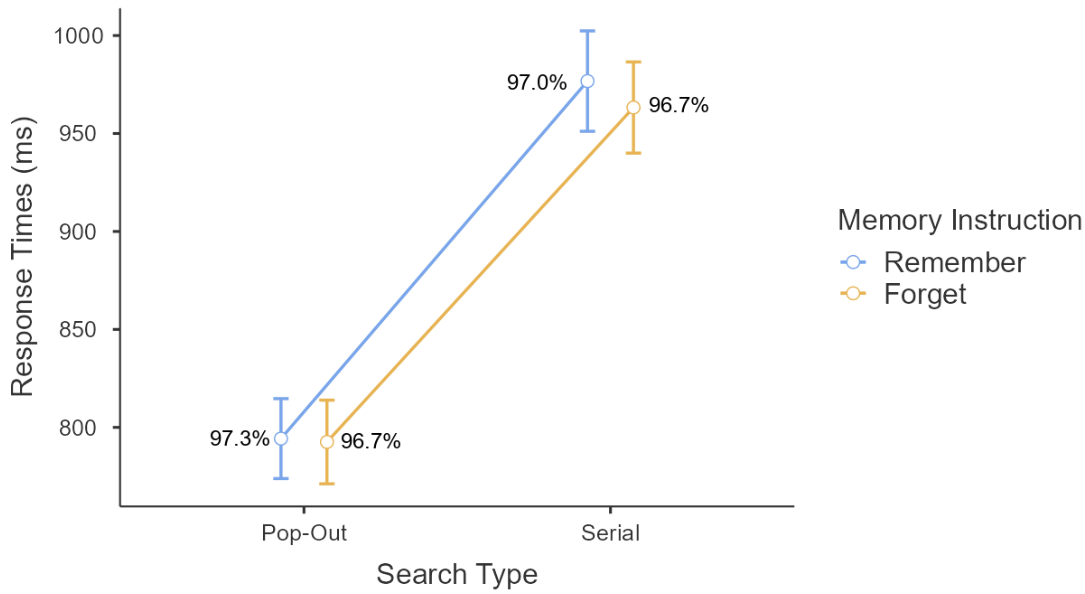

Figure 6. Mean search target RT in milliseconds on serial and pop out searches after R and F instructions for Experiment 4. Error bars represent one standard error of the mean. Percentages represent search accuracy for the adjacent condition.

significant main effect of Search Type, $F(1,38) = 408.61$, $MSe = 2991$, $p < .001$, $\eta^2_p = .92$, with overall slower RT on serial search trials ($M = 970$ms, $SE = 23.9$) than on pop-out search trials ($M = 793$ms, $SE = 20.6$). Contrary to our hypothesis, the critical two-way interaction between Memory Instruction and Search Type was not significant, $F(1, 38) = 0.30$, $MSe = 1640$, $p = .37$, $\eta^2_p = .02$.

5.2.3 Visual Search Accuracy

Search accuracy was calculated as a percentage of correctly identified search targets on trials with RT that were within +/- 2 SDs of the serial search and pop-out search means for each participant. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) repeated measures ANOVA was performed on search accuracy. Search accuracies are summarized as percentages in **Figure 6**. There was no significant main effect of Memory Instruction, $F(1,38) = 0.21$, $MSe = 11.0$, $p = .65$, $\eta^2_p =$ .006, and no significant main effect of Search Type, $F(1,38) = 0.002$, $MSe = 13.3$, $p =$ .96, $\eta^2_p = 0.002$. Furthermore, no significant interaction was found between Memory Instructions and Search Type, $F(1, 38) = 0.19$, $p = .96$, $\eta^2_p = .00$.

Discussion

Experiment 4 replicated the methods of Experiment 3 in an in-person lab setting. We were able to replicate the DF effect with better recognition of R items than F items and the main effect of search type, with serial>pop-out RT. Just like Experiment 3, we found null results for the main effect of memory instruction and the critical interaction of memory instruction and search type. Thus, even with the simplified design of Experiments 3 and 4, we found no evidence to support the critical interaction of memory instruction and search type that we predicted should F instructions leave attention relatively unavailable for use in a secondary task compared to R instructions (see **Appendix F** for a formal comparison of Experiments 3 and 4).

In considering reasons why we do not find the critical interaction, it is possible that attentional resources have already been withdrawn and recovered by the time our search target has appeared. Fawcett and Taylor (2008) determined that the F>R effect on RT remained in their probe detection task up to an instruction-target SOA of 1800ms. As such, adjusting the timing of our present search paradigm may be necessary to reveal our predicted interaction. For the next experiment, we altered the timing to fall into the range in which the F>R RT difference was reported for a simple probe detection task. Doing so should replicate the conditions under which instantiating an F instruction is purportedly more cognitively effortful than instantiating an R instruction due to differences in the allocation of attention. To better connect with the methods of the literature, the modality of the memory instruction will also be changed from visual cues to auditory tones. Finally, as there was no evidence that the online (Experiment 3) and in-person (Experiment 4) studies differed in their pattern of results, we chose to run the final experiment online. Experiment 5 represents our last attempt in the present study to reveal a magnified serial>pop-out RT difference following F compared to R instructions as predicted by our attentional withdrawal hypothesis.

Chapter 6: Experiment 5

Our item-method search paradigm undergoes a major change in its procedure for Experiment 5, namely in the timing of stimuli and the shift from visual to auditory memory instructions. This switch in medium of the memory instruction was done to better align with other item-method DF paradigms that have embedded probe detection and identification tasks, as these have primarily utilized audio tones to deliver the memory instructions. Our change in display times of stimuli was intended to replicate the conditions under which Fawcett and Taylor's (2008) probe study found a slowing of RT following F compared to R instructions. Prior visual probe detection studies have shown F>R RT effects only with post-instruction target SOAs of 1400ms and 1800ms while probe discrimination tasks revealed this effect at SOAs of 1800ms and 2600ms (e.g. Fawcett 2008; 2012). Therefore, we considered that this could be a major factor in the critical interaction of memory instruction and search type not being significant in Experiments 1-4 of the present study: if attentional withdrawal follows F instructions, it may be that this difference is only detectable within a narrow time window such that the longer search display times used in our previous experiments obscured any such effect of attentional withdrawal. We once again hypothesized that if attention is made less available following F instructions, the serial>pop-out RT difference will be magnified relative to R trials.

6.1 Methods

6.1.1 Participants

A total of 75 undergraduate students enrolled at Dalhousie University participated in the experiment in exchange for course credit awarded through the SONA-systems interface. Participants completed the experiment online through Pavlovia with the experiment lasting no more than an hour. Participants were asked to take part in the study only if they had normal or corrected-to-normal vision, had not previously taken part in directed forgetting research, and could complete the study on a computer that had reliable internet access and a physical keyboard.

6.1.2 Materials and Apparatus

Materials used in Experiment 5 were the same as Experiments 1-4 with a critical exception: memory instructions were now presented through audio tones rather than text. For a remember instruction, a high frequency tone (1156 Hz) was played whereas a low frequency (260 Hz) was played for forget instructions. These were implemented using custom Python 3 scripts in PsychoPy 3 builder interface and converted into JavaScript for running the experiment online through Pavlovia.

6.1.3 Procedure

The procedure of Experiment 5 began similarly to Experiments 1-4 with task instructions delivered to participants through text. However, this time participants were informed that there would be an audio component of the experiment and were asked to utilize headphones for the duration of the experiment if possible. Either way, they were asked to only perform the experiment in alone in a quiet area.

Practice Trials

Before the study trials, participants completed a set of 10 practice trials that were drawn from study phase conditions. The purpose of this was to familiarize participants with responding to the visual search tasks and with the general presentation of the study trials. Practice trials were identical to those in the study phase (described below) with the exception that the that the word '*word'* appeared on every practice trial instead of a new study word; the text "remember" or "forget" accompanied the playing of the high frequency and low frequency tones, respectively; and participants did not need to follow the memory instructions during practice. To ensure equal exposure to the audio tones, a total of 5 R trials and 5 F trials always appeared during practice.

Study Trials

The study phase procedure for Experiment 5 is summarized in **Figure 7.** Each study trial began with the presentation of a central fixation cross for 1000ms. A study word then replaced the center fixation cross for 1000ms. This study word was then replaced by the central fixation cross which was displayed for another 2000ms. At the end of this duration, the fixation cross disappeared, leaving a blank screen. At this time, the audio tone that served as the memory instruction was played for 400ms. A randomized half of trials played the high tone to signify an R instruction while the other half played the low tone to signify an F instruction. The screen continued to be blank for

Experiment 5: Probe Study Timecourse Replication

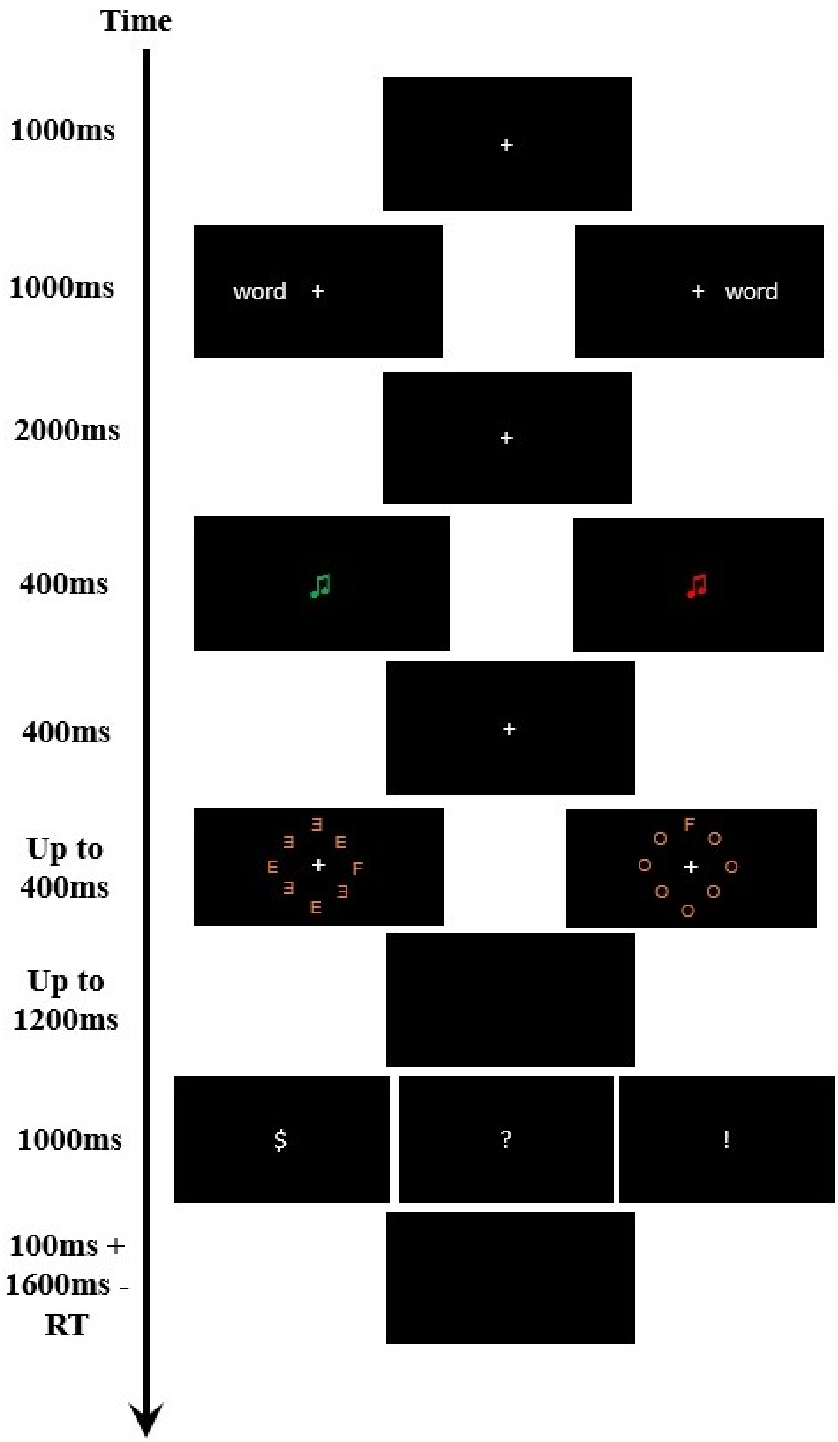

Figure 7. Depiction of the timecourse for experiment 5. The music note (♪) represents the playing of the high or low audio tone serving as R and F instructions respectively.

an additional 1400ms after the end of the memory instruction tone. Immediately following this duration, the visual search display appeared for 400ms.

Like in Experiments 1 and 2, the target was an F that appeared in a serial search display with seven E distractors in normal or mirror reversed orientation or in a pop-out search display with seven O distractors. Up to an additional 1200 ms was provided for the participant to make a response following the disappearance of the visual search display, giving a total of 1600ms to make a response to the orientation of the F target as normal or mirror-reversed; this was done through a press of the ‘n’ or ‘m’ keys on the keyboard respectively. Visual feedback was presented for 1000ms in place of the central fixation stimulus, to indicate whether the response was correct ($), incorrect (!), or timed out (?). If the participant made a valid response in this time, they received visual feedback with a dollar sign ($) if they identified the target correctly or an exclamation point (!) if they were incorrect. If the participant failed to make a valid response quickly enough, a question mark (?) appeared to inform them that they had timed out. A bide time was set between trials so that regardless of the RT of participants, any given trial lasted exactly 8500ms with a minimum 100ms interval between the end of feedback and the start of the next trial should participants timeout during search. Following this, the subsequent trial of the study phase would begin until a total of 128 trials was reached.

Test Phase

The test phase was identical to the test phases of Experiments 1-4.

6.2 Results

Of the 75 participants that completed Experiment 5, 12 participants were removed upon request that their data not be included in analysis, opting to be observers rather than participants of the study. Remaining participants with False Alarm Rates greater than 2 SDs above the mean and less than 50% search accuracy throughout study trials were eliminated from analysis. A total of 5 participants were eliminated due to meeting one or both of these exclusion criteria. This left a total of sample size of 57 participants for analysis. To complete the online study, 38 participants used an Intel Macintosh computer, and 19 participants used a Windows 32-bit machine. The FRs of the participant's operating systems are provided in **Table 7**.

Table 7. The number (N) of participants who performed the experiment under recorded FRs for each operating system. All FRs are reported in Hz.

Operating System	FR	N
Intel Macintosh	50	1
	60	36
	70	1
Windows 32-bit	40	1
	60	16
	75	1
	155	1

6.2.1 Recognition Test Performance

Recognition test performance was calculated as a proportion of yes versus no responses. This represents hits for remember and forget items and false alarms for foil words. A one-way repeated measures ANOVA compared proportion yes responses for R, F, and foil items. A significant difference was found between the three word types in proportion yes responses on the yes-no recognition test, $F(2, 112) = 148$, $p < .001$, $\eta^2_p =$

.73. Confirming a DF effect, recognition hits were higher for R words and than F words, $t(56) = 6.45$, $p <. 001$, $d = 0.85$. Forget hits were also significantly higher than foil false alarms, $t(567) = 12.54$, $p < .001$, $d = 1.66$. Recognition test data are summarized in See **Appendix G** for an analysis of recognition performance for R and F items with respect to search type**.**

Table 8. The mean proportion of 'yes' responses on the yes-no recognition test for remember, forget, and foil words in Experiment 5.

Memory Instruction	M	SE
Remember	0.58	0.024
Forget	0.45	0.023
Foil	0.19	0.017

6.2.2 Visual Search Response Times

When calculating mean RT for correct search trials, means and SDs for serial and pop-out search RT were first calculated for each participant. Pop-out search trials that were +/- 2 SDs above or below the participant's average pop-out search RT were excluded from analysis as errors. Likewise, serial search trials that were +/- 2 SDs above or below the participant's average serial search RT were excluded from analysis as errors. A total of 8% of serial trials and 6% of pop-out trials to be excluded based on RTs. For the remaining trials, only search trials in which the orientation of the search target was accurately identified were included in the calculation of mean search RT.

To assess search RT, a 2 (Memory Instruction: remember, Forget) × 2 (search Type: serial, pop-Out) repeated measures ANOVA was conducted on trials which participants correctly identified the search target orientation. Search RTs are summarized in **Figure 8.** Unlike experiments 1-4, a significant main effect of Memory Instruction was found, $F(1,56) = 5.15$, $MSe = 1596$, $p < .05$, $\eta^2_p = 0.08$, with slower RTs for F items

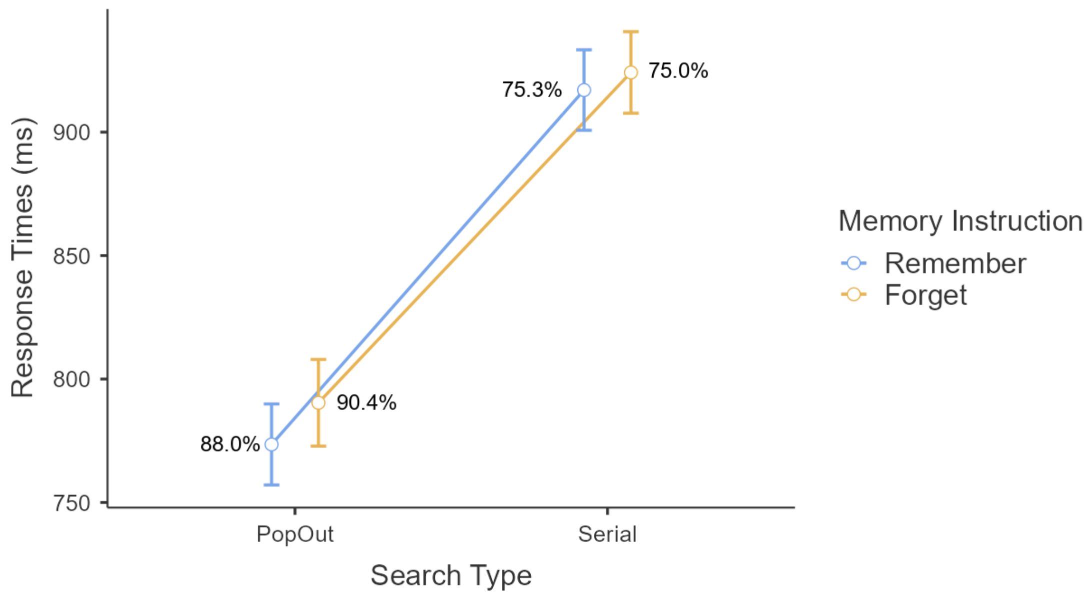

Figure 8. Mean search target RT in milliseconds on serial and pop out searches after R and F instructions for Experiment 5. Error bars represent one standard error of the mean. Percentages represent accuracy for adjacent conditions.

(M = 857ms, SE = *17*) compared to R items (M = 845ms, SE = 16), replicating the pattern observed in Fawcett and Taylor's (2008) probe study. A main effect was also found for Search Type, $F(1,56) = 329.94$, $MSe = 3307$, $p < .001$, $\eta^2_p = .86$, with participants being slower to respond to serial searches, (M = 921ms, SE = 16) than pop-out searches (M = 782ms, SE = 17). Once again the critical interaction between Memory Instruction and Search Type was not significant, $F(1,56) = 1.50$, $MSe = 904$, $p = .23$, $\eta^2_p = .03$.

6.2.3 Search Accuracy

Search accuracy was calculated as a percentage of correctly identified search targets on trials with RTs that were within +/- 2 SDs of the serial search and pop-out search means for each participant. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) repeated-measures ANOVA was conducted on search accuracy, which is summarized as percentages in **Figure 8.** There was no significant main effect of Memory Instruction, $F(1,56) = 1.40$, $MSe = 41.7$, $p = .24$, $\eta^2_p = .02$. There was however, a main effect of Search Type, $F(1,56) = 229.39$, $MSe = 49.3$, $p < .001$, $\eta^2_p = .80$: the slower serial searches ($M = 75.1$, $SE = 1.3$) were significantly less accurate than the faster pop-out searches ($M = 89.2$, $SE = 1.2$). The two-way interaction between Memory Instruction and Search Type was not significant, $F(1, 56) = 2.03$, $MSe = 49.0$, $p = .16$, $\eta^2_p = .04$.

6.3 Discussion

Experiment 5 changed the timing of study phase stimuli in our DF Search paradigm as well as the modality of the memory instruction from visual cues to auditory cues. These changes were motivated by a desire to more closely replicate the timing conditions of prior DF probe studies which showed that an F>R RT effect occurred when probe onsets requiring a speeded response appeared 1800ms post-instruction onset (e.g. Fawcett and Taylor, 2008). As our prior experiments failed to find the critical magnified serial>pop-out RT difference following F compared to R instructions, we reasoned that we may need to alter the post-instruction timing of our search target to reveal this difference if attention were withdrawn from F items as we hypothesized.

Even with these changes in stimulus timing and memory instruction modality, we found a classic DF effect and showed that serial search continued to be slower than pop-out search. Contrary to our hypothesis, however, the critical interaction of memory instruction and search type once again was not significant. This was true even though - unlike Experiments 1-4 - we found a main effect of memory instruction on RT, wherein F trials were slower compared to R trials. Altering the post-instruction onset of the visual search display and reducing its duration thus allowed our search RT to fall into the response window wherein instantiating an F instruction is relatively more demanding than an R instruction. In so doing, Experiment 5 replicated prior visual probe and IOR studies (e.g. Taylor, 2005; Taylor and Fawcett, 2011; Thompson and Taylor; 2015). Clearly though, this was not enough to reveal the predicted interaction of memory instruction and search type. We will consider these results further in the General Discussion.

Chapter 7: General Discussion

This thesis presented five experiments that embedded two versions of a visual search task into the study phase of an item-method DF paradigm to investigate potential differences in attentional allocation following F versus Rinstructions. The visual search tasks consisted of an attentionally demanding serial search display and a non-demanding pop-out search display, which were presented after instructions to remember or forget in an item-method DF paradigm (Treisman and Gelade, 1980; Wolfe, 2021). Experiments 1 and 2 presented study words to the left or right of a central fixation point, followed by a visual instruction to remember or forget the study word. A visual search display was subsequently presented which required a speeded key press to discriminate the orientation of a target letter “F” as being in either a normal or a mirror-reversed orientation. The target could appear left, right, above or below the central fixation so that the study word and target were presented in either the same or in a different location on each trial. Critically, we manipulated the attentional demands of the visual search task by embedding the target “F” among 7 letter E distractors in normal and mirror-reverse orientation (serial search) or 7 letter O distractors (pop-out search). Experiments 3 and 4 replicated the design of Experiments 1 and 2 but presented the study word at center to remove the manipulation of word-target location. Lastly, Experiment 5 altered the methods of Experiments 3 and 4 by changing the modality of the memory instructions to auditory tones, as well as altering the timing of trials to replicate the timing conditions of Fawcett and Taylor’s (2008) probe detection study. Our purpose in running these experiments was to determine whether attention is withdrawn following instructions to forget versus remember and thereby made relatively less available for a secondary task, as had been suggested by prior studies (e.g. Taylor, 2005; Taylor and Fawcett 2011; Thompson and Taylor, 2015).

Across all five experiments, we consistently found a DF effect, whereby more R items were recognized by participants than F items. We also observed a robust effect of search type, such that participants were slower to report target orientations in serial searches compared to pop-out searches. However, contrary to our hypothesis of the serial>pop-out RT difference being magnified following F compared to R instructions, we found only null results in the critical interaction of memory instruction and search type. If F instructions had led to a withdrawal of attentional resources, serial search RTs should have been particularly sensitive to this unavailability compared to the less demanding pop-out search (Taylor and Fawcett, 2011). The fact that the critical two-way interaction did not emerge in any of the 5 experiments suggests that that attention is not withdrawn following F instructions in the way that we thought.

To determine whether the evidence favours endorsing the null hypothesis (that F and R trials produce similar magnitude serial>pop-out differences in RT), the data from all 5 experiments were conglomerated into a single pool of 256 participants. On a participant-by-participant basis we calculated the mean RT difference between serial and pop-out searches separately for R and F trials. We then conducted a Bayesian one-tailed paired samples t-test to test our hypothesis of larger RT difference between serial and pop-out searches on F compared to R trials. This analysis revealed a Bayes factor (B+0) of 0.039. which indicates that the present data were 25.63 times more likely to occur under the null hypothesis than under our directional alternative hypothesis (see **Figure 9**). According to conventional interpretations of BF magnitude, the data strongly favour

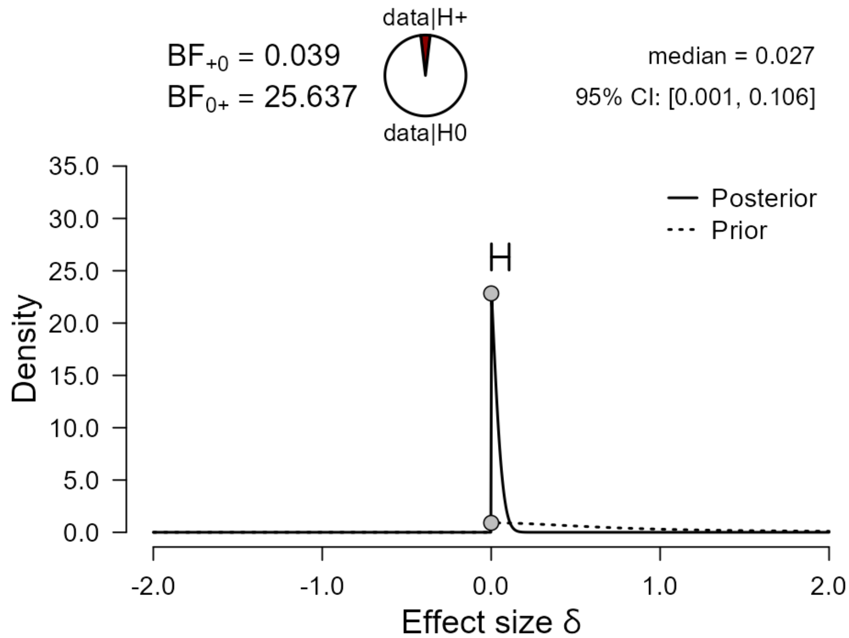

Figure 9. As described by Gross-Sampson (2020), this figure plots the prior distribution (dashed line) and the posterior distribution (solid line) and was created using JASP software (JASP Team, 2023). The two grey dots represent density values at an effect size of 0. The evidence supports the null hypothesis when the dot on the posterior distribution is higher than the dot on the prior distribution. The pie chart shows the relative amount of evidence for the alternative hypothesis (H+) and the null hypothesis (H0). Also shown are the median effect size and 95% credible intervals (represented by the horizontal line).

the null hypothesis over the alternative hypothesis of a magnified serial>pop-out difference on F compared to R trials (Goss-Sampson, 2020; Van Doorn et al, 2019).

While none of the experiments of the present study revealed the critical memory instruction × search type interaction either alone or when collapsed together, it is noteworthy that Experiment 5 replicated previous probe detection and discrimination studies by revealing overall slower RTs on F compared to R trials, (e.g. Taylor, 2008; Fawcett and Taylor, 2012). This means that by altering the memory instruction-target SOA to 1800ms in Experiment 5, we were successful in placing the search task into the time window during which intentional forgetting has been found to be more effortful than remembering. The fact that this RT difference appeared without the word-target location manipulation suggests that effortful instantiation of the F compared to the R instruction does not rely on the target appearing at the same specific location as the study item in space. Even so, there was no interaction of memory instruction with search type, suggesting that even when instantiating F instructions is relatively effortful, attention is not made any less available for a performing an attentionally demanding secondary task. It would seem that if attention is in fact withdrawn from study items following an F instruction, this withdrawal must be short-lived, with resources quickly brought back on-line and able to be reallocated - perhaps towards the task of cumulative rehearsal – such that there is no obvious impairment for performing a subsequent unrelated task and also no increased vulnerability to capture (Taylor and Hamm, 2016; Rubinfield et al., 2019).

With evidence strongly arguing against a role for a long-lasting withdrawal of attentional resources following F compared to R instructions, we must consider the outstanding question of whether processes other than attentional withdrawal might instead be responsible for the effortful nature of intentional forgetting. As noted earlier in our literature review, neuroimaging studies have found unique activation in right frontal cortex (implicated in cognitive control) when forgetting was intentional compared to incidental, and when participants intentionally remembered (Rizio et al., 2013; Wylie et al., 2008). This was seen as a sign of an active cognitive mechanism operating during the instantiation of an F instruction that *may* be related to attentional withdrawal but that *could* instead be a sign of another top-down control mechanism.

Recent work by Hubbard and Sahakyan (2021; 2023) used an item-method DF paradigm which, along with R and F instructions, included an additional "imagine" condition, wherein an image was presented instead of a memory instruction. Each image was accompanied by a prompt for participants to visualize rather than focus on the study word (e.g. a picture of a house served as a prompt for participants to imagine travelling through their childhood home). This manipulation was intended to compare the effectiveness of encoding suppression (i.e. traditional F instructions) with the strategy of thought substitution (i.e. imagine a house instead of focusing on the study word) to produce DF effects. Participants were simultaneously monitored with an electroencephalograph (EEG) to determine differences in the neural correlates between strategies. While both strategies elicited the DF effect in a recognition test, the magnitude of the DF effect was greater following encoding suppression compared to thought substitution (Hubbard and Sahakyan, 2021). Furthermore, successful forgetting after each strategy was correlated with different patterns of neural activity, with F instructions engaging greater frontal activity which enhanced the likelihood of participants successfully forgetting the study item (Hubbard and Sahakyan, 2021).

Results of the encoding suppression and thought substitution comparison were extended in a subsequent study that correlated performance on a stop-signal task with the magnitude of the DF effects accomplished through each strategy (Hubbard and Sahakyan, 2023). Analyzed in the context of brain activity measured by an EEG, this study revealed that faster instantiation of a stop-signal was associated with the successful forgetting of F items and EEG analysis showed that the magnitude of right-frontal brain activity was associated both with stop-signal RTs and with the magnitude of the DF effect for encoding suppression. This association with frontal activity did not appear during thought substitution, with no discernable relationship between successful stop-signal inhibition and successful forgetting.

Considered along with their previous study, Hubbard and Sahakyan (2023) argued for a domain-general inhibitory mechanism that is employed during the instantiation of an F instruction, perhaps as a means of further reducing the strength of the unwanted memory trace. While some researchers have argued that inhibition is not a necessary construct for explaining behavioural patterns that can otherwise be explained by selective rehearsal alone (MacLeod et al, 2003; Tan et al, 2020), such an inhibitory mechanism could co-exist with the selective elaborative rehearsal of R items over F items to maximize the chances of successfully instantiating of the memory instructions (see Fellner, Waldhauser, and Axmacher, 2020). Indeed, evidence indicates that activity associated with successful intentional forgetting occurs later than that associated with successful intentional remembering (Fellner, Waldhauser, and Axmacher, 2020).

Previous item-method DF studies that embedded a Posner cueing paradigm after the R and F memory instructions argued that magnified IOR effects following F instructions compared to R instructions were caused by attention being more readily withdrawn from the study item (to thereby unmask the IOR effect at the peripheral study word location). How might this be reconciled with domain-general inhibition? Thompson and Taylor (2015) found that F instructions magnified both motoric (i.e. eye movements free to be made) and visual (i.e. eye movement restricted) IOR. These two variants of IOR manifest based on separate mechanisms: motoric IOR is a motor response bias against responding to cued locations whereas visual IOR leads to a decrease in perceptual processing of the cued location (Hilchey, Klein and Ivanoff, 2012). Due to this, Thompson and Taylor argued that intentional forgetting must interact with other upstream processes that would affect both forms of IOR and pointed to a potential role for a fronto-parietal network in the inhibition of parietal regions associated with the spatial saliency map following F but not R instructions (see Bourgeois, Chica, Valero-Cabré, & Bartolomeo, 2013). Consider that the same frontal areas are recruited for inhibiting a motor response in a stop-signal task and for suppressing the encoding of a study item following F instructions (Hubbard and Sahakyan, 2023). In the domain-general inhibition view, the recruitment of frontal areas that inhibit further encoding would at the same time compete with perceptual processing and extend to inhibiting motor responses (e.g. button press, eye movement). This inhibitory process could thus provide the common upstream influence between the magnified motoric and visual IOR effects on F compared to R trials.

It is also notable that the successful instantiation of R instructions but not F instructions is predicted by an early P200 ERP component which is associated with, among other things, greater attentional allocation to visual stimuli and repetition effects in memory (Gao, Cao, Qi, Wang, Zhang, & Li, 2016; Hubbard and Sahakyan, 2021). It could be that during this early time window, attention is focused on further R item rehearsal, which could explain why limited-capacity resources do not refresh as readily following R compared to F instructions (see Taylor, 2018). To the extent that these attentional differences are short-lived and used within the context of rehearsal in the memory task, such attentional differences could potentially co-exist with the postulated effects of generalized inhibition, potentially operating on a different timecourse (e.g., with attentional effects occurring earlier than inhibitory effects). Removed the line on cognitive load hypothesis – felt like a reach and off in the flow of argument

We are intrigued by this notion of a domain-general inhibitory mechanism. The presumed operation of such a mechanism appears to be consistent with the existing literature and could also help explain why we found no evidence of greater attentional withdrawal following F compared to R instructions in any of our experiments — not even when RTs were overall slower following F instructions than following R instructions. Nevertheless, arguments for the operation of non-attentional inhibition are obviously post-hoc and confirming the existence of such a mechanism will require further investigation.

7.2 Conclusion

Our investigation into the role of attentional withdrawal in DF utilized a novel paradigm that embedded a visual search task into the post-instruction interval of an item-method DF task. By comparing target RTs on serial versus pop-out trials, we were able to isolate any effects of memory instructions on attention, while controlling for all other post-instruction processing differences that might otherwise occur. Despite this direct measurement of post-instruction attentional availability and control over non-attentional post-instruction processing differences, we uncovered strong evidence against the idea that attention becomes relatively unavailable following F compared to R instructions. This conclusion is based on five experiments run both online and in person which failed to find a magnified serial>pop-out difference on F compared to R trials. This was true even though Experiment 5 utilized methods capable of replicating longer overall RTs following instructions to forget than instructions to remember. Given the strong evidence in our experiments against differences in attentional availability on F compared to R trials, it may be that an inhibitory mechanism acting independently of attentional allocation (e.g., Hubbard and Sahakyan, 2023) is responsible for the longer target RTs on F compared to R trials that has otherwise been attributed to an effortful withdrawal of attention from unwanted F item representations. While confirming the nature of such an inhibitory mechanism will require investigation by future studies, we feel confident to conclude that current conceptualizations of the role that attentional withdrawal plays in item-method DF is likely incorrect. Even though selective rehearsal undoubtedly plays a strong role in the preferential encoding of R over F items, there appear to be additional active processes — seemingly unrelated to attention — that may work in tandem with selective rehearsal to reduce the encoding of unwanted items into long-term memory. It will be up to future studies to characterize the nature and timecourse of these other active — potentially inhibitory — processes.

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Appendix A: Recognition Results Experiment 1

While not of central importance to the current investigation, we performed an analysis to determine whether subsequent recognition memory was influenced by the trial conditions under which R and F items were studied in Experiment 1. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) was performed to assess yes-response proportions on the recognition test. A significant main effect of Memory Instruction was found, $F(1,60) = 38.16$, $p < .001$, $\eta^2_p = .34$, where items that received R instructions ($M = 0.58$, $SE = .023$) were correctly recognized more often than those that received F instructions ($M = 0.42$, $SE = 0.021$). There was no significant main effect of Search Type, $F(1,60) = 0.32$, $p = .57$, $\eta^2_p = .01$, and no significant main effect of Word-Target Location, $F(1,60) = 1.70$, $p = .20$, $\eta^2_p = .03$.

There were no significant two-way interactions between Memory Instruction and Search Type, $F(1,60) = 3.67$, $MSe = 22.5$, $p = .06$, $\eta^2_p = .06$, between Memory Instruction and Word-Target Location, $F(1,60) = 0.23$, $p = .63$, $\eta^2_p = .004$, or between Search Type and Word-Target Location, $F(1,60) = 1.34$, $p = .25$, $\eta^2_p = .02$. There was no significant three-way interaction between Memory Instruction, Search Type, and Word-Target Location, $F(1,60) = 0.66$, $p = .80$, $\eta^2_p = .00$.

Appendix B: Recognition Results Experiment 2

While not of central importance to the current investigation, we performed an analysis to determine whether subsequent recognition memory was influenced by the trial conditions under which R and F items were studied in Experiment 2. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) × 2 (Word-Target Location: same, different) was performed to assess yes-response proportions on the recognition test. A significant main effect of Memory Instruction was found, $F(1,40) = 58.69$, $p < .001$, $\eta^2_p = .60$, where items that received R instructions ($M = 0.65$, $SE = .028$) were correctly recognized more often than F instructions ($M = 0.41$, $SE = 0.032$). There was no significant main effect of Search Type, $F(1,40) = 0.77$, $p = .39$, $\eta^2_p = .02$, and no significant main effect of Word-Target Location, $F(1,40) = 0.25$, $p = .62$, $\eta^2_p = .01$.

There was no significant two-way interaction between Memory Instruction and Search Type, $F(1,40) = 0.34$, $p = .56$, $\eta^2_p = .01$. However, there was a significant interaction between Memory Instruction and Word-Target Location, $F(1,60) = 4.68$, $p < .05$, $\eta^2_p = .11$. In exploring this interaction, we found that different word-target location trials led to a smaller difference in recognition between R ($M = 0.62$, $SE = 0.03$) and F ($M = 0.42$, $SE = 0.03$) items compared to the difference between R ($M = 0.66$, $SE = 0.03$) and F ($M = 0.40$, $SE = 0.03$) items for same word-target location trials. The interaction between Search Type and Word-Target Location was not significant, $F(1,40) = 0.37$, $p = .55$, $\eta^2_p = .01$. There was also no significant three-way interaction between Memory Instruction, Search Type, and Word-Target Location, $F(1,60) = 1.58$, $p = .22$, $\eta^2_p = .04$.

Appendix C: Experiment 1 & 2 Comparison

To directly compare the results of Experiment 1 with those of Experiment 2, participants were pooled and compared on RT in a mixed-subject ANOVA that incorporated Experiment Type (online, in-person) as a between subjects factor. Together, this totalled to a sample size of 102 participants. The following will only focus on those effects that included Experiment Type. This analysis revealed a main effect of Experiment Type, whereby online participants had overall slower RTs (M = 1025ms, SE = 26) than in-person participants (M = 896ms, SE = 26), $F(1,100) = 8.04$, $MSe = 367626$, $p < .01$, $\eta^2_p = .07$.

No significant interaction was found between Experiment Type and Memory Instruction, $F(1,100) = 0.32$, $MSe = 9382$, $p = .58$, $\eta^2_p = .00$. A significant interaction was found between Experiment Type and Search Type on RT, $F(1,100) = 15.1$, $MSe = 29520$, $p <. 001$, $\eta^2_p = .13$. Participants who performed serial searches online (M = 1166ms, SE = 32) had slower RTs those who performed serial searches in person (M = 995ms, SE = 39), $t(100) = 3.34$, $p < .01$, d = .68. There was no significant interaction between Experiment Type and Word-Target Location, $F(1,100) = 0.57$, $MSe = 7872$, $p = .45$, $\eta^2_p = .01$.

There was no significant three-way interaction between Experiment Type, Memory Instruction, and Search Type, $F(1,100) = 0.51$, $MSe = 5188$, $p = .82$, $\eta^2_p = .00$, or between Experiment Type, Memory Instruction, and Word-Target Location, $F(1,100) = 0.46$, $MSe = 5296$, $p = .50$, $\eta^2_p = .01$. There was however, a significant three-way interaction between Experiment Type, Search Type, and Word-Target Location, $F(1,100) = 5.71$, $MSe = 5578$, $p <. 05$, $\eta^2_p = .05$. In exploring this interaction, we found that the magnitude of the serial>pop-out RT difference was greater when the Word-Target Location was the same online (M = 260ms, SE = 23), compared to in-person, (M = 191ms, SE = 16), $t(100) = 2.30$, $p < .01$, $d = .46$. The magnitude of the serial>pop-out RT difference was also greater when the Word-Target Location was different online (M = 303ms, SE = 17), compared to in-person, (M = 182ms, SE = 12), $t(100) = 5.37$, $p < .001$, $d = 1.09$. No significant four-way interaction was found between Experiment Type, Memory Instruction, Search Type, and Word-Target Location, $F(1,100) = 1.61$, $MSe = 5613$, $p = .21$, $\eta^2_p = .02$.

Another mixed-subjects ANOVA was used to analyze the search accuracy of participants. There was a significant main effect of Experiment Type where participants were less accurate in identifying the search target orientation online (M = 93, SE = 0.9) than in-person (M = 97, SE = 0.9), $F(1,122) = 9.63$, $MSe = 406$, $p < .01$, $\eta^2_p = .07$. There was no significant interaction between Experiment Type and Memory Instructions, $F(1,93) = 0.09$, $MSe = 19.7$, $p = .77$, $\eta^2_p = .00$. There was, however, a significant interaction of Experiment Type and Search Type, $F\ (1,100) = 5.14$, $MSe = 89.2$, $p <. 05$, $\eta^2_p = .05$, with serial searches performed by online participants (M = 91.8, SE = 1.2) being less accurate than those performed by in-person participants (M = 97.3, SE = 1.5), $t(100) = 2.86$, $p < .01$, $d = .58$. There was no significant interaction between Experiment Type and Word-Target Location, $F(1,100) = 3.39$, $MSe = 29.4$, $p = .07$, $\eta^2_p = .03$.

There was also no significant interaction between Experiment Type, Memory Instruction, and Search Type, $F(1,100) = 3.57$, $MSe = 40.8$, $p = .06$, $\eta^2_p = .03$, between Experiment Type, Memory Instruction, and Word-Target Location, $F(1,93) = 0.63$, $MSe = 33.1$, $p = .43$, $\eta^2_p = .01$, between Experiment Type, Search Type, and Word-Target

Location, $F(1,100) = 0.25$, $MSe = 34.4$, $p = .62$, $\eta^2_p = .00$, or between Experiment Type, Memory Instruction, Search Type, and Word-Target Location, $F(1,100) = 0.77$, $MSe = 45.0$, $p = .38$, $\eta^2_p = .01$.

Appendix D: Recognition Results Experiment 3

While not of central importance to the current investigation, we performed an analysis to determine whether subsequent recognition memory was influenced by the trial conditions under which R and F items were studied in Experiment 3. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) was performed to assess yes-response proportions on the recognition test. A significant main effect of Memory Instruction was found, $F(1,55) = 82.99$, $p < .001$, $\eta^2_p = .60$, where items that received R instructions ($M = 0.58$, $SE = .023$) were correctly recognized more often than those that received F instructions ($M = 0.42$, $SE = 0.021$). There was no significant main effect of Search Type, $F(1,55) = 2.33$, $p = .13$, $\eta^2_p = .04$, and no significant two-way interaction between Memory Instruction and Search Type, $F(1,55) = 0.01$, $p = .93$, $\eta^2_p = .00$.

Appendix E: Recognition Results Experiment 4

While not of central importance to the current investigation, we performed an analysis to determine whether subsequent recognition memory was influenced by the trial conditions under which R and F items were studied in Experiment 4. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) was performed to assess yes-response proportions on the recognition test. A significant main effect of Memory Instruction was found, $F(1,38) = 93.46$, $p < .001$, $\eta^2_p = .71$, where items that received R instructions ($M = 0.71$, $SE = .028$) were correctly recognized more often than those that received F instructions ($M = 0.47$, $SE = 0.030$). There was no significant main effect of Search Type, $F(1,38) = 0.004$, $p = .95$, $\eta^2_p = .00$, and no significant two-way interaction between Memory Instruction and Search Type, $F(1,38) = 0.59$, $p = .45$, $\eta^2_p = .02$.

Appendix F: Experiment 3 & 4 Comparison

To directly compare the results of Experiment 3 with those of Experiment 4, participants were pooled together and analyzed in a mixed-subject ANOVA with Experiment Type (Online, In-Person) as a between-subjects factor. Together, this totaled to a sample size of 95 participants. This analysis revealed a significant main effect of Experiment Type, whereby online participants had overall slower RTs (*M* = 1023ms, *SE* = 24) than in-person participants (*M* = 882ms, SE = 29), $F(1,93) = 14.4$, *MSe* = 367626, $p < .01$, $\eta^2_p = .07$.

There was no significant interaction between Experiment Type and Memory Instruction, $F(1,93) = 0.72$, *MSe* = 2284, $p = .40$, $\eta^2_p = .01$. There was however, a significant interaction between Experiment Type and Search Type on RT, $F(1,93) = 34.75$, *MSe* = 8807, $p <. 001$, $\eta^2_p = .27$. Participants who performed the experiment online had slower serial search RTs (*M* = 1169ms, *SE* = 28) compared to in-person serial searches (*M* = 970ms, *SE* = 34), $t(93) = 4.56$, $p < .01$, d = .95. Furthermore, Participants who performed the experiment online had slower pop-out search RTs (*M* = 877ms, *SE* = 21) compared to in-person Pop-Out searches (*M* = 793ms, *SE* = 21), $t(93) = 2.56$, $p < .05$, d = .53. There was no significant three-way interaction between Experiment Type, Memory Instruction, and Search Type, $F(1,93) = 0.09$, *MSe* = 1824, $p = .77$, $\eta^2_p = .00$.

In examining search accuracy, there was a significant main effect of Experiment Type where participants were less accurate in identifying the search target orientation online (*M* = 94.8, *SE* = 0.5) than in-person (*M* = 96.8, *SE* = 0.6), $F(1,93) = 6.80$, *MSe* = 394.5, $p < .05$, $\eta^2_p = .07$. There was no significant interaction between Experiment Type and Memory Instructions, $F(1,93) = 0.09$, *MSe* = 19.7, $p = .77$, $\eta^2_p = .00$, or between

Experiment Type and Search Type, $F(1,93) = 0.57$, $MSe = 22.6$, $p = .45$, $\eta^2_p = .01$. There was also no significant interaction between Experiment Type, Memory Instruction and Search Type, $F(1,93) = 1.39$, $MSe = 15.2$, $p = .24$, $\eta^2_p = .02$.

While not of primary interest to this thesis, our comparisons of online vs in-person experiments found that participants were both more accurate and faster in their responses in-person compared to online. Due to this, we would suggest that a controlled in-person setting is the preferred option for running DF and attention-based tasks in future studies.

Appendix G: Recognition Results Experiment 5

While not of central importance to the current investigation, we performed an analysis to determine whether subsequent recognition memory was influenced by the trial conditions under which R and F items were studied in Experiment 5. A 2 (Memory Instruction: remember, forget) × 2 (Search Type: serial, pop-out) was performed to assess yes-response proportions on the recognition test. A significant main effect of Memory Instruction was found, $F(1,56) = 41.64$, $p < .001$, $\eta^2_p = .43$, where items that received R instructions ($M = 0.58$, $SE = .024$) were correctly recognized more often than those that received F instructions ($M = 0.45$, $SE = 0.023$). There was no significant main effect of Search Type, $F(1,56) = 0.00$, $p = .98$, $\eta^2_p = .00$, and no significant two-way interaction between Memory Instruction and Search Type, $F(1,56) = 0.04$, $p = .84$, $\eta^2_p = .00$.