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Effects of top-down attention and individual differences on recognition memory and recollective experience.

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EFFECTS OF TOP-DOWN ATTENTION AND INDIVIDUAL DIFFERENCES ON RECOGNITION MEMORY AND RECOLLECTIVE EXPERIENCE

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ABSTRACT

EFFECTS OF TOP-DOWN ATTENTION AND INDIVIDUAL DIFFERENCES ON RECOGNITION MEMORY AND RECOLLECTIVE EXPERIENCE

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Memory accuracy and detail hold practical importance, and psychology has studied means to improve memory. One such means is performing visually guided saccades immediately before a memory test. Previous work has found this intervention to improve memory performance, an effect dubbed Saccade-Induced Retrieval Enhancement or SIRE. The top-down attentional control account posits that SIRE occurs because saccades activate attentional control regions in the brain, which contributes to executing top-down attentional control when searching memory. The current experiment tested this account of SIRE by attempting to replicate previous results and investigating whether a different attentional task, the Revised Attention Network Test (ANT-R), would produce SIRE-like effects. Attention interventions were expected to be specifically beneficial in reducing output interference—a phenomenon where memory accuracy declines in the latter parts of a recognition test—and improving subjective judgments of recollective experience. Individual differences in attentional control and handedness consistency were also considered. It was expected that individuals who are less inclined to execute top-down attentional control in their everyday life would benefit more from attention-based memory interventions. Handedness consistency was measured and controlled for, because previous research has indicated that handedness consistency may have a moderating effect on SIRE. In contrast to predictions, although output interference was found, the new attentional intervention did not improve memory performance. Neither saccades nor the ANT-R increased recollective detail, and self-reported individual differences in attentional control did not affect recognition. Support was found for saccades reducing output interference; however, evidence also suggested that the control condition reduced output interference for discrimination. Failure to fully replicate previous SIRE results and to provide consistent for support the top-down attentional control account generate questions regarding the reliability of saccades as a memory enhancement technique and future research is needed to fully understand when and how this effect occurs.

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CHAPTER I: INTRODUCTION

The accuracy and detail of one's memory is often important. In everyday life, it is important to recall the date and time of a scheduled meeting or the name of a new business partner. More consequential examples include students' need to recall information on high-stakes exams and the court's need for eyewitnesses to accurately recall their explicit memory for evidence in criminal investigations. Because our memories hold such importance, it is a common goal to want to ensure that we can retrieve the most accurate and detailed information possible. Psychology has studied multiple ways to improve memory, including repeated quizzing (e.g., Karpicke, 2012), interview techniques (e.g., Memon & Higham, 1999), and—most relevant to the current research—interventions introduced at the time of retrieval.

One means of enhancing memory that has been investigated in the laboratory is performing *visually-guided saccades*, henceforth referred to as *saccades*, immediately before retrieval. Saccadic eye movements are rapid eye movements that shift focus to a particular point or target in the visual field. To implement saccades in laboratory studies, participants move their eyes to follow a flashing dot as it alternates between two locations on a computer screen, typically left and right of participants' midline, at a steady pace. Participants complete one full cycle of eye movements—one saccadic eye movement to the left and one to the right—every second (see Christman et al., 2003). Superior memory performance following saccades versus a control condition is dubbed *saccade-induced retrieval enhancement* (*SIRE*; Lyle & Martin, 2010). SIRE has been found on various tests of explicit memory, including free recall (e.g., Christman et al., 2004; Lyle, Logan et al., 2008; Nieuwenhuis et al., 2013), cued recall (e.g., Lyle & Edlin, 2015; Parker et al., 2018), and associative recognition (e.g., Lyle et al., 2012; Parker et al., 2008). SIRE appears not to occur for tests of implicit memory (Christman et al., 2003; Parker et al., 2018).

It was initially proposed that saccades enhance retrieval by increasing the interaction between the two hemispheres of the brain (Christman et al., 2003). However, behavioral and electrophysiological data have provided no evidence of a saccade-induced increase in interhemispheric interaction (Fleck et al., 2018; Lyle & Martin, 2010; Lyle & Orsborn, 2011; Propper et al., 2007; Samara et al., 2011). A more promising explanation is that saccades pre-activate top-down attentional control regions in the brain, which enhances memory retrieval specifically when retrieval requires a high degree of top-down attentional control (Lyle & Edlin, 2015; Lyle & Orsborn, 2011). This explanation will be referred to as the *top-down attentional control account*.

A central aim of this experiment was to test a hypothesis that follows naturally from the top-down attentional control account. Namely, if saccades improve memory due to activation of top-down attentional control, then tasks other than saccades that recruit top-down attentional control should also enhance memory retrieval. No prior research has tested whether tasks other than saccades can produce SIRE-like effects. This experiment was designed to replicate previous results and to expand upon current SIRE research by testing whether a different task recruiting top-down attentional control would produce

SIRE-like effects.

In addition, to effectively use an intervention like saccades or other attentional tasks to enhance memory, it is important to consider individual differences that are likely to interact with an attention-based intervention. Because the proposed mechanism driving SIRE is the involvement of attention in memory retrieval, individual differences in baseline *attentional control* were measured and interactions between this measure and the experimental activities were tested. Also, because previous research demonstrated that *handedness consistency* may interact with saccades, this factor was measured and controlled in the current experiment.

Literature Review

Mechanisms of SIRE

Christman et al. (2003) hypothesized that saccades temporarily increase interhemispheric interaction at the time of memory retrieval. Left-right bilateral eye movements were thought to result in activation of both hemispheres of the brain, thereby facilitating interhemispheric interaction. Increased interhemispheric interaction was theorized to enhance retrieval based on the tenets of the *hemispheric-encoding-retrieval-asymmetry model*, which posits that memory encoding occurs in the left hemisphere and memory retrieval occurs in the right (Cabeza & Nyberg, 2000; Tulving et al., 1994). The interhemispheric interaction account has not been supported by behavioral or electrophysiological research. Saccades have not been found to increase behavioral measures of interhemispheric interaction (Lyle & Martin, 2010; Lyle & Orsborn, 2011) and, to the contrary, have been found to *reduce* interhemispheric coherence in the gamma and alpha frequency bands (Fleck et al., 2018; Propper et al., 2007; Samara et al., 2011).

The top-down attentional control account offers an alternative explanation for SIRE, attributing retrieval enhancement to the contribution of attentional control regions to memory retrieval. Attention can be allocated internally to our memories in a similar manner to how it is allocated externally to our environment (De Brigard, 2011; Lückmann et al., 2014). Allocation of attention can be done in a top-down manner, meaning that attention is purposefully controlled in line with current goals, or in a bottom-up manner, meaning that attention is automatically captured by salient stimuli (Corbetta & Shulman, 2002). Performing saccades requires external attentional control to sustain attention on the target stimulus, and task-related activation is seen in the intraparietal sulcus and frontal eye field when saccades are performed (Corbetta, 1998; Corbetta & Shulman, 2002). Lyle and colleagues have theorized that SIRE occurs because activation in frontoparietal regions contributes to executing top-down attentional control internally when searching memory (Lyle & Edlin, 2015; Lyle & Orsborn, 2011).

SIRE has been found for a variety of test formats and stimuli, enhancing retrieval of memories when top-down attention is required. For example, saccades have been found to increase free recall of target words (Lyle, Logan et al., 2008, Experiment 1; Nieuwenhuis et al., 2013, Experiment 1; Phaf, 2017). Free-recall memory tests often consist of prompts to recall anything and everything from the study phase; these tests provide little environmental support because they present no elements of the original stimuli (Craik, 1983). Participants must elaborate on the cue for themselves by reconstructing the encoded event or items, biasing their memory search in a controlled manner, and evaluating what retrieved information is relevant and accurate. Thus, these tests require greater contributions of top-down attention for accurate and thorough memory retrieval.

On the other end of the spectrum, tests of recognition in general provide a large amount of environmental support because the entirety of an encoded item is presented. However, different recognition tests can create demands for top-down attentional control. To understand these differences, some commonalities of recognition testing must first be understood. On recognition tests, previously studied items presented during the testing phase are known as *targets*, and new items presented during the testing phase are known as *lures*. Correctly identifying a target as such is classified as a *hit*. Incorrectly identifying a target as a lure is classified as a *false alarm*.

SIRE has been found for recognition tests specifically when top-down attentional control is needed. Saccades have been found to increase the ability to discriminate between seen and unseen details following the presentation of misinformation (Lyle & Jacobs, 2010). Top-down attention and source monitoring are necessary to accurately identify information that was presented at study and to inhibit or reject memories of information presented in a later account.

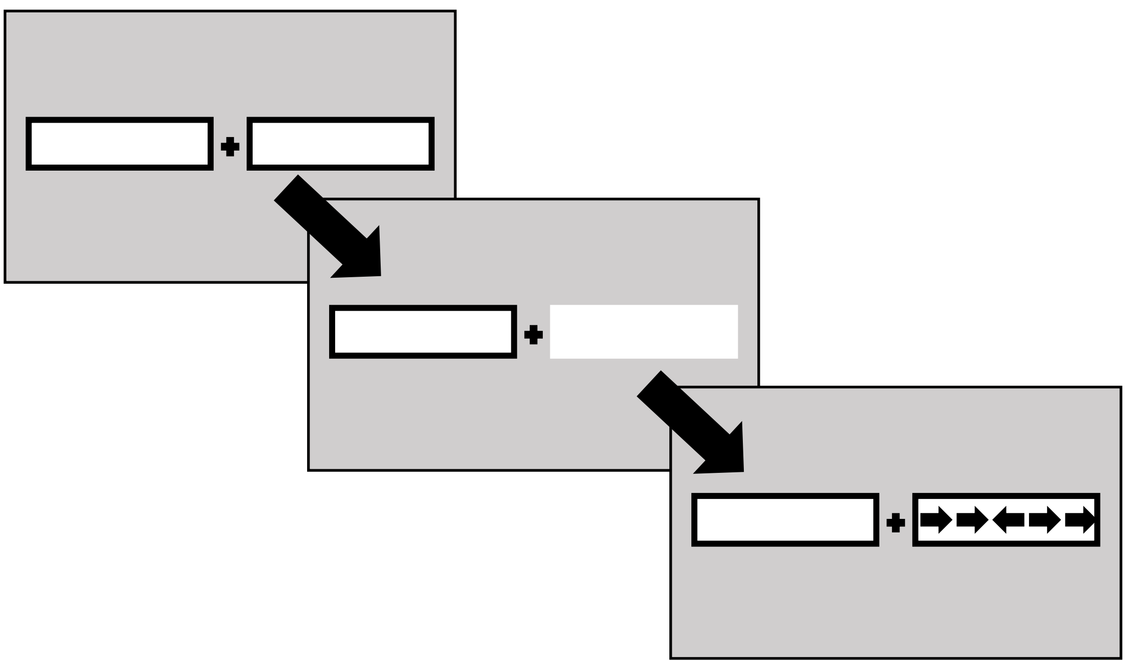
Lyle and Edlin (2015, Experiment 2) found that performing saccades before each half of a recognition test reduced output interference. Output interference is a memory phenomenon where discrimination between targets and lures becomes worse in the later parts of a recognition test (Criss et al., 2011; Malmberg et al., 2012; Norman & Waugh, 1968; Smith, 1971). Criss and colleagues (2011) proposed that output interference stems from the encoding of information during testing. For a recognition test, on trials where the item is recognized as a target, an episodic memory trace is retrieved and then updated; on trials where the item is judged to be a lure, a new episodic trace is stored. Confusion is created because non-target memory traces can share features with the retrieval cue provided. As the test proceeds, interference builds up from the encoding and updating of similar memory traces and memory declines. Lyle and Edlin (2015) hypothesized that, as output interference increases in later stages of testing, top-down attentional control is useful for increasing the accessibility of target memories. On the first half of the recognition test, discrimination of old and new items theoretically needs relatively little top-down attentional control because there has not been a build-up of output interference. Thus, SIRE was only seen for the second half of the test, after sufficient interference had built up and top-down attention was necessary.

Saccades have also been shown to increase the number of correct Remember responses compared to fixation but were not found to affect the number of correct Know responses on recognition tests (Parker et al., 2008, 2009, 2019). Remember responses indicate recognition of a target with additional episodic detail (Tulving, 1985), meaning information associated with the initial presentation of an item, such as thoughts a participant had when a word was first studied (Kihlstrom, 2020; Williams & Lindsay, 2019). Know responses indicate recognition of a target that is lacking in episodic detail. An increase in Remember responses following saccades suggests that saccades increase retrieval of episodic memories containing specific contextual details (Aggleton & Brown, 2006; Parker et al., 2009; Tulving, 1985). Episodic recall requires reconstruction and retrieval of information from encoding, likely facilitated by top-down attentional control.

Outside of memory research, key support for the top-down attentional control account comes from Edlin and Lyle’s (2013) study of the effects of saccades on the revised attention network test (ANT-R; Fan et al., 2009). The ANT-R measures the operation of alerting, orienting, and, of particular interest, executive function networks. On the ANT-R, a series of arrows are briefly displayed to the left or right of a fixation cross, and participants indicate the direction of the center (target) arrow. Target presentation is preceded by no cues, double cues, single valid cues, or single invalid cues. Double cues appear on both sides of the fixation cross. Single cues appear either on the same side as the target (valid) or the opposite side (invalid). When the target is presented, the flankers surrounding the target point in either the same direction (congruent) or the opposite direction (incongruent). See Figure 1 for an example of an ANT-R trial. Performance of the executive function network is operationalized as the difference in response times between trials with congruent and incongruent flankers.

Figure 1

Example of an ANT-R Trial



Note. This example trial includes the inter-trial stimulus (left), a single valid cue (middle), and a target with incongruent flankers (right).

Compared to a fixation control group, performing saccades immediately before completing the ANT-R reduced response times on trials with incongruent flankers and those with invalid cues (Edlin & Lyle, 2013). It therefore seems that saccades enhanced performance when attentional control was required to overcome contradictory information. Incongruent flankers and invalid cues capture attention in a bottom-up fashion, and purposeful attentional control is needed to overcome this. The improvement specifically on trials that require top-down attention to avoid mistakes supports the assertion that saccades potentiate top-down attentional control, and this may be what drives retrieval enhancement.

The top-down attentional control account is further supported by imaging research. Similar attentional control regions, including the superior parietal lobe and frontal eye fields, are implicated in the performance of saccades and the executive function network (Corbetta, 1998; Corbetta & Shulman, 2002; Konrad et al., 2005; Muggleton et al., 2010). Pre-activation of the superior parietal lobe via the performance of saccades may have contributed to participants' ability to ignore incongruent flankers or invalid cues because this region has previously been implicated in ignoring distractors (Kim & Hopfinger, 2010). It is also possible that pre-activation of the frontal eye fields facilitated identification of the target arrow because transcranial magnetic stimulation of frontal eye fields has been found to increase target detection (Grosbras & Paus, 2002).

Individual Differences

Attentional Control

It stands to reason that, if the recruitment of top-down attentional control drives memory enhancement following saccades, individuals who are less likely to engage top-down attention on everyday tasks may benefit most from an attentional intervention. Conversely, individuals who are already more oriented to engage top-down attention without prompting may not experience the same degree of memory enhancement. There are, however, few measures of this specific individual difference. The most widespread questionnaire addressing attentional differences is the Attentional Control Scale (Derryberry & Reed, 2002), which primarily measures externally oriented attentional control and is used primarily in the context of studying psychopathology. Although potentially relevant to studies of SIRE, the Attentional Control Scale does not directly address differences of internal attentional control.

The Attentional Style Questionnaire was developed by Van Calster and colleagues (2018) to measure differences in top-down and bottom-up orientation in attentional control for *both* internal and external stimuli. Individuals who are more top-down oriented are identified as those who more often control their focus, sticking to the task at hand. Individuals who are more bottom-up oriented are identified as those who tend to be distracted by irrelevant stimuli or thoughts. The Attentional Style Questionnaire was developed by performing confirmatory factor analysis and testing goodness of fit, as well as analyzing the relationship between these scores and scores on other measures relating to attention and distraction (Van Calster et al., 2018). These analyses provided evidence that the questionnaire measures individuals' tendency to control attention along both internal and external dimensions. Given the recent development of this measure, there is still much room to explore how scores on the questionnaire relate to behavioral measures of attention as well as if and how this measure may relate to memory performance. It is fitting then to include the Attentional

Style Questionnaire in research of SIRE, because the effects of saccades should uniquely relate to both dimensions addressed by the measure.

Handedness as a Moderating Factor of SIRE

Individuals differ not only in the direction of the hand they use for various tasks (left vs. right), but also in the consistency of their hand usage. *Consistent-handers* consistently use one hand when performing unimanual tasks (Lyle et al., 2012) whereas *inconsistent-handers* are more variable. Consistent-handers have routinely exhibited SIRE, whereas results for inconsistent-handers have been varied.

Handedness consistency has previously been shown to be a moderator of SIRE (Kelley & Lyle, 2020; Lyle, 2018; Lyle & Edlin, 2015; Lyle, Logan et al., 2008). Although one study showed SIRE for inconsistent-handers (Lyle & Jacobs, 2010), most studies have not. Some of these studies have shown that inconsistent-handers are unaffected by saccades. Saccades did not affect inconsistent-handers' recall of details of the perpetrator of a crime or the victim of a theft (Kelley & Lyle, 2020; Lyle, 2018, Experiment 2), nor did they affect inconsistent-handers' recall or recognition of studied words (Lyle & Edlin, 2015, Experiment 2; Lyle, Logan et al., 2008). In other studies, saccades have harmed inconsistent-handers' memory performance. Following saccades, inconsistent-handers recalled less precise information about elements of a staged crime (Kelley & Lyle, 2020), falsely recalled more unstudied words (Lyle, Logan et al., 2008), and had more false alarms on a test of recognition (Lyle, Logan et al., 2008, Experiment 2). Together, these results indicate that handedness consistency may moderate SIRE.

The moderating effect of handedness consistency on SIRE likely relates to findings that neural activation associated with performance of saccades differs depending on handedness consistency. In Petit et al. (2015), inconsistent-handers demonstrated a stronger rightward lateralization of activation than consistent-handers when performing saccades. In Fleck et al. (2018), inconsistent-handers showed an increase in absolute power for the theta frequency band following saccades whereas consistent-handers did not. Although complete neurocognitive accounts remain to be developed, it seems likely that differences in neural structure and function between consistent- and inconsistent-handers impact memory following performance of saccades.

Measuring Handedness. Given that consistent-handers reliably exhibit SIRE, but inconsistent-handers do not, it is important that participants are correctly classified in any experiment that is exploring SIRE. Self-report is the most common way to assess handedness, and multiple handedness inventories are available. One commonly cited measure is the Edinburgh Handedness Inventory, or EHI (Oldfield, 1971). On this inventory, participants indicate their hand preference (direction and frequency) for ten activities: writing, drawing, throwing, using scissors, using a toothbrush, using a knife without a fork, using a spoon, sweeping with a broom (top hand), opening a box lid, and striking a match. Many SIRE studies have utilized a modified version of the EHI with changes to the items, response format, and scoring scheme (see Lyle, McCabe et al., 2008). This version of the EHI, which has no agreed-upon designation, will be referred to here as the EHI-A. The broom and box lid items do not appear on the EHI-A and are instead replaced with opening a jar and using a comb.

The replacement of the broom and box lid items stems from various criticisms of the items. The two items have been criticized for being activities performed with relatively low frequency (Bryden, 1977), making it difficult for respondents to know and report their hand preference for these tasks. Responses to these items have been found to be unstable over time (Flindall & Gonzalez, 2019; Ransil & Schachter, 1994) and to have greater error variance than variance attributable to the handedness construct, indicating that they are sensitive to ambiguity of interpretation (Dragovic, 2004). The problematic items have been found to contribute little to the measurement of handedness, and removal of these items improves the psychometric properties of the inventory (Milenkovic & Dragovic, 2013). In contrast, the jar and comb items have both been shown to be useful in distinguishing between inconsistent- and consistent-handers (Prichard et al., 2020). Direct comparisons between the original EHI and EHI-A have not been made, but the accuracy of handedness classifications using the original items is suspect due to the poor psychometric properties of the broom and box lid items.

Current Experiment

Testing Memory Enhancement of Attention-based Interventions

The top-down attentional control account posits that attention is the key mediator between saccades and retrieval enhancement. If this theory is correct, then attentional tasks other than saccades should also produce retrieval enhancement. Other tasks recruit the same attentional control regions as saccades, and performing these tasks should enhance memory similarly to saccades. Prior research has not explored whether any other task can produce a SIRE-like effect when performed before retrieval. One task that could theoretically enhance retrieval is performing trials of the ANT-R that involve conflict (i.e., incongruent flankers or invalid cues). Prior research has shown that saccades reduced response times on conflict trials of the ANT-R (Edlin & Lyle, 2013). This effect was proposed to have occurred because saccades recruited attentional control processes that were needed to overcome conflict on the ANT-R. It follows that ANT-R conflict trials themselves recruit attentional control processes. Theoretically, the recruitment of those processes could enhance retrieval on a subsequent memory test. By examining whether ANT-R trials have similar results on memory retrieval as saccades, this study is directly testing the theory that saccades recruit top-down attentional control.

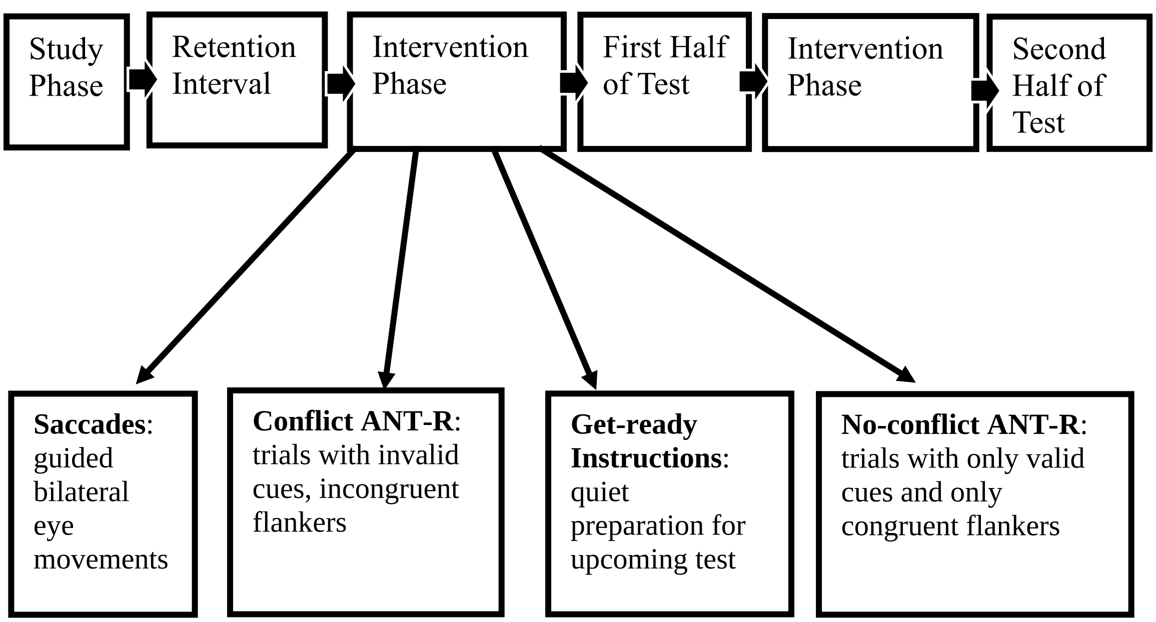
To test whether tasks recruiting top-down attentional control enhance memory performance, four experimental conditions were used. In the *saccades condition*, participants performed visually-guided saccades for 30 seconds by following a flashing dot that alternated between the left and right side of the screen. Based on previous SIRE research, this condition was expected to recruit top-down attentional control regions and enhance subsequent memory retrieval. In the control condition (*get-ready condition*), participants received instructions to mentally prepare for the upcoming memory test, and quietly got ready for 30 seconds. Get-ready instructions were previously found to result in equivalent performance to maintaining fixation (Lyle et al., 2008, Experiment 2), and so were expected to have no effect on attention or memory retrieval.

In the remaining two conditions, participants responded to ANT-R trials for 30 seconds. For one of these conditions, trials sometimes contained conflicting information (incongruent flankers and/or invalid cues) and sometimes contained no conflicting information. This condition will be referred to as the *conflict ANT-R condition*. Previous research has shown that saccades improved performance on the ANT-R, specifically when conflicting information was presented, meaning that there is reason to believe that there is an overlap in recruitment of attentional regions between these two tasks. Thus, the conflict ANT-R condition was expected to recruit top-down attentional regions and enhance subsequent memory retrieval.

To isolate whether specifically top-down attentional recruitment is necessary to produce memory enhancement effects, a final condition was included in which trials never contained conflicting information. This condition will be referred to as the *no-conflict ANT-R condition*. This condition was not predicted to recruit top-down attentional control regions. Participants could rely on bottom-up attentional capture of cues and flankers in the absence of conflicting information, and saccades did not improve performance on ANT-R trials that did not contain conflicting information. Thus, performance in this condition should be similar to performance following get-ready instructions. The four experimental conditions are outlined in Figure 2.

Figure 2

Study Procedure with Descriptions of Each Condition



The current experiment utilized a type of memory test on which SIRE has previously been observed. Saccades have previously been found to reduce output interference on a two-part recognition test (Lyle & Edlin, 2015). The stimuli for the recognition test were specifically chosen to be especially susceptible to output interference. Each target item had a corresponding semantically related lure item (i.e., “actor” and “actress”). This meant that each presented lure had the opportunity to create confusion.

In addition to reducing output interference, saccades have increased the number of correct Remember responses provided for recognition tests (Parker et al., 2008, 2009, 2019). If the potentiation of top-down attentional control drove these previous results, then performing saccades or an abbreviated version of the ANT-R immediately before a recognition-memory test should enhance memory. Specifically, either task should improve performance on the second half of the test, reducing output interference, and increase the amount of Remember responses across both halves. Receiving get-ready instructions or performing no-conflict ANT-R trials should not have this effect; participants’ performance in these two conditions should worsen on the second half of the test compared to the first, and they should have fewer Remember responses than those in the other two conditions.

Accounting for Individual Differences

To study the potential interaction between an attention-based memory intervention and individual attentional style, individual differences in attentional control were measured using the Attentional Style Questionnaire. This measure is designed to address both top-down and bottom-up, as well as internal and external attention. If contributions of top-down attention to the memory search are driving SIRE, then individuals who do not regularly engage top-down attention for everyday tasks should especially benefit from an attentional intervention prior to a memory test and demonstrate retrieval enhancement. On the other hand, individuals who are already practiced and self motivated to engage top-down attention in their day-to-day life may not show much improvement in their memory performance. Memory is clearly an internal target, and thus having a measure of attentional control that includes items addressing internally directed attention may be especially relevant to examining the relationship between attention and memory. Measures focused solely or primarily on individual differences in *external* attention may not accurately reflect individual tendencies in controlling *internal* attention, which is necessary in a dedicated memory search.

To account for the variability in inconsistent-handers' performance following saccades and for the purpose of clarity in the analyses, participants were classified as consistent- or inconsistent-handers, and inconsistent-handers were not included in analyses of condition effects. Because there is variability in how handedness is measured, and some items included on the original EHI are especially suspect, participant handedness was classified using two scoring schemes. One scheme used the 10 original EHI items, and the second scheme used the 10 EHI-A items. Consistency classifications based on the original EHI items were compared to those based on the EHI-A to explore whether the inclusion of the weaker items on the original inventory altered how participants were categorized. The previously described analyses testing for memory enhancement following attentional interventions were run once with consistent-handers as classified with the original EHI and once with consistent-handers as classified by the EHI-A to investigate whether results would be impacted by the specific handedness measure used.

Theoretical and Practical Implications

The current experiment can help broaden our understanding of SIRE and the interaction between memory retrieval and attention. This experiment was designed to replicate previous results, to test a hypothesis stemming from an explanation of the mechanisms underlying SIRE, and to investigate whether individual differences interact with pre-retrieval interventions. Replication of SIRE and empirical support for the prediction that attention-based tasks will enhance memory would reinforce the top-down attentional control account of SIRE. Support for the top-down attentional control account would indicate that the recruitment of top-down attentional control can be beneficial for a seemingly unrelated memory test. Further, an interaction between individual differences in attentional control and performance of attentional tasks would provide more evidence that attention is a key mechanism in SIRE and possibly in enhancement following other interventions. Failure to replicate and/or a lack of support for the proposed hypothesis would undermine the top-down attentional control account, calling into question how specifically attentional tasks and attention in general relate to memory retrieval.

Secondarily, this experiment expands on research on output interference as well as the use of self-report measures for studying individual differences. Output interference has been found for measures of accuracy on recognition tests but has not been tested for Remember/Know judgments specifically. Replication of output interference would further support the existence of this phenomenon, and a failure to replicate could call it into question. Either an extension of output interference showing that Remember responses also decline in the later parts of a test, or results showing no evidence of output interference for Remember responses, could provide insight into why this phenomenon occurs.

The Attentional Style Questionnaire and handedness inventory are both self-report measures of behavior. It is possible that either or both measures have weaknesses in accurately representing the differences they propose to quantify. This will be tested for the handedness inventory by comparing classifications done with the inclusion or replacement of weaker items. The Attentional Style Questionnaire will not be directly tested in this way, but the use of this relatively new measure of attentional differences will provide directions for future investigations into the questionnaire.

Practically, this experiment contributes to the body of evidence testing what interventions might ultimately be used to enhance memory in other settings. Interventions like saccades and the ANT-R are ideal for memory enhancement outside of lab settings because they are utilized at the time of retrieval, take a short amount of time to complete, and can be completed using only a computer. However, in order to confidently recommend and use interventions like this, we must first be certain that they can enhance memory. Understanding when, how, and for whom such interventions work through controlled laboratory studies is essential to applying them in complicated practical settings.

CHAPTER II: METHOD

Participants

Participants were 170 undergraduate students aged 18-30 years (*M* = 19.57, *SD* = 1.77) who participated in return for credit in their psychology courses. The breakdown of participants' gender according to self-report was 118 women, 47 men, and four nonbinary or gender nonconforming individuals; one participant opted not to provide this information. Data from 10 additional participants were excluded due to technological errors (*N* = 4), failure to complete a portion of the study (*N* = 5), or providing the same response for every test item (*N* = 1). There were 113 consistent-handers, categorized using the modified EHI. The number of consistent-handers assigned to each condition is shown in Table 1.

Table 1

Number of Consistent-Handers by Condition

Condition	*N*
Saccades	28 (27)
Conflict ANT-R	28 (26)
No-conflict ANT-R	28 (26)
Get Ready	29 (28)

Note. The number of consistent-handers as classified using the original EHI is noted in parenthesis.

Materials

Materials in this experiment fall into one of three groupings: memory stimuli, experimental tasks, and measures of individual differences. All materials pertaining to each category are described below. Participants only performed one experimental task, and this task varied by condition assignment. All other materials were included in every condition.

Memory Stimuli

Memory stimuli consisted of a list of 100 words of low-to-medium frequency according to the English Lexicon Project (Balota et al., 2002). Half of these words appeared as targets during the study phase, and the other half were used as lures on the memory test. The assignment of words as targets or lures was counterbalanced across participants. For each target item on the recognition test, there was a semantically related lure item (e.g., actor and actress). During the study phase, words appeared in a randomized order in all caps and were displayed on participants’ computer monitors for two seconds each with a 500-ms interstimulus interval. Participants were told to pay attention to each word because they would be tested later, and that they did not need to press any buttons during the study phase.

Stimuli for the retention interval were 60 two-digit addition and subtraction math problems. Each problem appeared on the computer screen for 10 seconds, during which time participants could input their responses using the keyboard.

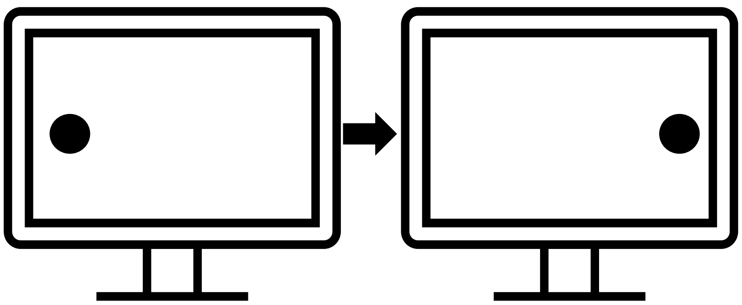
For the test phase, 25 of the studied words were randomly selected to appear on the first half of the test, and the remaining 25 appeared on the second half. The assignment of words to the first or second half of the test was counterbalanced, and the presentation of the words on each half was randomized for each participant. Participants were told to respond to the series of test words by pressing the space bar, F key, or J key on the keyboard. One key indicated that a word was not previously studied; this response option was labeled as New. The words Remember and Know were not used because there is reason to believe participants do not always interpret them in the manner intended by researchers (Migo et al., 2012; Umanath & Coane, 2020). Participants instead were told to press one key for items they can consciously recall studying (i.e., those for which they can remember associated details from the study phase). This response was labeled as Type 1 but will henceforth be referred to as Remember responses. Another key was assigned for items that participants recalled studying, but for which they could not remember any study-phase details. This response was labelled as Type 2 and is equivalent to a Know response. The assignment of response keys to the different labels was counterbalanced, and the response keys appeared on screen with each test word. Both test halves were self-paced.

Experimental Tasks

Saccades. The stimuli for the saccades condition were a computerized sequence presenting a black circle on a white background (see Figure 3). At a viewing distance of 24 in., the circle alternated between 13.5° left and 13.5° right of the vertical midline every 500 ms for 30 s. These stimulus parameters have been used in most prior SIRE studies. Participants received the instructions: “In this task you will see a dot repeatedly appear and disappear. The dot will alternate between the left side of the screen and the right. First the dot will appear on the left, then the right, then the left, then the right, and so on. Your job is to follow the dot with your eyes. Move your eyes left and right in time with the dot. Do not stop moving your eyes until you see a screen telling you that it is okay for you to stop moving your eyes. Please sit so that your chin is in line with the edge of the desk."

Figure 3

Visualization of One Trial of the Saccades Task



Get-ready Instructions. For the get-ready condition, participants were provided with the instructions: "You will now have 30 seconds to get ready for a test on the words you saw earlier." Once the timer began, the computer displayed the words "Please wait," and participants sat quietly and waited.

Conflict ANT-R. Participants were instructed to look at the fixation cross in the center of the screen (see Figure 1). On either side of the fixation cross, there were two rectangles. On each trial, one of the rectangles flashed white to cue the appearance of the target. The cue lasted 100 ms and occurred either immediately, 400 ms, or 800 ms before the appearance of the target. A target arrow with two flanker arrows on either side then appeared in one of the two rectangles for 500 ms. Participants completed three trials with no delay between cue and target, four with a 400 ms delay, and four with an 800 ms delay in a random order. Participants used the arrow keys to indicate the direction of the center arrow. The cues sometimes were valid (on the same side as the target) and sometimes invalid (on the opposite side). The flankers were sometimes congruent with the target (pointing the same direction) and sometimes incongruent (pointing the opposite direction). Participants had a window of 1700 ms following the disappearance of the arrows to provide a response. Participants were instructed to prioritize both speed and accuracy on this task. Completion of these trials took 30 seconds.

No-conflict ANT-R. The instructions, visual display, response keys, and timing were the same for both the conflict and no-conflict ANT-R trials. The no-conflict ANT-R trials only differed in that they contained no invalid cues or incongruent flankers. This meant that flanker arrows always pointed in the same direction as the target arrow, and cues always appeared on the same side as the upcoming target on each trial.

Individual Differences Measures

Attentional Style Questionnaire. The Attentional Style Questionnaire (Van Calster et al., 2018) has participants rate their agreement with 12 statements (Cronbach's $\alpha = .83$) relating to their ability to control attention and avoid distractions. Participants provided their responses using a 6-point Likert scale (1=*completely disagree*, 6=*completely agree*). Five items were reverse scored. Scores range from 12 to 72, with 42 being the midpoint of the scale. Higher scores indicate more bottom-up oriented attentional control, and lower scores indicate more top-down attentional control. For consistent-handers in this study, scores ranged from 23 to 67. The average score was 46.02 ($SD = 8.88$) and the modal score was 45.

Handedness Inventory. Handedness was assessed with a modified version of the EHI (Oldfield, 1971) on which participants indicated their hand preference for everyday activities. The activities included the 10 original EHI items: writing, drawing, throwing, using scissors, using a toothbrush, using a knife without a fork, using a spoon, sweeping with a broom (top hand), opening a box lid, and striking a match. In addition to these items, participants rated their hand preference for the two items that were introduced on the EHI-A: opening a jar and combing hair. Handedness consistency for each participant was scored twice: once with the 10 original EHI items and once with the 10 EHI-A items. Participants indicated their hand preference for all 12 of the activities using the response options *always left*, *sometimes left*, *no preference*, *sometimes right*, or *always right.* Each response option had a corresponding point value of -10, -5, 0, +5, and +10, respectively. Scores for both the original EHI and EHI-A ranged from -100 (exclusive left-handedness) to +100 (exclusive right-handedness) in 5-point intervals. Participants with absolute value scores of 80 or higher were classified as consistent-handers and those with absolute value scores of less than 80 were classified as inconsistent-handers.

Procedure

Participants were randomly assigned to experimental condition (saccades, get-ready instructions, conflict ANT-R trials, or no-conflict ANT-R trials). All participants were informed that they were participating in a study of people’s memory for words. Participants first completed the handedness inventory on paper, then worked through the remaining experimental materials at individual computer stations in sessions of 1 to 5 individuals. A researcher provided verbal instructions for the different phases of the experiment and monitored participation.

At the computer stations, participants first completed the Attentional Style Questionnaire by providing a response using the keyboard number keys. Participants then studied a list of words that were displayed on the computer screen. This task was followed by a 10-minute retention interval, during which participants responded to two-digit addition and subtraction problems. After the retention interval, participants received instructions for their assigned experimental condition. Following the experimental task, participants worked through the first half of the recognition test. At the midway point of the test, participants repeated the same experimental task that they had done before the first half of the test, with the same instructions. Participants then completed the second half of the recognition test. Lastly, participants were debriefed about the purpose of the study. All study procedures were approved by the University Institutional Review Board.

CHAPTER III: RESULTS

Data Analysis

The main purpose of the experiment was to test whether a different attentional task enhances memory as saccades have been shown to do. To investigate this, I tested for test half, condition, and interaction effects on corrected recognition, *d'*, and correct Remember responses for a word recognition test. Corrected recognition was calculated as the difference between the hit and false alarm scores. Discrimination as measured by *d'* was calculated by subtracting the *z* score corresponding to the false-alarm rate from the *z* score corresponding to the hit rate for each participant (Stanislaw & Todorov, 1999). With this calculation, hit or false alarm rates of one or zero mean that *d'* is indeterminate. To combat this, rates of zero and one were recalculated based on the formulas proposed by Macmillan and Kaplan (1985). Rates of one were replaced with (n - .05)/n, and rates of zero were replaced with 0.5/n with n being the number of target or lure trials. There were 25 target and 25 lure trials on each half of the recognition test, so n was equal to 25. Thus, rates of one were converted to equal 0.98 and rates of zero were converted to equal 0.02. The proportion of correct Remember responses was calculated by dividing the number of Remember hits by the total number of target items on each half of the test (25) for each participant.

All dependent variables were submitted to 2 (test half: first or second) × 4 (condition: saccades, conflict ANT-R, no-conflict ANT-R, get ready) mixed-factorial ANOVAs, with test half as a within-subjects factor and condition as a between-subjects factor. I hypothesized that there would be a significant interaction between test half and condition assignment for corrected recognition and discrimination. Specifically, participants receiving get-ready instructions or performing the no-conflict ANT-R would demonstrate output interference, meaning that corrected recognition and discrimination would be worse on the second as compared to the first half of the test for these two conditions. On the other hand, I hypothesized that output interference would be reduced in the saccade and conflict ANT-R conditions, meaning that there would be no significant difference in corrected recognition between test half for these two conditions. To further explore the predicted interaction, two types of planned comparisons were run for all of the dependent variables. First, planned comparisons tested whether overall test performance differed between any of the experimental conditions. Second, planned comparisons tested whether performance differed between the two test halves for each condition separately.

For correct Remember responses, I hypothesized that there would be a main effect of condition, such that saccades and conflict ANT-R conditions would increase recollective experience during recognition memory compared to get-ready and no-conflict ANT-R conditions. Test half was included as a within-subjects independent variable, because it was possible that an interaction may be present. Output interference may be found for recollective experience, meaning that participants may provide fewer Remember responses on the second half of the test than on the first half. Test half was included in this analysis for this reason.

The secondary exploratory analyses addressed the effects of individual differences in attentional control on memory enhancement using attention interventions. The dependent variables of interest were the difference scores of corrected recognition and *d'* between the two test halves, calculated by subtracting the score on the second half of the test from the first. With these measures, higher difference scores indicate greater output interference. The relationship between difference scores and Attentional Style Questionnaire scores were explored through correlation analyses performed separately for each experimental condition. I predicted that individuals in the get-ready or no-conflict ANT-R conditions would show greater output interference as Attentional Style Questionnaire scores increased; this would indicate that bottom-up oriented individuals are more susceptible to output interference. For individuals in the saccade or conflict ANT-R conditions, difference scores would not change with Attentional Style Questionnaire scores because participants in these conditions would not demonstrate output interference as a result of completing the attentional intervention.

To control for handedness interactions with condition, all of the previously outlined analyses only included consistent-handers. To explore whether the inclusion of psychometrically weak items on a self-report measure affects classification of handedness consistency, handedness classification based on the original EHI items and classification based on the EHI-A items were submitted to a McNemar's test. I hypothesized that including items that have been previously found to have poor psychometric properties would alter the classification of some participants' handedness consistency. Specifically, the number of participants classified as consistent using the EHI-A would differ significantly from the number classified as consistent using the original EHI. To further investigate whether any changes in handedness classification affect the results found in memory enhancement studies, the previously discussed ANOVAs and correlations were run once using consistent-handers classified using the EHI-A and once using consistent-handers classified using the original EHI.

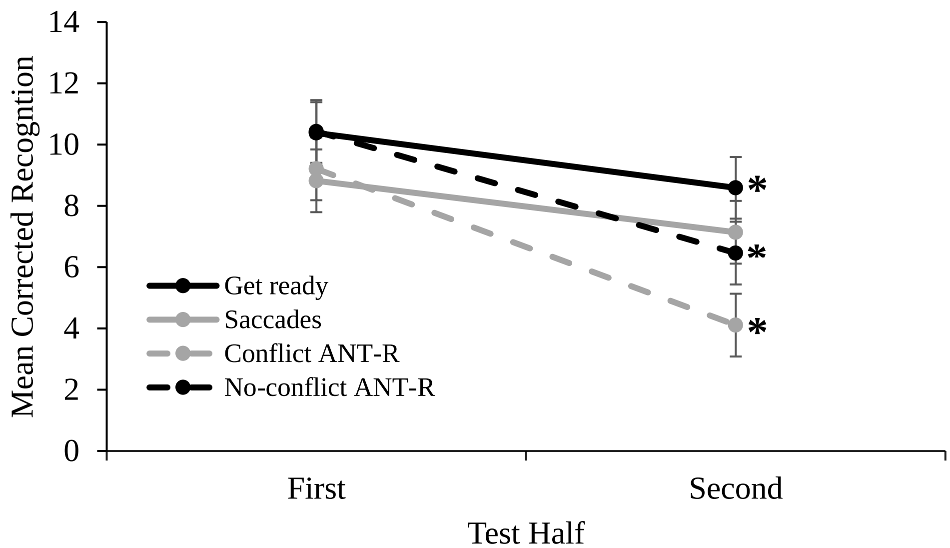
Memory Performance

Accuracy Measures

Corrected Recognition. A mixed factorial ANOVA was run to compare the main effects of test half and experimental condition assignment and the interaction between these two factors. There was a significant difference in corrected recognition based on test half, $F(1, 109) = 29.33$, $p < .001$, $\eta_p^2 = .21$. Participants had significantly lower corrected recognition on the second half of the test ($M = 6.58$, $SE = .51$) than the first half ($M = 9.71$, $SE = .42$). The means for each condition by test half are depicted in Figure 4.

Figure 4

Mean Corrected Recognition by Test Half and Condition



Note. Error bars represent ±1 SE. *$p < 0.05$.

There were no significant differences based on condition, $F(3, 109) = 2.57$, $p = .058$. Planned comparisons showed that, overall, only the get-ready and conflict ANT-R conditions significantly differed from each other, $t(55) = 2.73$, $p = .009$, $d = .72$. Participants in the get-ready condition had higher corrected recognition ($M = 9.48$, $SE = 0.71$) than those in the conflict ANT-R condition ($M = 6.66$, $SE = 0.76$). No other comparisons were statistically significant, all *p*s > .08.

The interaction of test half and condition was not significant, $F(3, 109) = 2.11$, $p = .103$. Planned comparisons revealed that there were significant differences in corrected recognition between the first and second halves of the test for participants in the get-ready, $t(28) = 2.23$, $p = .034$, $d = .41$, conflict ANT-R, $t(27) = 4.55$, $p < .001$, $d = .86$, and no-conflict ANT-R, $t(27) = 2.54$, $p = .017$, $d = .48$, conditions. Participants in these conditions had lower corrected recognition on the second half of the test as compared to the first (see Table 2). Corrected recognition was not significantly different between the two test halves for participants in the saccades condition, $t(27) = 1.63$, $p = .115$.

Table 2

Mean Corrected Recognition (SE in parentheses)

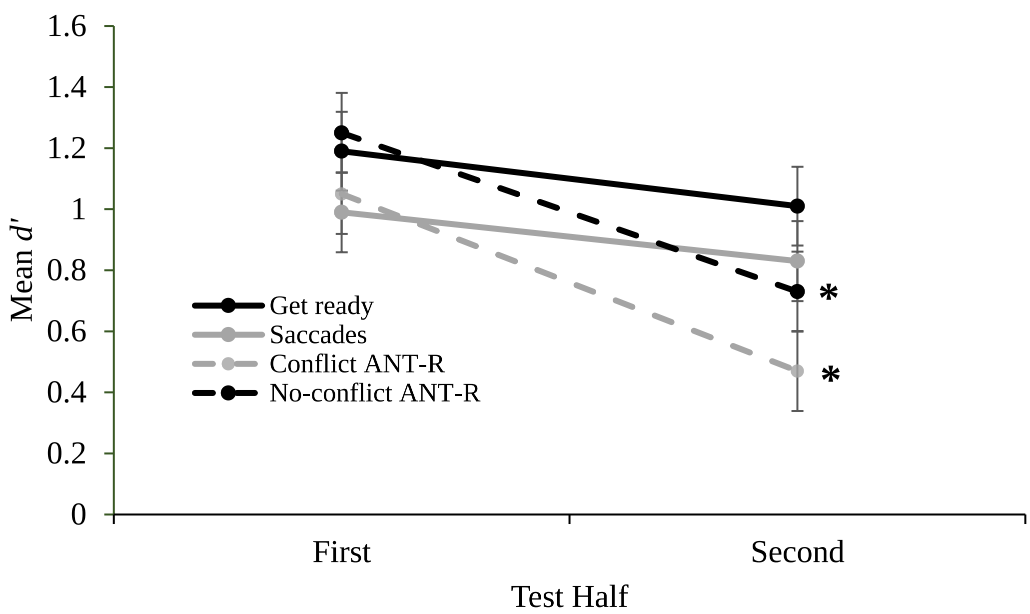
Condition	First Half Corrected Recognition	Second Half Corrected Recognition
Get Ready	10.34 (0.83)	8.59 (0.79)*
Saccades	8.82 (0.78)	7.14 (0.82)
Conflict ANT-R	9.21 (0.75)	4.11 (1.10)*
No-conflict ANT-R	10.43 (0.98)	6.46 (1.29)*

Note. *$p < 0.05$.

Discrimination. Results of a mixed factorial ANOVA indicated that there was a significant difference in *d'* based on test half, $F(1, 109) = 23.85$, $p < .001$, $\eta_p^2 = .18$. Discrimination was worse on the second half of the test ($M = 0.76$, $SE = .07$) than the first half ($M = 1.12$, $SE = .06$). The means for each condition by test half are shown in Figure 5.

Figure 5

Mean d' by Test Half and Condition



Note. Error bars represent ±SE. *$p < 0.05$.

The test of condition effects for discrimination was not significant, $F(3, 109) = 2.20$, $p = .092$. There was not a significant interaction between condition and test half, $F(3, 109) = 2.17$, $p = .095$. Planned comparisons examining the effect of condition in the second test half showed that only the get-ready and conflict ANT-R conditions significantly differed from each other, $t(55) = 2.50$, $p = .015$, $d = .66$. Participants in the get-ready condition had higher *d'* ($M = 1.10$, $SE = 0.09$) than those in the conflict ANT-R condition ($M = 0.76$, $SE = 0.10$). No other comparisons were statistically significant, all *p*s > .09.

Planned comparisons comparing the first and second test halves for each condition revealed that there were significant differences in discrimination for participants in the conflict ANT-R, $t(27) = 4.61$, $p < .001$, $d = .87$, and no-conflict ANT-R, $t(27) = 2.41$, $p = .023$, $d = .46$, conditions. For both conditions, participants had lower discrimination on the second as compared to the first half of the test (see Table 3). There was no significant difference in discrimination between test half for the get-ready, $t(28) = 2.23$, $p = .110$, or the saccades, $t(27) = 1.39$, $p = .176$, conditions.

Table 3

Mean Discrimination (SE in parentheses)

Condition	First Half Corrected Recognition	Second Half Corrected Recognition
Get Ready	1.19 (0.11)	1.01 (0.10)
Saccades	0.99 (0.09)	0.83 (0.09)
Conflict ANT-R	1.05 (0.10)	0.47 (0.13)*
No-conflict ANT-R	1.25 (0.14)	0.73 (0.18)*

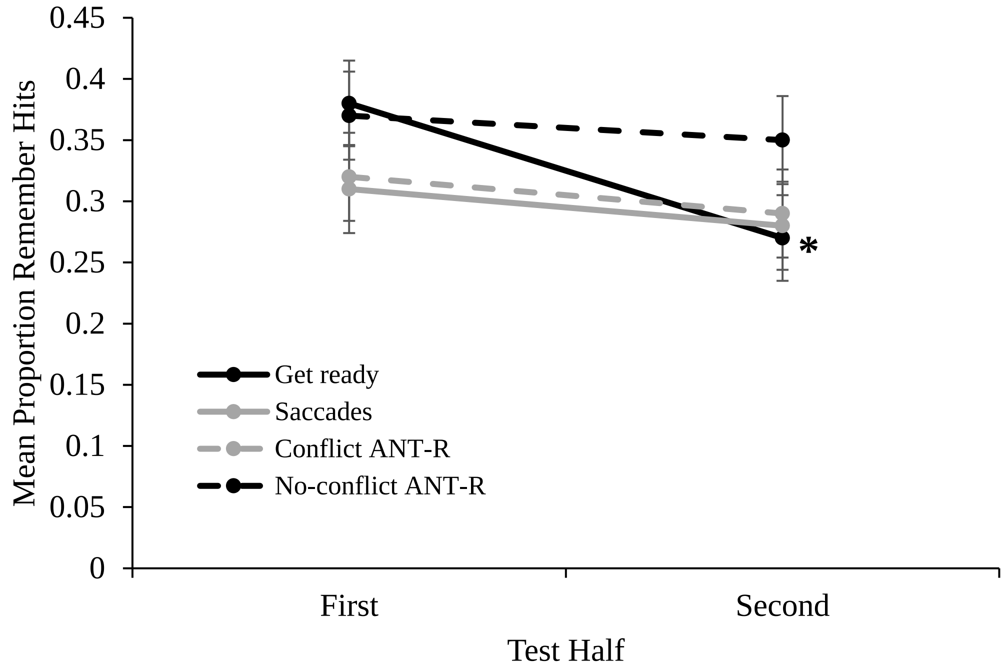
Note. *p <*0.05.*

Recollective Experience

A mixed factorial ANOVA was used to test for main effects of test half and condition assignment as well as an interaction of these two factors. There was a significant difference in the proportion of correct Remember responses based on test half, $F(1, 109) = 8.93$, $p = .003$, $\eta_p^2 = .08$. The proportion of correct Remember responses was lower on the second half of the test ($M = .29$, $SE = .02$) than the first ($M = .35$, $SE = .02$). The means for each condition by test half are presented in Figure 6.

Figure 6

Mean Proportion Correct Hits by Test Half and Condition



Note. Error bars represent ±SE. *$p < 0.05$.

Tests of condition effects were not significant, $F(3, 109) = .91$, $p = .440$. Planned comparisons showed there were no significant differences between any of the experimental conditions for the proportion of Remember hits, all *p*s > .10.

The interaction between condition and test half was not significant, $F(3, 109) = 1.23$, $p = .301$. Planned comparisons revealed that there was a significant difference between the proportion of Remember hits for the first and second half of the test for participants in the get-ready condition, $t(28) = 3.17$, $p = .004$, $d = .59$. Participants in this condition provided more Remember hits on the first half of the test ($M = .38$, $SE = 0.04$) than the second half ($M = .27$, $SE = 0.03$). There were no significant differences between test half for the saccades, $t(27) = 1.35$, $p = .189$, conflict ANT-R, $t(27) = 0.81$, $p = .423$, or no-conflict ANT-R conditions, $t(27) = 0.69$, $p = .495$.

Table 4

Mean Proportion of Remember Hits (SE in parentheses)

Condition	First Half Corrected Recognition	Second Half Corrected Recognition
Get Ready	.38 (0.04)	.27 (0.03)*
Saccades	.31 (0.03)	.26 (0.03)
Conflict ANT-R	.32 (0.04)	.30 (0.04)
No-conflict ANT-R	.37 (0.05)	.35 (0.04)

Note. *$p < 0.05$.

Individual differences

Attentional Control

Correlations between Attentional Style Questionnaire scores and difference scores in corrected recognition and discrimination were examined separately for each experimental condition. There were no significant associations between Attentional Style Questionnaire scores and either of the dependent variables for any of the conditions, *p*s > .20. Because no significant relationships were found, further analyses of possible moderating effects of attentional differences on condition effects were not explored. All of the examined correlations are summarized in Table 2.

Table 5

Simple Correlations between Attentional Style Questionnaire Scores and Memory Performance for Each Experimental Condition

Get-ready Condition	Corrected Recognition	*r* = -.05, *p* = .791
	d'	*r* = -.09, *p* = .640
Saccades Condition	Corrected Recognition	*r* = -.21, *p* = .293
	d'	*r* = -.16, *p* = .418
Conflict ANT-R Condition	Corrected Recognition	*r* = .12, *p* = .553
	d'	*r* = .10, *p* = .615
No-Conflict ANT-R Condition	Corrected Recognition	*r* = .11, *p* = .571
	d'	*r* = .15, *p* = .434

Measuring Handedness

A McNemar's test was used to test whether the difference between the groupings was significant. Results determined that there was not a significant difference in participants classified as consistent or inconsistent using the EHI-A as compared to the original EHI, $p = .238$. Handedness classification differed between the EHI-A and original EHI measures for six participants, all of whom were classified as consistent-handers with the EHI-A and inconsistent-handers with the original EHI. Although the difference was not significant, prior analyses were performed with both categorizations to determine if the difference impacted results. The analyses based on the EHI-A classifications produced the same findings as the original EHI classification. Thus, only the results based on the EHI-A classification are presented in the preceding sections.

CHAPTER IV: DISCUSSION

This study was designed to build on previous research demonstrating that saccades can enhance memory retrieval, an effect known as SIRE. SIRE is predicted to occur because performing saccades activates top-down attentional control regions in the brain, which is proposed to help allocate top-down attention to memory retrieval on a subsequent test. The current study explored this explanation of SIRE by testing whether another task known to rely on top-down attentional control, the ANT-R, would also enhance memory. It was hypothesized that performing saccades or ANT-R trials containing conflicting information—and so requiring top-down attentional control—would enhance memory by reducing output interference and increasing the number of correct Remember responses on a recognition test in comparison to conditions expected to have no effect on attention. Output interference is the phenomenon when memory accuracy decreases in the later part of a test. Remember responses are meant to indicate recognition with additional recollective detail. Both measures were expected to benefit from additional attention given to memory retrieval. The non-attentional tasks were get-ready instructions and no-conflict ANT-R trials. Get-ready instructions simply advised participants to wait and prepare for the test to begin. No-conflict ANT-R trials had no conflicting information on any trial, allowing participants to rely on bottom-up attentional capture of the stimuli. Both conditions were predicted to have no effect on top-down attention for the subsequent test because neither should require top-down attentional control specifically.

Significant main effects were found for test half, demonstrating output interference for all measures. Corrected recognition, discrimination, and correct Remember responses were lower on the second as compared to the first half of the recognition test. This finding replicates previous research showing output interference for accuracy (Criss et al., 2011; Lyle & Edlin, 2015, Experiment 2; Malmberg et al., 2012) and provides new findings of output interference for recollective experience.

SIRE was replicated for corrected recognition, with saccades reducing output interference for this measure. Participants in the other experimental conditions showed a decline in corrected recognition on the second half of the test (see Figure 4). Planned comparisons demonstrated that output interference for discrimination occurred following the conflict and no-conflict ANT-R trials but not following saccades or get-ready instructions—the intended control condition (see Figure 5). In contrast to expectations, conflict ANT-R trials did not enhance retrieval in terms of recognition accuracy or discrimination, and neither saccades nor conflict ANT-R trials increased the proportion of provided Remember responses. Planned comparisons revealed that participants completing conflict ANT-R trials actually performed worse than those receiving get-ready instructions on accuracy and discrimination measures.

Using Attention-based Tasks for Memory Enhancement

Saccades and Accuracy

The lack of output interference following saccades for corrected recognition and discrimination is in line with predictions based on the attentional control account of

SIRE. It has been suggested that top-down attention is necessary on the second half of a recognition test because of the buildup of output interference (Lyle & Edlin, 2015). Saccades then should be specifically beneficial for combatting a decline in accuracy due to output interference, and this was supported by the current study.

However, results related to the saccades condition did not entirely follow predictions. There were no significant main effects or interactions, contradicting predictions that participants performing saccades would have reduced output interference compared to participants performing no-conflict ANT-R trials or receiving get-ready instructions. These results may have been influenced by the statistical power of the experiment. Given the sample size, the current experiment had appropriate power (.80) to detect effect sizes of 0.10 or larger. The effect size for the interaction in the previous experiment (Lyle & Edlin, 2015, Experiment 2) finding reduced output interference was not reported, but the effect sizes for the current interactions and condition main effects were between .06 and .07. Thus, an interaction or main effect of condition may have been detected if a larger sample size had been used.

The lack of output interference in discrimination following the get-ready instructions was surprising. The get-ready instructions had participants sit quietly for 30 seconds with instructions to simply “prepare for the upcoming memory test.” This was meant to be a comparison condition for both performance of saccades and of the ANT-R; participants’ eye movements were not controlled, and they were not asked to provide any motor responses. Lyle and Edlin (2015, Experiment 2) found a reduction in output interference following saccades compared to a fixation condition. It may be the case that participants in the current study were mentally rehearsing the studied words during the waiting period in the get-ready condition. If rehearsal occurred, this act could aid performance on the subsequent recognition test. Saccades may enhance memory compared to fixation because both tasks do not encourage mental rehearsal of target memories. The activation of attentional control regions due to saccades may then be useful for test performance in comparison to the simple distractor task of maintaining fixation.

A previous study (Lyle et al., 2008, Experiment 2) found that providing get-ready instructions resulted in similar memory performance as maintaining fixation. Specifically, discrimination in each of these conditions was not significantly different. However, the specific means for these conditions are not provided in the published article. Additionally, in that study, participants were assigned to one of four conditions: get-ready instructions, fixation, horizontal saccades, or vertical saccades. The get-ready and fixation conditions were collapsed into one group, as were the horizontal and vertical saccades conditions. Although the horizontal and vertical conditions were not significantly different from each other, it is stated that the vertical condition had numerically higher *d'* than the horizontal condition. It is possible that collapsing the conditions may have driven the significant differences found between the eye movements and no eye movements conditions. Performance in the get-ready condition and the horizontal saccades condition may not have significantly differed if they were compared directly, an idea that is supported by the planned comparison results reported in the current experiment.

It is possible that any effects of saccades are especially influenced by study methodology, as proposed by Roberts and colleagues (2020). Across two experiments, these researchers found either no or very weak effects of saccades on memory performance. The experiments were not designed specifically to replicate SIRE results, but performance of the saccades and comparison conditions—as well as the study, retention interval, and testing phases—closely matched previous SIRE studies. The authors postulated that saccades may not have reliable usage as a memory enhancement technique if effects are only being observed for specific designs or from specific laboratories. A strong influence of study methodology on SIRE could explain the similar performance between the saccades and control condition for discrimination.

ANT-R and Accuracy

The current results do not support the prediction that performance of the conflict ANT-R can reduce output interference. Participants performing conflict ANT-R trials had worse corrected recognition and discrimination than participants in the get-ready condition, and showed significant output interference for both of these measures (see Figures 4 and 5). Because the ANT-R is a measure of attentional processes (Fan et al., 2009) and was affected by saccades performed immediately before (Edlin & Lyle, 2013), it is very likely that the activity has some influence on top-down attentional control. However, the results of this study indicate that pre-activating attentional regions may not always be beneficial for memory, as seen by the reduction in output interference following saccades and the worsening performance following the conflict ANT-R.

These findings suggest that conflict ANT-R trials may have resulted in cognitive fatigue or ego depletion (Hagger et al., 2010), reducing performance on the subsequent memory test. Completing conflict ANT-R trials is a more complicated and involved attentional task than performing saccades. Conflict ANT-R trials are more visibly complex than the stimuli for saccades and require self-control and executive functioning to inhibit any irrelevant conflicting information when providing a response to each trial. Maintaining the attention and self-control needed for the conflict ANT-R trials may have taxed cognitive resources, and performance on the memory test may have suffered as a result. Given that the targets and lures on the recognition test were semantically related—making the test more difficult—and that output interference accumulated as the test went on, participants may have been especially susceptible to ego depletion following the conflict ANT-R.

Performance following the no-conflict ANT-R trials matched predictions: participants in this condition demonstrated output interference for both corrected recognition and discrimination. This could provide support for the assertion that this activity has no effect on top-down attentional control or memory performance. However, this assertion is tentative when taking the performance of the participants in the get-ready and conflict ANT-R conditions into consideration. Participants in the no-conflict ANT-R condition were expected to have equivalent performance to those in the get-ready condition. However, participants in the get-ready condition did not show output interference for discrimination. For corrected recognition, participants completing no-conflict ANT-R trials had a numerically greater decline between the first and second half of the test than participants receiving get-ready instructions. Performance following the conflict and no-conflict ANT-R trials were similar, but participants in the conflict ANT-R condition performed numerically worse on each half and had a greater decline between halves. It is possible then that no-conflict ANT-R trials were sufficient to induce some level of ego depletion.

Saccades may occupy a kind of "sweet spot" in terms of attentional activation for subsequent memory searches. Too little attentional activation, as is proposed to occur from maintaining fixation, can result in no benefits for a memory test. Too much attentional activation, as may occur when completing ANT-R trials, can result in worse performance on a memory test. The benefits of pre-activating attentional control regions for memory may be a delicate balancing act, requiring enough engagement without overly taxing one's executive functioning.

Attention Tasks and Recollective Detail

This study provided new information regarding output interference, linking it to recollective experience. Participants provided a lower proportion of correct Remember responses on the second half of the test as compared to the first. Both the replication of output interference and the results regarding recollective experience support Criss and colleagues (2011) model of output interference. The abundant opportunities for errors to occur throughout the test, given the related nature of the targets and lures, is likely to create strong interference that can be seen in the decline in corrected recognition and discrimination from the first to the second half of the test. It follows that output interference would extend to specific measures of Remember hits. Hit rates should be especially affected by output interference because both the updating of old memory traces and the creation of new traces are expected to decrease hit rates (Criss et al, 2011). Remember responses are meant to reflect recognition that relies on episodic recollection of contextual details, and it is logical that this category of memory would be especially disrupted by interference.

Results did not support the prediction that saccades and conflict ANT-R trials would increase correct Remember responses as found in previous studies (Parker et al., 2008, 2009, 2019). The failure to replicate a main effect of saccades for this measure may be related to the test material used. In two of the studies finding an increase in Remember responses, the recognition test was for picture stimuli (Parker et al., 2009, 2019) and the third was for words presented in pairs (Parker et al., 2008). In the current experiment study and test words were all presented individually with no visually distinguishing characteristics. Saccades may be useful for improving recollective detail specifically for visual information. More work is needed to parse the potential usefulness of saccades for recollective detail for a variety of stimuli.

It may also be the case that saccades improve recollective experience for non-visual information specifically by reducing output interference. Although the condition main effect and interaction were not significant, planned comparisons demonstrated that participants in the get-ready condition drove the significant main effect of test half for correct Remember responses. The get-ready condition was the only one to show a significant difference in Remember hits between the first and second halves of the test (see Figure 6). This finding could indicate that the other conditions may have some use in combatting a drop in correct responses that rely on more episodic memory. This is a promising result for SIRE, however, the potential costs to overall accuracy following ANT-R trials may limit the usefulness of such an intervention for tests of recognition.

Individual Differences in Attention

In addition to the main investigation of the attentional control account of SIRE, potentially relevant individual differences were explored. It was predicted that individuals who are more predisposed to engage top-down attention in everyday life may benefit less from performing attentional tasks before retrieval. On the other hand, individuals who are more prone to distraction from bottom-up attentional capture may benefit greatly from a specific attentional task. In contrast to expectations, individual differences in attentional control were not related to memory performance (see Table 5).

Attentional Style Questionnaire score did not significantly relate to memory performance. The Attentional Style Questionnaire (Van Calster et al., 2018) is a self-report measure, and so it is possible that participants do not have an accurate understanding of their own ability to control their attention. Research has not been conducted to compare scores on this questionnaire to any behavioral measures of attention. Participants may then over- or underestimate their ability to control their attention, resulting in a score that does not appropriately quantify their attentional style.

Measuring Handedness

Previous work on SIRE has demonstrated that handedness consistency may be a moderator of SIRE, however, there is variability in how handedness consistency is measured. Handedness consistency was measured in this study using a self-report questionnaire to control for this moderator, and analyses were run to investigate whether the inclusion of weak items affected handedness classification. Although a small number of participants did change classification, the number of participants classified as consistent or inconsistent was not significantly different between two versions of the handedness inventory, and the changes in classification did not affect study results.

The lack of any noticeable changes between which items were used to classify consistency may relate to the finding that the broom and box lid items from the original inventory have been found to contribute little to the measure of handedness (Milenkovic

& Dragovic, 2013). Perhaps these items contribute so little that neither their presence nor absence has a noticeable impact on consistency classifications. Regardless, transparency in the specifics of self-report measures is necessary to further understand handedness as a concept as well as its interactions with interventions like saccades.

Limitations

It is possible that both saccades and the get-ready instructions may have allowed participants to mentally rehearse the studied words prior to each half of the test. However, it seems unlikely that participants mentally rehearsed during saccades. First, mental rehearsal is more likely to occur with get-ready instructions because of the prompt specifically to “prepare for the upcoming memory test.” Because this is left open-ended, participants may interpret “preparing” as mentally reviewing and rehearsing what they studied. For the saccades condition, instructions for the task focus on how participants are meant to move their eyes by focusing on the presented stimulus, and thus participants may not think to rehearse for the test at this time.

Second, if participants did rehearse while performing saccades, previous research would indicate that performance on the memory test is likely to decline. Eye Movement Desensitization and Reprocessing is a therapeutic technique used to treat post-traumatic stress disorder. For this technique, participants recall memories while following a stimulus (usually a therapist’s finger) as it moves back and forth horizontally (Shapiro, 1995), a procedure that is very similar to the saccades condition here. Research on this form of therapy has found that recalling memories while performing eye movements reduces the vividness of the memories (e.g., Maxfield et al., 2008; Leer et al., 2014). One study specifically found that performing eye movements while remembering a previously viewed video increased false memory rates (Houben et al., 2018). Thus, if participants in the current experiment were rehearsing the studied words during saccades, it would be expected that their accuracy and recollective detail would decline. At the very least, memory performance should not be enhanced with simultaneous saccades and mental rehearsal. More work is needed to specifically explore the effects of saccades on memory retrieval performed simultaneously.

The main limitation of the current study is the exclusion of a fixation comparison condition. Most studies finding SIRE have compared memory after saccades to memory after fixation. Given previous findings that performance following fixation was not significantly different than that following get-ready instructions (Lyle et al., 2008, Experiment 2), it was expected that get-ready instructions would be a suitable control condition to compare to both saccades and ANT-R trials. The get-ready instructions were intended to create a condition that was more like what participants would naturally do before a memory test; they were made aware of the test, but their eye movements and behavior were not constrained. With the lack of evidence for output interference in discrimination following the get-ready instructions, it is possible that a) performance following get-ready instructions is not equivalent to performance following fixation and/or b) saccades are more effective for memory enhancement when comparing to fixation. If either of these assertions are supported by future research, the usefulness of saccades is undermined. In practical settings, individuals will not be maintaining fixation prior to a memory test. They are more likely to behave as they did in the get-ready condition in the current experiment, and if saccades do not enhance retrieval in comparison to more naturalistic behaviors, they may not prove beneficial.

Additionally, this study has other limitations related to generalizability. The study was conducted with a relatively homogenous group of college student, young adult, primarily women participants and, as such, results may not be fully generalizable to the broader population or to different demographics. Generalizability is also limited when considering the potential moderating effects of handedness consistency. If SIRE is only seen for a specific handedness demographic, then its practical usefulness is limited to a subset of the population. When considering practical application of saccades in more naturalistic settings, the short retention interval (10 minutes) between the study and test is not likely to occur in settings outside of the laboratory. The simple nature of the test material is also rather far removed from the complex information one must remember in more high-stakes situations, such as an exam. These factors likely limit the generalizability of results. However, the sample collected and procedure used here was very similar to previous research investigating SIRE.

It is possible that current results may have been influenced by the statistical power of the current experiment. An interaction or main effect of condition may have been detected if a larger sample size had been used. However, given the planned comparison results showing that participants receiving get-ready instructions did not demonstrate output interference for discrimination, a larger sample size may not result in the originally predicted outcomes. Instead, it seems that greater statistical power would further confirm detrimental effects of performing the conflict ANT-R.

Related to statistical power, it is possible that there may have been differences in the baseline memory performance of the different experimental conditions. Participants were randomly assigned to each condition with the aim of evenly distributing participants of varying recognition skill and motivation across the four conditions. However, the first half scores were numerically higher for all the dependent measures for participants in the get-ready and no-conflict ANT-R conditions in comparison to the saccades and conflict ANT-R conditions. It is possible that the former and latter groups differed in unmeasured aspects and that this impacted the study results.

Future Directions

Previous research showing SIRE needs to be replicated to better understand the circumstances under which is occurs and the possible mechanisms at play. Multiple studies have found SIRE, however, many of these have differed in stimuli and/or methodology. If saccades are to be considered as a practical intervention for enhancing retrieval, the conditions under which the effect occurs must first be established and confirmed to be reliable and consistent. As such, it is of the essence to carefully control and plan methodology, as well as to be as clear as possible when writing what was done in each experiment and how. Included in this is considering handedness consistency, which should be controlled for and re-tested to determine what relationship may exist between consistency and SIRE. If SIRE is especially sensitive to changes in methodology or is only found in comparison to specific conditions or for specific measures, the use of saccades outside of the laboratory is questionable.

More research needs to be done to further understand the relationship between attention and memory and the possible carry-over effects of task performance before retrieval. Work can be done testing attentional tasks to determine what tasks may be sufficient to enhance retrieval, if any, and what tasks may be detrimental. Potential comparison activities could include a saccades-like task in which participants must press a response key in time with the regularly presented stimulus, rather than simply observing. This would add a motor response as required in the ANT-R but would eliminate any conflicting information or need to identify the presented stimulus, potentially reducing any negative effects of the task for memory. With the numerically better scores of participants in the get-ready condition, inspiration for pre-retrieval tasks can also be pulled from work on mindfulness and memory performance, testing activities that are more explicitly and externally attention-based, like the ANT-R, against those that involve mindful internal attention, like guided meditation. Control conditions can have participants wait and not be constrained in their eye or motor movements (i.e., not ask them to perform a specific task) but have distractions present in the room at this time, such as quiet conversation unrelated to the experiment or allowing participants to use their phones during the wait period. This would both mimic more natural behavior when waiting for an upcoming test and discourage or interfere with mental rehearsal of the studied material.

Finally, more needs to be done to determine the relationship between baseline attentional differences and memory differences. To further explore self-report measures of attentional differences, it could be useful to have participants complete the Attentional Style Questionnaire and to observe them performing various tasks with distractions present to examine their attentional control in the presence of external stimuli. To examine attentional control for internal stimuli, participants could keep a detailed report of when they were able to focus and when they were distracted over a period of days, and this could be compared to their questionnaire scores. Such research could further our understanding of the validity of the Attention Style Questionnaire as well as offer possible avenues for improving the measure to better reflect behavior. To counteract self-report errors or possible issues with the specific measure of attention used, behavioral performance on an attention task can be compared to memory performance. Given the possibility of carry-over effects of the tasks—be they positive or negative—such research would need to be appropriately designed to ensure that performance of either the attention or memory task itself does not affect performance on the other task.

Conclusions

The current experiment explored the attentional control account of SIRE by investigating whether predicted top-down attentional tasks (saccades and conflict ANT-R trials) enhanced memory in comparison to non-attentional tasks (get-ready instructions and no-conflict ANT-R trials) with consideration of individual differences in attentional control and handedness consistency and the measurement of the latter. Results were mixed in their support of the attentional control account. Saccades reduced output interference for corrected recognition and discrimination. However, output interference was also not observed for discrimination following the control condition, and saccades did not enhance recollective detail. Conflict ANT-R trials did not improve memory accuracy or increase recollective detail, and Attentional Style Questionnaire scores did not relate to memory performance. The mixed support for the hypothesis raises some questions regarding the usefulness of SIRE and the theoretical explanations for it. SIRE may only occur in very specific circumstances, and so more research needs to be done to replicate and extend SIRE results. The current results indicate that the relationship between top-down attention and memory may not be straightforward; engagement of top-down attention before a memory test may not always be beneficial. More investigation is needed regarding possible carry-over effects of attention tasks on subsequent memory performance. Research is also needed to investigate the relationship between Attentional Style Questionnaire scores and behavioral measures of attention and memory.

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