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Investigation of the Effect of Repetitive Eye Movements on Episodic Memory

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LAKE FOREST COLLEGE

Senior Thesis

Investigation of the Effect of Repetitive Eye Movements on Episodic Memory

by

Belen Martinez-Caro Aguado

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The report of the investigation undertaken as a
Senior Thesis, to carry one course of credit in
the Department of Psychology

Michael T. Orr
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Abstract

Previous studies show that making horizontal eye movements for thirty seconds prior to a memory task improves performance for right-handed participants. Two theories explain this phenomenon from conflicting perspectives: the inter-hemispheric interaction hypothesis claims eye movements increase interaction between hemispheres, whereas the top-down attentional control hypothesis claims they improve top-down attentional control subsequently improving episodic memory retrieval. The current study tests these theories by investigating the effect of vertical, horizontal, and no-eye movements on the ability of participants to remember words requiring little effort (bottom-up processing) or more significant cognitive effort (top-down). Results did not replicate eye movements improving episodic memory. This may be due to it being a small effect that may require a larger sample size to show.

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Saccade Induced Retrieval Enhancement (SIRE) is a remarkable phenomenon in which making eye movements, known as saccades, from left to right for 30 seconds directly prior to a memory test enhances the retrieval of information compared to fixating on a flashing circle in the center of the screen (Lyle & Martin, 2010). This effect has been shown to arise in various types of tests and stimuli. For instance, these eye movements have been shown to increase recall of words previously studied and decrease false recall of new words (Lyle, Logan, & Roediger III, 2008). In addition, they have increased discrimination of target words from lures and distractors in recognition tests (Parker & Dagnall, 2007). Finally, they have also enhanced the recall of episodic autobiographical memories (Christman, Garvey, Propper, & Phaneuf, 2003). Prior to reviewing the literature on SIRE, I will be explaining the memory systems that SIRE appears to influence and the different techniques that have been constructed to evaluate the memory performance for these memory systems.

In his textbook on cognitive psychology, Goldstein (2015) notes that long-term memory is one of two major systems of memory that is in charge of retaining information for longer time periods. Two divisions of long-term memory are episodic memory and semantic memory, which store different types of information: episodic memory is composed of memories of experiences and semantic memory is composed of memories of facts, vocabulary, concepts and numbers.

As discussed by Tulving, Donaldson and Bower (1972), episodic memory and semantic memory are two individual cognitive processing systems that differ in several ways and have a similar main function. They both collect particular material from the systems that receive perceptual information or from any cognitive system, they then store numerous aspects of the material retrieved, and when necessary, they both relay the material to other systems in the brain responsible for the translation of the information into conscious awareness and a behavior (Tulving et al., 1972). These systems often are related and they can influence each other. One way in which they do so is that prior factual knowledge regarding a specific event can influence the way in which you experience the event, thus semantic memory can influence how the episodic memory is encoded. Another aspect is that autobiographical memories are composed of both semantic and episodic memories (Goldstein, 2015).

On the other hand, the episodic and semantic memory systems differ in some aspects. One of the main aspects differentiating episodic memory from semantic memory is that episodic memory requires “mental time travel” when there is retrieval of the information stored, thus this information is linked to time and space (Tulving et al., 1972). This mental time travel is defined as travelling to the time the event occurred in the past for recollection of the information. This can involve experiencing the emotions felt at the time of the event, and remembering details of the experience apart from the target information, thus inducing a sense of reliving the memory (Goldstein, 2015). For example, you could be telling someone about the time you went sailing and saw a dolphin, and while telling your story you could also remember that the sun was shinning bright that day and all your family was in the sailboat with you. This sort of experience while time travelling mentally was termed ‘remembering’ by Tulving and his colleagues (1972).

Goldstein (2015) notes that when retrieval of semantic information occurs, there is no specific personal experience linked to the information retrieved in the memory. Instead, when there is retrieval of semantic memories, information that is familiar is recalled without reference to personal experience (Goldstein, 2015). For example, you could know that Obama is the current president of the United States. Thus Tulving and colleagues (1972) termed the experience in this memory as ‘knowing’ as it does not require mental time travel through personal experience.

There are two main ways in which retrieval of information from memory can be assessed that are discussed in the literature. One of them is known as the ‘Remember’ versus ‘Know’ recognition procedure (Goldstein, 2015). In this procedure, individuals are shown stimuli previously learned and asked to identify if they a) remembered that stimulus previously appearing, b) if they knew the stimulus had previously appeared based on familiarity, or c) if they did not remember the stimulus (Goldstein, 2015). This procedure allows the researcher to assess the retrieval of both episodic and semantic memory. This is because the ‘Remember’ aspect of the procedure purportedly tests for the episodic memory as previously noted, and the ‘Know’ aspect tests for semantic memory. Another procedure used is free recall, in which participants are asked to recall as many of the previously learned items as possible without providing them with the list of items while they retrieve the information. According to Parker, Relph and Dagnall (2008), the ‘Remember’ versus ‘Know’ recognition procedure taps into both semantic and episodic memory. As recognition appears to have two distinctive memory processes, Propper, Christman and Phaneuf (2005) suggest recall may be a more pure measure for assessing of episodic memory, even though no completely pure form exists to fully dissociate both processes.

I will next review the current literature on Saccade Induced Retrieval Enhancement (SIRE) involvement in semantic and episodic memory. Then, I will discuss the evidence showing SIRE in recognition and recall procedures, followed by examining the two theories that attempt to explain the cause of SIRE, namely the *Interhemispheric Interaction Hypothesis* and the *Top-down Attentional Control Hypothesis*. Finally, I will evaluate the ramifications of SIRE in Alzheimer's and the Eye Movement Desensitization and Reprocessing (EMDR) therapy used in PTSD treatment.

Saccadic Induced Retrieval Enhancement in Semantic Versus Episodic Memory

Tulving and colleagues (1994) as cited by Propper and Christman (2008) suggested a model of episodic memory called the Hemispheric Encoding/Retrieval Asymmetry (HERA) model. This model proposed that the encoding of episodic memory occurs in the left hemisphere, and the retrieval of the information encoded occurs in the right hemisphere. On the other hand, this model proposed that semantic memory is encoded and retrieved only in the left hemisphere. In confirmation, a study conducted by Habib, Nyberg and Tulving (2003) demonstrated that the left hemisphere of the prefrontral cortex is most active during the encoding stage of episodic memory, and the right hemisphere of the prefrontal cortex is most active during the retrieval stage.

SIRE has been studied in both episodic and semantic memory, and the evidence suggests that the effect only appears to occur in measures of episodic memory. This may be due to the fact that the encoding and retrieval of episodic memory occur in different hemispheres of the brain, and so there was must be some interaction between the two hemispheres to ensure efficient retrieval of the information encoded. SIRE could affect the interaction between the hemispheres (Christman et al., 2003; Parker, Parkin & Dagnall, 2013).

Christman et al. (2003) conducted two experiments to assess the involvement of SIRE on episodic memory. Episodic memory was assessed using a recognition test, and implicit memory was assessed using a word fragment completion task. A total of 36 words were presented to participants for memorization, after which they completed a filler task for a 30-minute retention interval. Following this break, participants performed the saccade task of the condition they were assigned to.

Participants in the horizontal saccadic condition (HS) moved their eyes to follow a black dot moving from left to right, and in the vertical saccadic condition (VS) followed a black dot moving up and down on a white background. If they were assigned to the fixation condition (FX), they maintained fixation on a stationary black dot and then they completed the memory test after the filler task. Half of the participants completed the episodic memory task in which they were shown a list of 72 words consisting of the 36 previously shown words and 36 new words, and were asked to identify the words they remembered seeing. The other half of participants completed the implicit memory task in which they were given a list of 72 word fragments. Half of the word fragments were created from 36 of the words they had previously seen and the other half were 36 words they have not seen before. For this task, participants were asked to complete as many of the word fragments as they could, without being told they had previously seen some of the words.

A 3 (Eye Movement Type: Saccadic, Smooth Pursuit, or No eye movement) x 2 (Task Type: Recognition or Fragment Completion) Analysis of Variance (ANOVA) was calculated for the horizontal and the vertical conditions. In the horizontal condition, the recognition task had significantly higher performance than the fixation task (p=.006). In contrast, there was no significant difference between eye movement types in the word fragment task. This showed that the SIRE appeared to influence the performance of participants completing the recognition task and seemed to have no influence on their performance in the word fragment task.

An analysis of hits and false alarms in the recognition task revealed a 2.6% increase in hit rates from 79.7% in the fixation condition to 81.8% in the horizontal saccadic condition. This analysis also showed a 75.2% decrease in the false alarm rate from 6.6% in the fixation condition to 1.7% in the horizontal saccadic condition, thus showing that the horizontal eye movement condition lead to improved episodic memory accuracy. When analyzing the word fragment completion task, there were no significant differences found between any of the eye movement conditions. Thus, SIRE did not improve semantic memory in this study.

To summarize, the findings of the Christman et al. (2003) experiment demonstrate that discrimination in the recognition task was enhanced by horizontal saccades. This shows that SIRE is present in the recognition task, and as this task was measuring episodic memory, these results suggest the SIRE therefore occurs in episodic memory. In addition, no effect of SIRE was found in the word fragment task, thus suggesting that it is not found in semantic memory. However, the participants learned the same words and were given either a recognition test or a word fragment test with the purpose of testing different types of memory. Whether this methodology actually succeeds in separating the effects of SIRE on semantic versus episodic memory is questionable, though. Participants are learned the same information in both tasks, so it is possible that it was encoded in exactly the same regardless of whether participants were assigned to the recognition or word fragment task.

A second experiment reported in the same paper by Christman et al. (2003) examined the generalizability of these previously mentioned findings to real world autobiographical and hence episodic memories. Participants were asked to keep a journal of personal events for a total of six days, and record 10 unusual events that occurred. These journals were collected on the seventh day, and participants were asked to recall the contents about two weeks afterwards. Before being tested, participants performed the saccade task (HS, VS, or FX) of the condition they were assigned to. The same tasks used in the first experiment were used for the second; however, the fixation task differed in that it consisted of a flashing circle changing colors in the center of the screen for 30 seconds.

A one-way ANOVA of accuracy scores (expressed as *d'* values) per eye movement task revealed that there was a main effect for eye movement condition, exploration of which indicated that the horizontal saccade condition had higher accuracy recall of episodic memories ($M = 1.79$) compared to the fixation condition ($M = 1.06$). In addition, relative to the fixation condition, the horizontal saccade condition had a 18.9% increase in hits (from 37.0% to 44.0%), and a 70% decrease in false alarms (from 17.7% to 5.3%). These results demonstrate that horizontal eye movements caused an increase in episodic retrieval for autobiographical memories and a decrease in retrieval of false memories, thus suggesting that SIRE is present in real world episodic memories (Christman et al., 2003).

Additionally, Parker et al. (2013) also investigated the presence of SIRE on episodic and semantic aspects of autobiographical memories. A total of 69 participants were tested on specific personal events to assess episodic autobiographical memory, friends and teachers' names to assess semantic autobiographical memory, and category examples to assess general semantic memory.

Three 3 (Eye Movement Type: Horizontal, Vertical, or Fixation) x 2 (Autobiographical Memory Period: 5-11 years, or 12-18 years) x 3 (Recall Period: 30s vs. 60s vs. 90s) ANOVAs were calculated for the number of items recalled of each type (i.e., episodic autobiographical memories, semantic autobiographical, and general semantic). There was a main effect of eye movement type for episodic autobiographical memory, $F(2, 66)=3.57$, $p=.03$. For further analysis of the main effect, individual t-tests were conducted comparing eye movement types in pairs: horizontal vs vertical ($p=.09$), horizontal vs fixation ($p=.01$), and vertical vs fixation ($p=.09$). The comparable ANOVAs calculated for number of both semantic autobiographical and general semantic memories revealed no main effects, thus not showing an effect of SIRE on these types of semantic memory.

As the only significant effect of saccades was that of horizontal saccades in episodic memories, these results further support Christman et al.'s (2003) findings that showed repetitive saccadic eye movements can enhance the retrieval of episodic memories but not semantic memories, either general or autobiographical (Parker et al., 2013).

Overall, these studies suggest that SIRE only appears to occur in episodic memory. This is as expected by the Hemispheric Encoding/Retrieval Asymmetry model since only episodic memory involves the interaction between both hemispheres of the brain as encoding occurs in the left hemisphere and retrieval occurs in the right hemisphere. However, there are some limitations to the experiments. Specifically, in the first experiment conducted by Christman et al. (2003), there was no chance to make a clear dissociation between the remembering and knowing aspects of the recognition task, thus it is hard to conclude that SIRE only occurred in episodic memory. In addition, the autobiographical experiments (i.e., Christman et al., 2003, Exp 2; Parker et al., 2013) collected information in diaries that came from the participants themselves, thus there was no appropriate way to assess the validity of the information provided by participants. Moreover, three experiments are not enough to verify that this effect is present only in episodic memory, especially if there is no clear distinction that the measurements made were purely of episodic memory or semantic memory, independent of each other. Nonetheless, there is currently more evidence that supports the presence of SIRE in episodic memory and thus the current study will investigate SIRE in episodic memory to further add knowledge to that body of literature. The remainder of the paper will only focus on discussing methodologies that purport to measure episodic memory.

Saccade Induced Retrieval Enhancement and Recognition Memory Testing

The dual-process model of recognition memory uses familiarity and recollection. According to Parker et al. (2008), the familiarity process of recognition occurs as an automatic process of comparing the test item to all the items already stored in memory: when a match is found, a recognition decision is made. The second process they discuss is recollection. Parker et al., (2008) state relies on a retrieval mechanism consisting of elaborative or associative information, and they suggest this retrieval mechanism is used by episodic memory. Evidence shows that SIRE positively influenced the recollection aspect of recognition memory, with no effect shown for the familiarity aspect (Parker et al., 2008). In addition, false alarms were decreased for individuals that moved their eyes horizontally (Parker and Dagnall, 2007; Christman et al., 2003). Thus SIRE was present only in the recollection aspect of recognition memory, which purportedly assesses episodic memory, and thus the recollection aspect of the recognition procedure is proposed to assess episodic memory individually.

As previously mentioned, Tulving et al. (1972) termed semantic memory as the ‘know’ memory and episodic memory as the ‘remember’ memory. According to Parker et al. (2008), when it comes to recognition tasks, familiarity reflects the ‘know’ memory and recollection reflects the ‘remember’ memory. Thus, to assess the effects of HS on both of the processes involved in recognition tasks, Parker et al. (2008) used a ’remember’ versus ‘know’ procedure in the memory test. ‘Remember’ was thought to indicate recollection and ‘know’ indicated familiarity. An associative recognition test was also utilized, in which participants had to distinguish the pairs previously shown to them from a list of the studied items and rearranged studied items. To correctly recall pairs previously shown, a participant would have to use recollection, and not simple familiarity matching.

A total of 96 participants were presented 100 word pairs to study. Participants then continued to complete a saccade task; either a HS, VS or FX task for 30 seconds. Half of the participants were tested using the ‘remember’ vs ‘know’ recognition test, and the other half using the associative recognition test. For the first memory test they were shown a list of 60 words consisting of 30 previously seen and 30 new words. Instructions were to specify each word they recognized and judge whether they ‘remembered’ seeing it, they ‘knew’ they had seen it, or whether they ‘guessed’ their response. For the second memory test participants were shown a list of word pairs, consisting of pairs identical to the study list and rearranged pairs of the same studied words. They were instructed to indicate if the pairs were identical or rearranged compared to those previously seen.

The proportions of hits for ‘remember’ responses was evaluated with an ANOVA with eye movement condition as the between-subjects factor. There was a significant effect of the eye movement condition, $F(2,45)=8.92$, $p=.001$. There was a significantly higher proportion of hits for ‘remember’ responses for the HS ($M = 0.45$) condition in comparison to both the FX ($M = 0.31$) and VS ($M = 0.32$) conditions ($p=.002$ and $p=.001$, respectively). An ANOVA for the ‘know’ responses revealed no significant effect of the type of eye movement condition on the proportion of hits for ‘know’ responses $F(2,45)=1.76$, $p=.18$. The mean proportions of ‘know’ responses were $M = 0.11$ for the HS condition in comparison to the FX ($M = 0.12$) and VS ($M = 0.16$) conditions. This pattern of findings suggests that the horizontal saccades only influenced the episodic (i.e., ‘remember’) memory aspect of the memory task, and had no effect on the semantic (i.e., ‘know’) aspect. This is in accordance with the proposal of the previous section in which SIRE reportedly only affected episodic memory.

An ANOVA analysis of the associative recognition hit rate yielded a significant effect of eye movement condition $F(2, 45) = 5.59$, $p=.007$. The HS ($M = 0.73$) condition had a significantly higher hit rate when compared to either the FX ($M = 0.59$) and VS ($M = 0.63$) conditions (Parker et al., 2008).

To summarize, of the many comparisons that were made in first experiment of the Parker et al. (2008) study, the ‘remember’ responses and the associative recognition responses were the only ones to show significance, and for both of these tests, only the HS condition showed enhancement of memory. These findings suggest that repetitive horizontal saccades can enhance the recollection component of recognition memory as episodic memory recall. Furthermore, according to Parker et al. (2008), since the ‘know’ responses showed no significance, this suggests that familiarity processes were not influenced. Thus, saccades do not appear to affect these superficial and automatic processes of semantic memory, but rather only appear to enhance episodic memory.

The Christman et al. (2003) paper previously mentioned also applied recognition testing procedures. Because the results obtained in this study showed that the HS made by participants enhanced their hit rate and decreased their false alarm rate while performing a recognition test, this is further evidence that SIRE affects the recognition memory aspect of episodic memory.

Recognition memory testing also has a false memory component, in which individuals state they remember a word as previously seen when the word was never included in the learning list. In Parker et al. (2008), false recall was also assessed. Two ANOVAs analyzing the false alarm rate for ‘remember’ and ‘know’ responses individually revealed a significant main effect of the type of eye movement performed, $F(2,45)=5.31$, $p=.009$ and $F(2,45)=7.42$, $p=.002$, respectively. The ‘remember’ responses had a significantly lower proportion of false alarms in the HS ($M = 0.04$) condition compared to the FX condition (*M* = 0.10). In addition, the VS (*M* = 0.05) condition had significantly lower false alarm responses compared to FX condition. However, there was no significant difference for the HS and VS conditions (*p*=0.26). For the 'know' responses, the HS (*M* = .09) condition had a significantly lower false recall when compared to either FX (*M* = 0.18) or VS (*M* = 0.19) conditions (Parker et al., 2008). These findings demonstrate that HS and VS enhanced memory accuracy for the 'remember' aspect of the recognition task, and thus enhanced episodic memory. However, there was also an increase of memory accuracy produced by HS in the 'know' aspect of the recognition. Because Propper and Christman (2004) suggested that the 'know' aspect is linked to semantic memory, the Parker et al., (2008) findings contradict the claim that SIRE only affects episodic memory and not semantic memory. On the other hand, SIRE may only decrease false alarm rates, but not increase retrieval for semantic memory.

To look further into false recall, Parker and Dagnall (2007) conducted an experiment using the Deese-Roediger-McDermott (DRM) paradigm to further investigate the reduction of false recognition in episodic memory as a result of HS. The DRM paradigm is designed to produce large amounts of false memories. Researchers hypothesized that following horizontal saccades (HS), participants would have reduction in false recognition and an enhancement in true recognition.

There were a total of 102 participants, randomly assigned to either of three conditions: HS, VS or FX for a total duration of 30 seconds. Participants were presented 10 lists of words, each consisting of 15 words, spoken out by a male voice. Subsequently, participants completed their assigned saccade task. Then they completed a recognition test in which they were presented with a total of 90 words: 10 critical lures which were new words highly associated to the learned words, 40 words from the 150 previously learned words, and 40 non-presented words as new words. Participants were instructed to identify whether they had previously seen the word or if the word was new.

A one-way ANOVA test of the proportion of 'yes' responses to the studied words revealed a main effect, $F(2,99)=14.24$, $p<.001$. The results showed that participants following the HS condition had a significantly higher mean proportion of 'yes' responses to the studied words (0.66) compared to both VS (0.53) and FX (0.50) conditions. In addition, analysis of the proportion of 'yes' answers to critical lures showed a significant effect of the eye movements, $F(2,99)=18.03$, $p<.001$. There was a significantly lower proportion for the HS (0.50) condition compared to VS (0.76) and FX (0.78) conditions, indicating lower false memory for HS. Furthermore, similar results were found when analyzing the proportion of 'yes' answers to non-studied non-critical words, with the HS condition having a significantly lower proportion (0.07) compared to VS (0.13) and FX (0.15) conditions, $F(2,99)=5.14$, $p=.007$ (Parker & Dagnall, 2007).

Another contribution of the Parker and Dagnall (2007) study was that the words were presented by voice whereas all other studies in the literature presented the words visually to participants. Thus, the Parker and Dagnall (2007) study expands the generalizability of prior results in this body of literature. Nevertheless, the results still showed that participants in the horizontal condition had lower false recall. Thus horizontal saccades appeared to enhance true recognition and decrease false recognition.

In summary, the SIRE effect has been found in recognition tests for episodic memory. However, since recognition memory procedure confounds two known processes, recollection and familiarity, it is most likely involving the retrieval of both semantic and episodic memory. Because of this, using a recall procedure may be a more appropriate way to test SIRE on episodic memory individually, as it could be more able to tease apart episodic memory from semantic memory.

Saccade Induced Retrieval Enhancement and Recall Memory Testing

An alternatively used and more efficient method for directly testing episodic memory is recall (free recall) memory tests. Propper et al. (2005) suggest recall could be a purer measurement of episodic memory, rather than the dual-processes involved in recognition. Studies using free recall as the method of memory assessment have shown that SIRE is present in autobiographical memories (Christman et al., Exp 2, 2003), in tasks involving emotional and neutral words (Nieuwenhuis, Elzinga, Ras, Berends, Duijs, Samara & Slagter, 2013), and in normal verbal tasks (Lyle et al., 2008).

The second experiment reported by Christman et al. (2003) examined episodic autobiographical memories using a free recall task. As previously discussed, the results found there was saccade induced retrieval enhancement (SIRE) for participants who made HS prior to free recall of information. Thus the Christman et al. paper demonstrates that SIRE is present in free recall tests of episodic memory, most importantly, it is present in autobiographical memory and so is applicable to real world memories.

An experiment by Nieuwenhuis et al. (2013) replicated results that showed HS enhancing retrieval of information during a free recall task. Nieuwenhuis et al. (2013) assessed SIRE on emotionally neutral and negative word lists. A total of 50 participants were shown a total of 72 words with neutral (i.e., flute) or negative emotions (i.e., anger). After a one-minute filler task, participants completed a HS or FX task. As soon as this task was completed, participants were asked to write as many of the words previously shown as they could remember.

The participants in the HS condition recalled significantly more words (M = 11) than those in the FX condition (M = 8.5) as shown in a significant ANOVA, $F(1,48)=23.0$, $p<.001$. Once more, the results of this study show that HS enhanced memory retrieval in free recall task of episodic memory (Nieuwenhuis, et al., 2013).

Lyle et al. (2008) conducted a study in which their first experiment examined SIRE on a free recall memory task. A total of 142 participants were shown a total of 50 words to study. Following this, they performed the saccade condition they were assigned to: HS or FX. Subsequently, participants were asked to recall as many of the words previously shown as possible. There was no delay between any of the tasks in the study.

An independent samples *t*-test showed that the participants remembered a significantly greater number of words after completing the HS task ($M = 15.4$) compared to the FX task ($M = 12.4$) (p=.03). In addition, they had significantly lower false recall following HS ($M = .51$ words) compared to the FX (M =.93 words). These results demonstrate that participants who did HS performed better in the recall task than those who did not. Once again, this shows that the eye movements influenced the episodic memory of participants (Lyle et al., 2008).

The three studies reviewed in this section demonstrate that SIRE is present in episodic memory, and they do so by utilizing the free recall method of testing memory retrieval. Since participants were not shown any of the previously learned material during the recall test, familiarity was purported to have no effect on the retrieval of words, thus semantic memory should not have been involved in the retrieval process. Free recall has been suggested to more purely test for episodic memory and thus is proposed to be a more appropriate measure for this type of memory. Even though there may be some debate as to whether free recall of a list of words is a pure method of measuring episodic memory, this was chosen as the procedure to be used for the current study in order to be consistent with previous studies in the literature.

Saccade Induced Retrieval Enhancement and Handedness

An important aspect of the research completed on SIRE is the factor of handedness and its role in the episodic memory of individuals and the influence in SIRE.

To measure handedness, the original or modified version of the Edinburgh Handedness Inventory first developed by Oldfield (1971) was used in every experiment discussed in this paper. An individuals' handedness is the extent to which they use either hand (left or right) to perform daily activities. Handedness can be measured as a function of directionality of hand or degree of consistency. When focusing on the directionality, a researcher would concentrate on which hand (left or right) is the dominant hand. However, consistency measures the extent to which a specific hand, right or left, is used as the dominant hand in certain daily activities, regardless of direction of hand. The degree of consistency is the same for people who are dominantly left handed or dominantly right handed, and SIRE produces a positive effect of memory on these individuals (Lyle, Hanaver-Torrez, Hackländer & Edlin, 2012) as well as decreasing false recall memory (Lyle et al., 2008). Individuals who are inconsistently handed, using both their left and right hand for daily activities more equally, have been shown to have a better baseline memory accuracy without SIRE (Propper & Christman, 2004) and a larger corpus callosum than consistently handed individuals (Luders, Cherbuin, Thompson, Gutman, Anstey, Sachdev, & Toga, 2010). Therefore, handedness is an important factor to take into account when studying memory for the purpose of discrimination of participants' degree of handedness, especially if SIRE is the effect to be investigated, as it only appears to have a positive effect, if any, on individuals who are consistently handed.

The corpus callosum is an area located in between the left and right hemispheres of the brain, and acts as a connection of both hemispheres. This allows for the communication and cooperation of processes involved in each individual hemisphere (Breedlove, Watson and Rosenzweig, 2010). Due to the encoding of episodic memory occurring in the left hemisphere and the retrieval occurring in the right hemisphere, interaction of the two hemispheres is essential for episodic memory (Propper &

Christman, 2008). Therefore, the corpus callosum plays an important role in the integration of episodic memory information. Further evidence of the importance of the corpus callosum in episodic memory comes from studies of patients who had compromised interhemispheric processing from split-brain surgery. One consequence of the split-brain surgery was impaired episodic memory but intact semantic memory (Propper & Christman, 2004).

Handedness has been linked to the size of an individual's corpus callosum as a way to indirectly measure its size. Previous research suggests that left-handed and ambidextrous individuals have larger corpus callosum than right-handed individuals. However, some research does not show a relationship between handedness and the size of the corpus callosum (Lyle and Martin, 2010). This discrepancy in the findings may largely be due to the classification of handedness used across studies. Luders et al., (2010) has suggested that size of the corpus callosum has more to do with the consistency of handedness rather than the direction of the dominant hand (left or right hand.

Luders et al. (2010) conducted an experiment aimed to focus on the relationship between the degree of consistency in hand use and the size of the corpus callosum. The researchers hypothesized that inconsistent participants would have a larger callosal size, disregarding the direction of the handedness. There were a total of 398 participants. The Edinburgh Handedness Inventory was used to measure degree of handedness of participants, classifying them as moderately lateralized left-handed, or strongly, moderately or weakly lateralized right-hand based on the scores obtained. There were a total of 361 right-handed participants and 37 left-handed participants. Three-dimensional MRI images were obtained in the coronal plane to assess the corpus callosum size of each participant.

Luders et al. (2010) found multiple significant negative correlations between degree of consistency and callosal thickness (r=-1 to r=0, p<.05). Lower handedness lateralization scores were associated with thicker corpus callosum measures, regardless of direction of handedness. When less lateralized left-handed (more inconsistent) participants were compared to more lateralized right-handed participants (more consistent), the inconsistent participants had a larger corpus callosum size. When the more lateralized left-handed were compared to the less lateralized right-handed participants, the latter had a larger corpus callosum size (Luders et al., 2010). These results show that lateralization regardless of the direction of handedness is a key marker in the size of the corpus callosum, meaning that less lateralized individuals have a larger corpus callosum and thus have greater interaction between the two hemispheres. Although one limitation of the Luders et al. study is that there were far more right handed than left handed participants, the results still suggest that individuals will perform differently on tests of episodic memory retrieval depending on their handedness consistency, and so the measurement of such is important to consider.

According to Propper and Christman (2004), previous research has found that episodic memory performance is higher amongst inconsistent participants when performing free recall tests, however these results have not been successfully replicated with recognition tests. Thus Propper and Christman (2004) conducted two experiments to assess the baseline performance of individuals on a 'remember' versus 'know' recognition test procedure. The hypothesis stated that inconsistently handed participants would have a higher number of 'remember' judgments on the recognition test, and consistently handed participants would have higher 'know' judgments. Participants were shown a total of 36 words during the study phase. Then they filled out the Edinburgh Handedness Inventory as a distractor activity for a total of two minutes. They were classified as consistently right handed if they obtained a score of 75 or above, or classified as inconsistently handed if they obtained a score in between 45 and 70.

When analyzing the results, hits were considered as correctly recognized words, and false alarms were considered as distractors being recognized as previously presented words. A mixed ANOVA of response type ('remember' vs 'know') by handedness strength showed that overall participants significantly remembered items ($M = 20.28$) occurring more times than they knew ($M = 13.87$) of them occurring. There was a strong interaction between the response type of the participants (remember vs knowing) and the consistency of handedness, $F(1,45)=4.72$, $p<.05$. Inconsistently handed participants were significantly more likely to report that they remembered ($M = 24.58$ vs $M = 18.8$) an item been previously shown, and consistently right-handed participants were significantly more likely to report they knew ($M = 15.51$) that an item had been previously shown in comparison to inconsistent participants ($M = 9.08$). Further analysis revealed that participants who reported they 'remembered' an item were significantly more accurate, with inconsistent participants ($M = 22.42$) being more accurate than consistently right-handed participants ($M = 16.23$) (Propper & Christman, 2004)

The researchers replicated these results in a second experiment that showed an overall greater number of 'remember' responses than 'know'. In addition, there was an interaction with degree of consistency, showing that inconsistent participants had a significantly higher number of 'remember' responses ($M = 21.83$) compared to consistently right-handed participants ($M = 15.61$).

These findings are important as they show that consistently handed individuals remembered information more on 'knowing' compared to inconsistent handed individuals who remembered information more on 'remembering'. Even though there were no conclusive differences found for overall recognition accuracy between inconsistently and consistently handed participants in both experiments, the overall results suggest that inconsistent participants had higher episodic memory accuracy, and thus had higher interhemispheric interaction. These findings further add evidence to previous research that suggest that individuals with higher interhemispheric interaction have higher baseline episodic memory accuracy. This higher baseline of memory accuracy is important as it suggests that individuals that are inconsistently handed have an advantage in episodic memory retrieval over those that are consistently handed.

Lyle et al. (2012) investigated this baseline memory accuracy and the potential for enhancement via saccades for both consistently and inconsistently handed individuals. Previous research shows the SIRE effect is only present in consistently right-handed individuals, however this research fails to make a distinction of consistency by only categorizing participants as strongly right-handers or non-strongly right-handed. Thus Lyle at al. (2012) investigated SIRE on consistency of handedness regardless of the hand, and compared it to the direction (left or right hand). The researchers hypothesized that the consistently handed individuals would have a lower performance score in comparison to inconsistently handed individuals when completing the fixation task (FX). On the other hand, consistently handed individuals would show SIRE when completing the horizontal saccade task (HS).

Subjects were grouped as consistently left-handed or right-handed, or inconsistently left-handed or right-handed using the Edinburgh Handedness Inventory. Participants who obtained a score of +80 or above were classified as consistently right handed, and participants who obtained an -80 or below score were classified as consistently left handed. Any participants in between these scores were classified as inconsistently left handed (negative score above -80) or inconsistently right handed (positive score below +80).

The pretest activities were either a HS or FX task. Participants then engaged in an associative recognition task, in which they had to learn word pairs. When participants were tested, they had to identify whether the pair shown was the identical pair they had learned or a rearrangement of the pair. The response times and latency were documented. They completed this task twice, and the pretest activity was within-subjects, either HS or FX task was performed first.

Results from the handedness tests showed that degree of consistency was the same for left- and right-handed individuals. A 2 (consistency) x 2 (direction) x 2 (pretest activity) mixed-design analysis of variance was performed. The only results that were significant were the consistency compared to the pretest activity $F(1, 116) = 4.59$, $p=.034$. As per the hypothesis, when participants performed the FX task, the inconsistent individuals had a higher discrimination rate of word pairs ($M = 1.18$), compared to consistent individuals ($M = 0.83$) ($p=.024$). Hits and false alarms were also examined, and the results showed that inconsistently handed individuals made significantly fewer false alarms ($M = 0.22$) than consistently handed individuals ($M = 0.30$, $p=.003$); and they made more hits ($M = 0.61$), compared to consistently handed participants ($M = 0.58$, $p=.158$) when performing the FX task. This replicates the previous findings suggesting that inconsistently handed individuals have higher baseline memory accuracy than consistently handed individuals.

When examining the effect of the HS task, there was a significant decrease in discrimination rates for inconsistently right-handed individuals ($M = 0.98$, $p=.049$). However, the saccade task showed significant enhancement of discrimination for consistently handed individuals ($M = 1.02$, $p=.045$). Following the HS task, consistently handed participants had significantly higher hits ($M = 0.60$) compared to their performance following FX ($M = 0.57$, $p=.047$), however there was no significant reduction of false alarms. Following the HS task, inconsistently handed participants had significantly higher false alarms (*M* = 0.26, *p*=.029). These results also showed that as predicted, SIRE occurred for consistently handed participants, and not for inconsistent ones (Lyle et al., 2012).

The Lyle et al. (2012) study added further evidence showing that consistency, rather than direction, played an important role in the interaction of the eye movement activity with memory accuracy, as it was not important for memory performance if the participant was left or right handed. Thus Luders et al. (2010) suggested that consistency is a better measurement of baseline episodic memory and corpus callosum size than direction of handedness. Most importantly, the Luders et al. (2010) study showed that SIRE has a positive effect on the memory of consistent handed individuals, thus suggesting SIRE was a possibility of overcoming lower baseline memory accuracy. Furthermore, this study showed that the eye movement task had a negative effect on the memory of inconsistently handed participants.

In the study previously mentioned, conducted by Lyle et al. (2008) there was a significant interaction between handedness and eye movement task in the analysis of false recall, in which consistently right-handed participants had significantly lower false recall following the HS task (*M* = .51) compared to FX task (*M* =.93), however there was a significantly greater false recall for inconsistently right-handed participants following the HS task (*M* = .93) compared to the FX task (*M* =.31). This once more demonstrates that making the horizontal saccades did not have a benefit for inconsistently handed participants, but rather harmed their retrieval accuracy. This is important because it indicates that the inconsistently handed individuals appear to lose the advantage they originally had over the consistently handed individuals, of greater baseline memory accuracy, as a result of making the same saccades that enhance memory for consistently handed individuals. Due to this finding, the current senior research study included only consistently handed individuals. In addition, due to time constraints, only consistently right-handed individuals were recruited in the current study, as there are more right handed individuals in the population and thus they are easier to recruit.

In general, various studies have shown that horizontal eye movements enhanced the retrieval of episodic memories (Christman et al., 2003; Lyle et al., 2008; Lyle et al., 2012: Nieuwenhuis et al, 2013; Parker & Dagnall, 2007; Parker et al., 2008; Parker et al., 2013). The results of these studies show support for the *Interhemispheric Interaction Hypothesis*, therefore the next section will only refer to pertinent sections of these results to help explain the hypothesis.

Theory One: Interhemispheric Interaction Hypothesis

The *Interhemispheric Interaction Hypothesis* (Christman, et al., 2003). explains SIRE by stating that making horizontal saccades increases the interaction between the two hemispheres of the brain by equalizing the stimulation of both hemispheres. This increase in interaction then enhances episodic memory processing, as the retrieval of this type of memory requires interaction between the hemispheres to some degree (Propper & Christman, 2008).

Past research has suggested that episodic memory information is encoded in the left hemisphere, and retrieval of this information is then based on the right hemisphere (Habib et al., 2003). Hence, successful retrieval of the information requires proper interaction between the two hemispheres. If the interhemispheric interaction would be increased, then retrieval should be enhanced (Parker et al., 2013).

Participants with normal hemispheric commissures retrieve information more accurately than participants with split brains (Lyle et al., 2008). More specifically, individuals with compromised interhemispheric processing from split-brain surgery had impaired episodic memory, however semantic memory was intact. Thus there must be an interaction between the hemispheres playing an important role in episodic memory processing (Propper & Christman, 2004).

The interaction between the two hemispheres is mediated by the corpus callosum, a cranial structure connecting both the left and right hemispheres (Breedlove et al., 2010). The size of the corpus callosum appears to have an effect on the retrieval accuracy of episodic memory. Individuals with a larger corpus callosum had a higher performance in episodic memory retrieval, giving them a memory advantage over individuals with a smaller sized corpus callosum. Therefore, a bigger corpus callosum should mean a higher degree of interaction between the hemispheres (Luders et al., 2010).

Individuals with a smaller corpus callosum have a disadvantage as they are suggested to have less interaction between the hemispheres. A way in which this disadvantage has been decreased in the previously mentioned research is through horizontal saccades (SIRE), which have demonstrated an enhancement of episodic memory retrieval for such individuals (Christman et al., 2003; Lyle et al., 2008; Lyle et al., 2012; Nieuwenhuis et al., 2013; Parker & Dagnall, 2007; Parker et al., 2008; Parker et al, 2013; and Propper & Christman, 2008). SIRE shows no effect on semantic memory, which purportedly occurs in one hemisphere. Thus it only appears to help with dual hemispheric processes, so it should have influence over the interaction of the hemispheres (Christman et al., 2003; Parker et al., 2013).

According to Christman et al. (2003), past research on rapid eye movement during sleep demonstrates that the eye movements during sleep are primarily composed of horizontal saccades. In addition, encephalographic research has shown a significant increase of interhemispheric EEG coherence during REM sleep. Combining both of these findings suggests that there is increased interhemispheric coherence due to the horizontal saccades (Christman et al., 2003).

Christman and Propper (2008) suggest that there is a neurobiological framework that allows horizontal saccades to enhance episodic memory processing via the increased interaction between hemispheres through the corpus callosum. Past research has demonstrated that eye movements to the left or right of the visual field specifically activate the contralateral hemisphere, thus repetitive left and right eye movements should continuously stimulate both of the hemispheres. Therefore Christman et al. (2003) formulated the *Interhemispheric Interaction Hypothesis*, which is based on three postulates: horizontal saccades equalize the activation of the hemispheres; this in turn balances out for one hemisphere being more active than the other during retrieval therefore there is more efficient interaction with the less active hemisphere; and finally that this increased interaction enhances the retrieval of episodic memory because retrieval requires some degree of interaction between the hemispheres.

According to an unpublished paper by Christman and Butler (2005) the theory suggests that vertical and/or smooth pursuit eye movements should have little or no effect on relative hemispheric activation or interhemispheric interaction. Christman et al. (2003) analyzed the effect of saccades and smooth pursuit eye movements on memory performance. Horizontal saccades produced a marginally significant higher performance compared to the smooth pursuit eye movements (p=.055). In addition, results showed that the performance of individuals making vertical saccades had a performance score between horizontal saccades and fixation. This implies that smooth pursuit eye movements and vertical saccades do not have the same effect on the episodic memory as horizontal saccades, and thus do not appear to increase the interaction between the left and right hemispheres enough for enhancement of retrieval.

Samara, Elzinga, Slagter and Nieuwenhuis (2011) conducted a study with the purpose of investigating interhemispheric coherence in electroencephalogram data following horizontal saccades. Samara et al. (2011) hypothesized that EEG coherence would increase or change succeeding the horizontal saccades task. Considering past research discussed that this increase is important for episodic retrieval, the increase or change in EEG coherence should correlate positively with the recall results.

The Edinburgh Handedness Inventory was used to assess handedness. To be classified as consistently right-handed and thus included in the study, participants had to obtain a score of +8.0 or more out of a total of +10.0. Participants in the study were asked to come to the lab two times, in which they learned a list of 72 words consisting of both neutral and emotional words. After a 30-minute interval, they performed a saccade task, HS or FX. EEG data were collected prior to and soon after the saccade task. Following this, they were asked to recall as many of the words previously learned as possible.

Paired-samples *t*-tests were conducted to analyze the saccade task, and results showed a significantly higher number of emotional words remembered in the HS task ($M = 5.9$) compared to the FX task ($M = 4.5$), thus there was an enhancement of retrieval by making HS (p=.026).

In the analysis of the EEG coherence data, the only significant result was an amplitude coherence decline in the alpha band for the HS and increase in the FX. Other tests did not reveal a significant effect of saccades on interhemispheric coherence. No changes were found to have any effect on the recall performance (Samara et al., 2011). In addition, another study showed that gamma waves in EEG coherence were decreased following horizontal saccades (Propper, Pierce, Geisler, Christman & Bellorado, 2007).

These results of EEG coherence may challenge the interhemispheric interaction hypothesis that states that there is an increase of interhemispheric interaction that leads to enhancement of retrieval. The Samara et al. (2011) study showed that there was actually a decrease in interhemispheric interaction when performing horizontal saccades and there seemed to be no influence on recall memory, and thus does not provide evidence of the interaction of the two hemispheres as an explanation for SIRE.

In view of the fact that Samara et al. (2011) found no increase of interhemispheric interaction following horizontal saccades, Lyle and Martin (2010) conducted a study with the purpose of testing the interhemispheric interaction theory by investigating the effects of saccades on a task that can be performed with or without the need of interhemispheric interaction known as the simple letter-matching task.

Two uppercase letters used as probes were shown either to the left or the right of the fixation cross in the center of the screen. The target letter was a lowercase letter that was shown below the central horizontal line on the left or right side of the midline. If it was shown on the same side as the matching uppercase letter, this would be in the same visual field and there was no requirement for interhemispheric interaction and the trial was considered within-hemisphere. If the letter was shown in a different visual field, participants would require interhemispheric interaction to process the information and detect a match, thus it was considered an across-hemisphere trial. Participants were instructed to indicate as quickly as possible if the target letter matched any of the two uppercase letters shown simultaneously.

Researchers predicted that if SIRE would occurred due to an increase in interhemispheric interaction, then saccades should increase accuracy and decrease response time in comparison to the fixation task. Participants were categorized as strongly right handed if they obtained a score of +80 or above on the Edinburgh Handedness Inventory, and not strongly right-handed if they obtained a score below that. They then performed the letter-matching task in four different blocks, each consisting of

56 match trials and 56 no match trials. Participants performed a saccade task before each block, either a FX or HS task for a total of two times each. Response reaction times and accuracy were measured.

An ANOVA on the accuracy of the matching trials revealed a significantly higher proportion of correct responses following HS (M = 0.90) in within-hemisphere trials in comparison to the FX (M = 0.88). The across-hemisphere trials had the same accuracy for both tasks (M = 0.91). In the analysis of reaction times, there were no significant difference between the HS task and the FX task for both across- and within-hemisphere trials. In addition, not strongly right-handed participants (M = 0.92) were significantly more accurate than strongly right-handed participants (M = 0.88).

As accuracy was lower for the across-hemisphere trials following HS, these results are not consistent with the *Interhemispheric Interaction Hypothesis*. Most importantly, there was no difference in relation to handedness consistency, which contradicts the theory in regards to past research suggesting that strongly right-handed individuals should be affected by the eye movements to a larger degree than the not strongly right-handed participants (Lyle & Martin, 2010). This suggests that the size of the corpus callosum may not have an effect on the enhancement of retrieval, and thus the interaction of the hemispheres have no influence on this enhancement.

In summary, then, the *Interhemispheric Interaction Hypothesis* has received mixed support, at best. Studies of SIRE in horizontal eye movements by Christman et al. (2003), Lyle et al. (2008), Lyle et al. (2012), Nieuwenhuis et al. (2013), Parker & Dagnall (2007), Parker et al. (2008), Parker et al. (2013), and Propper & Christman (2008) show some support for this theory. In contrast, studies of EEG interhemispheric coherence during horizontal eye movements by Propper et al. (2007) and Samara et al. (2011), as well a study of SIRE on across-hemispheric versus unihemispheric tasks by Lyle et al. (2010) fail to support the hypothesis.

Theory Two: Top-Down Attentional Control Hypothesis

Due to the results that challenge the *Interhemispheric Interaction Hypothesis*, Lyle and Martin (2010) proposed another possible explanation for the increase of retrieval following saccades, later termed *Top-Down Attentional Control Hypothesis* by Lyle and Edlin (2014). Lyle and Martin (2010) suggested that the saccades alter attentional processes within each hemisphere but do not necessarily alter interhemispheric connections. Their evidence is that within-hemispheric trials are more attentionally demanding as they contain double the information in one visual field, and considering that the results showed higher accuracy following saccades, Lyle and Martin proposed that the saccades enhanced attentional processes subsequently used for retrieval of information. More specifically, they proposed that enhancement of retrieval occurred by shortly augmenting top-down attentional control due to the increased activation of the intraparietal sulcus, which is involved in attentional processes, via saccades performed prior to recall (Lyle & Martin, 2010).

They put forward that since the saccade task is a goal-oriented task, thus a top-down task itself, engaging in this task is what activates top-down attentional control processes in the duration of the task. Thus rather than directly enhancing retrieval, the saccades made prior to retrieval enhance cognition, and so the effect does not occur in tasks that do not depend on high levels of top-down attentional control (Lyle & Martin, 2010). In Christman et al. (2003), there was no effect of saccades in the word fragment completion task. In this task, they were not asked to identify whether words were new or old, they were just required to complete the word fragments, which could have been performed without the previously shown words. This task does not require high levels of top-down attentional control, and the saccades had no effect on performance, which demonstrates that this effect works on the top-down attentional control processes.

To investigate the involvement of attentional processes, Edlin and Lyle (2013) conducted a study on the attention network test (ANT). As previous research has not investigated the effects of saccade execution on attentional processing, the purpose of this study was to examine the performance on a revised version of the attention network test following either a HS task or a FX task. This attention network test is focused on assessing three areas: alerting, orienting, and executive function. Edlin and Lyle (2013) hypothesized that HS would increase attentional control in the executive function network for consistently handed individuals. They also predicted that these saccades would have no influence on or reduce the attentional control of inconsistent handed individuals.

A modified Edinburgh Handedness Inventory was used to assess participants' handedness, with a score of +80 or above as consistently handed, and the remainder as inconsistently handed. Participants were given 24 trials of the ANT-R to practice, and then they performed either a HS or FX task. Subsequently they performed a block of ANT-R trials for a total of seven minutes. This order was repeated for each of the remaining three blocks of ANT-R. In each trial, they were shown a target arrow, with a flanker arrow on either side showing direction as congruent or incongruent with the target. The arrows appeared on the left or the right side of the center of the screen for a total of 500 milliseconds. There were cues shown at the valid locations (75%) or at invalid locations (25%) at different time intervals (0 ms, 400 ms, or 800 ms) prior to the onset of the target stimulus.

To measure control of attention, the reaction time on the congruent versus incongruent trials was assessed, to measure the executive function component of the attention network test. Analysis of these data revealed that there was a significantly smaller reaction time cost following HS (*M* = 152.19 ms) in comparison to FX (*M* = 175.04 ms) for incongruent flankers. This was due to the significant reduction in reaction time for incongruent trials by HS (*M* = 797.96 ms) in comparison to FX (*M* = 842.31 ms). This effect was not significant for congruent trails. HS had reduced reaction time for both congruent and incongruent flankers in the invalid cue condition alone.

Edlin and Lyle's interpretation of these results is that saccades appeared to reduce the reaction time of individuals given incongruent information, as incongruent flankers and/or invalid spatial cue, by increasing attentional control and so allowing for them to overcome the incongruent information they were provided with. As results overall showed an increase in performance in the executive function portion of the attentional network test following HS, this suggests that the enhancement of attentional control is a possible cause for the saccade induced (cognition) enhancement.

This enhancement due to the goal-driven maintenance of attention during the horizontal saccade task, which leads to subsequent attentional control during episodic memory retrieval (Edlin & Lyle, 2013). Due to the fact that the task involves a simple black circle moving to fixed alternating locations against a white background, it does not capture the attention of the participants in a bottom-up fashion. Therefore, to be able to maintain focus on the alternating black circle, participants have to apply some amount of top-down attentional control (Lyle & Edlin, 2014).

Lyle and Edlin (2014) discussed some neuroimaging studies showing that when repetitive saccades are performed, the frontoparietal network of the brain is activated, including the intraparietal sulcus that is believed to work with top-down attentional control. In addition, while performing episodic retrieval tasks, regions of this network appear to be activated. Thus Lyle and Edlin (2014) further added to the *Top-Down*

Attentional Hypothesis by suggesting that performing the saccade task would shortly activate top-down attentional control before retrieval. This short activation would increase the subsequent operation of this same mechanism during the episodic retrieval task. They proposed that the increase in operation would help bring the items to be remembered into consciousness, thus additional activation of the mechanism should allow for recall of a higher proportion of items as well as help bring harder to remember items into consciousness (Lyle & Edlin, 2014).

Lyle and Edlin (2014) also investigated a phenomenon known as retrieval-induced forgetting, in which practice of retrieval items in certain categories inhibits the retrieval of other items within the same category. They manipulated this by choosing certain categories for practice (i.e. fruits), and only half the words within that same category be practiced, while the other half not (practiced: orange, lemon, and strawberry; not practiced: banana, mango, and tomato). This manipulation important because it is principally more challenging to remember items that were not practiced within a category that was practiced previously (i.e., tomato), compared to practiced items (i.e., orange). Among various factors causing this effect, one involves the output interference created when a subject retrieves practiced items (Pr+) before they retrieve nonpracticed items (Pr-) in the same category. Thus, if top-down attentional processing allows for bringing of these items into consciousness, SIRE should then promote higher retrieval of nonpracticed items in the same category as practiced items for HS rather than FX. In general, they proposed that eye movements should decrease retrieval-induced forgetting.

In their first experiment, Lyle and Edlin (2014) used a free recall task as their memory test procedure. The proportional recall of nonpracticed items from practiced (Pr-) and nonpracticed categories (Nrp) was analyzed by eye movement condition. A mixed ANOVA revealed that for both the HS and FX tasks, there were significantly more

Nrp (*M* = 0.44) recalled than Rp- (*M* = 0.39). However, the difference between these proportions was smaller for the horizontal saccades as there was higher recall of Rp- following HS (*M* = 0.41) in comparison to FX (*M* = 0.36).

The saccade task increased the retrieval of nonpracticed items from practiced categories, thus increased retrieval of words classified as most difficult to access. This suggests that the saccade task decreased the effect of retrieval-induced forgetting, by bringing harder to access words into consciousness via an enhancement of top-down attentional processes. The researchers stated it is significant to discuss that the saccade execution tasks had no effect on the retrieval of practiced items in practiced categories, thus had no effect on the words easiest to remember (Lyle & Edlin, 2014).

Saccade Induced Retrieval Enhancement and Vertical Eye Movements

In contradiction to the interhemispheric hypothesis, the top-down attentional control hypothesis suggests that vertical saccades should also produce SIRE, as these types of eye movements are also goal-oriented, and thus involve activation of top-down attentional control prior to retrieval of episodic memories (Lyle & Edlin, 2014). There have been a mixture of results found in this area, with some studies showing that vertical saccades also produce SIRE (Lyle et al., 2008; Lyle & Edlin, 2014), however other studies show that the vertical saccades had performance scores between HS and FX (Christman, 2003), or had no positive effect on memory retrieval (Parker & Dagnall, 2007).

Lyle and Edlin (2014) included vertical saccades (VS) in their second experiment. They utilized a recognition task, in which output interference occurred through adding more probes to the second part of the recognition task to make it harder to access episodic memories. Top-down attention in the second part should facilitate reduction of output interference. Thus researchers predicted that performing VS would facilitate the recognition of targets in the second part of the study, hence decreasing output interference, compared to a FX task.

Partly due to output interference, there was a significantly lower proportion of hits in the second list shown ($M = 0.72$) in comparison to the first list ($M = 0.77$). These findings show that the information in the second lists, which included probes, was more difficult to access. Mixed ANOVAs revealed that the VS task had significantly higher discrimination in comparison to the FX task ($p = 0.011$). As they had higher discrimination, this showed VS reduced the retrieval impairment created by the probed second list. This demonstrates that the VS task increase top-down attentional control to help in overcoming the output interference created by the probes in the second list. Most importantly, this suggests that vertical saccades also produce SIRE and so it contradicts the *Interhemispheric Interaction Hypothesis*, which states that horizontal eye movements alone cause this effect.

Lyle et al. (2008) also showed that both VS and HS benefited participants who were consistently right-handed. However, Christman et al. (2003) found that the performance scores of individuals performing VS were in between the scores of those who performed HS (highest scores) and the FX task (lowest). On the other hand, Parker and Dagnall (2007) obtained results that showed that there was no difference in the scores of participants performing VS and FX tasks. In addition, the results revealed that the VS produced significantly lower performance scores than the HS (Parker & Dagnall, 2007).

The *Top-Down Attentional Control Hypothesis* suggests that vertical saccades should have a similar enhancement of memory retrieval to horizontal saccades, however past research has obtained mixed results regarding the effect of vertical saccades on episodic memory retrieval. Thus the current study included vertical saccades as one of the saccade tasks to further investigate their influence on episodic memory retrieval, and as a way to distinguish which hypothesis is supported by results obtained.

Effect of Saccades Before Encoding

All previously mentioned research has examined the retrieval stage of memory. But an earlier stage of memory is encoding which is the first stage of memory that involves information from perceptual or cognitive systems to be received and integrated in memory (Tulving et al., 1972). Previous research has not examined the effect of saccades prior to encoding. Thus, Christman and Butler's (2005) unpublished study was the first to investigate if there was an effect of saccades on the retrieval of information if these saccades were performed before encoding.

Participants were shown a total of 36 words to study. The eye movement tasks were either a horizontal saccades condition or fixation. Participants either performed the HS task before encoding and retrieval, only before encoding, only before retrieval, or not at all for either of two memory tasks. Both eye movement tasks were performed, so if the HS task was not done, then a participant would do the FX task. To assess retrieval of memory, participants either performed a recall test or a word fragment completion task of the previously shown words.

An analysis of hits revealed a significant main effect of performing saccades before encoding (p =.003). Participants that performed the HS both before encoding and before retrieval had the lowest number of hits (M = 7.00), and those performing this task only before encoding had a slightly higher number of hits (M = 7.21). Those who did not perform the HS at any point, meaning they only did the FX task, had a mean hit rate of 8.37, and those that did the HS only before recall had the highest hit rate among all conditions (M = 10.16). These results show that individuals performing the horizontal saccades before encoding had poorer memory, and so these eye movements seemed to impair encoding of information (Christman & Butler, 2005).

These findings suggest that there is an overall impairment of horizontal saccades if they are performed before encoding when testing recall of episodic memory. There is lack of research investigation the effect of saccades before encoding in comparison to before retrieval, as only one study has examined this effect and the results were never published. Thus, the current study included performing a saccade task before encoding as part its methodology to further add to the analysis of this phenomenon.

Implications of SIRE in Disease Treatments

According to Propper and Christman (2008), Posttraumatic Stress Disorder (PTSD) affects up to 14% of the population in the United States. One of the symptoms of PTSD is having memory disruptions in which there is regular reexperiencing of the traumatic memories of the event. These memory intrusions appear to lead to the impaired retrieval of general episodic memories. Therefore, one of the features of PTSD appears to be a malfunction of episodic memory. The evidence for this is the previously mentioned intrusions that occur while an individual is conscious and asleep, and thus lead to incapacity to retrieve specific and nontraumatic episodic memories (Propper & Christman, 2008).

A treatment that has been shown to work for PTSD is called Eye Movement Desensitization and Reprocessing (EMDR). Individuals are asked to make horizontal saccades for sets of 30 seconds while simultaneously recalling segments of a specific memory. The purpose of making these saccades is to evoke retrieval of other information part of the memory, which individuals are then asked to focus on while performing another round of saccades. This cycle repeats, with new information retrieved and adapted into the initial memory (Propper & Christman, 2008).

The research on SIRE is important to distinguish the role of different types of eye movements in this therapy procedure. The research has investigated smooth pursuit versus saccadic eye movements, and shown that saccadic eye movements alone improve episodic memory. Some EMDR therapy tasks are actually using smooth pursuit eye movements when those have not been shown to influence episodic memory, and thus should be corrected to be saccadic eye movements instead. An example is the Shapiro protocol that consists of waving a finger from left to right in a patient's visual field, thus inducing smooth pursuit eye movements. This protocol is widely used and should be corrected according to research finding saccadic and not pursuit eye movements to enhance episodic memory (Propper & Christman, 2008).

Conducting experiments to further investigate the role of saccadic eye movements in episodic memory are important so as to broaden the understanding of the mechanism underlying the EMDR therapy procedure. This will allow for improvement of the procedure for delivery of the most efficient treatment for PTSD.

Another important idea to consider from this area of research is that it may help us understand and even develop treatments for individuals with neurodegenerative diseases such as Alzheimer's disease. According to Gold and Budson (2008), Alzheimer's disease is responsible for about two-thirds of the total cases of dementia in the population. The initial and foremost cognitive dysfunction in this disease is that of episodic memory impairment (Gold & Budson, 2008). This type of memory involves mental time travel and emotional links, thus it is a significant part of an individual's personality and autobiographical memories. Investigating methods that influence episodic memory can be an important aspect to focus on because the previous research suggests that saccades enhance episodic memory. Therefore, applying a technique similar to

EMDR used for PTSD on Alzheimer's patients may be a beneficial treatment to improve their episodic memory, thus improving life quality, even if by a small amount.

Saccade Induced Retrieval Enhancement in the Present Study

In conclusion, previous research on Saccade Induced Retrieval Enhancement (SIRE) has shown that saccades, especially horizontal saccades, appear to enhance the retrieval of episodic memories when performed prior to testing as compared to individuals not making saccades. This effect has been shown using recognition and recall memory testing procedures, however it is suggested that free recall procedures are a more appropriate way to measure the retrieval of episodic memories individually. The *Interhemispheric Interaction Hypothesis* states that SIRE occurs due to the increase of hemispheric interaction between the two hemispheres and so only occurs with horizontal saccades. On the other hand, the *Top-Down Attentional Control Hypothesis* states that SIRE occurs due to the activation of top-down attentional processes immediately prior to retrieval, which facilitates subsequent activation of the same mechanism when retrieving information thus allowing harder to recall information to enter consciousness and be retrieved. Consequently, memory enhancement should occur with both vertical and horizontal saccades.

In the current research study, SIRE was examined with the inclusion of horizontal, vertical saccades and fixation tasks with the purpose of using the results to assess the validity of each of the two main hypotheses that have been formulated to explain this phenomenon. As previous research suggests that episodic memory is the only type of memory affected by SIRE, the current study included an episodic memory task in its methodology. The current study involved examination of three main hypotheses. The first hypothesis stated that if SIRE was only present for horizontal saccades, the results would add further evidence to support the *Interhemispheric Interaction Hypothesis* however, if both horizontal and vertical saccades showed SIRE, the results would add further evidence to support the *Top-Down Attentional Control Hypothesis*. The second hypothesis stated that if a greater number of weakly associated words (more cognitively demanding) were remembered following eye movements compared to fixation, results would add support to the *Top-Down Attentional Control Hypothesis*. In addition, as studies have not explored SIRE on encoding in depth, the current study included the analysis of the influence of saccades occurring at encoding on the episodic memory retrieval accuracy. In accordance with previous research, the third hypothesis stated that saccades would not have a positive effect on the retrieval of episodic memories if they occur before encoding compared to occurring before retrieval.

Method

Participants

There were 66 strongly right-handed Lake Forest College students who participated for extra credit in their courses, if their course offered participation for extra credit. The value of the extra credit was left up to the discretion of the course instructor. The participants were 18 to 23 years old, with no ethnic or residential restrictions. Students were tested individually at a time that was convenient to them. To protect participant confidentiality, each participant was assigned a number to identify all data files and consent forms. Participants were provided with an informed consent form and debriefing form. The study was approved by the Lake Forest College Human Subjects Review Committee.

Design

The primary purpose of this study was to investigate the effect of the execution of saccadic eye movements either preceding the encoding of the material (i.e., before memorization of material) or preceding the retrieval of the material (i.e., before recollection of memorized material). To test the hypothesis that the effect of such eye movements would be the enhancement of memory recall processes, participants were randomly assigned to one group of the following three: Horizontal (HS) Group, Vertical (VS) Group, or Fixation (FX) Group. Hence, one of the factors in the design of this study was the Type of Eye Movement performed with three levels: horizontal (H), vertical (V), and fixation (F).

To further investigate the effect of the execution of saccadic eye movements, participants were randomly assigned to perform these eye movements either prior to encoding the material or prior to retrieving it. Hence a second factor in the design of this study was the Timing of when the saccadic eye movement task was completed. Participants were randomly assigned to one of the two levels in this factor: before encoding or before retrieval. Consequently, the Type of Eye Movements and the Timing of the eye movement task were between-subjects factors.

There were a total of six cells in the research design created by the crossing the two between-subjects factors: H before encoding; H before retrieval; V before encoding; V before retrieval; F before encoding; and F before retrieval. Participants were randomly assigned to one of the six possible cells as their condition for the study.

The third factor in the study design was within-subjects and was the Word Association Strength. The two levels of this factor were Strong Association (SA) and Weak Association (WA), according to how strongly associated words were to the category from which they were selected using familiarity as a measure of association strength. Strong association words were more familiar and therefore easier to recall when presented with the respective category name, and weak association words were less familiar and therefore harder to recall. A total of 10 categories of words were created:

four of the categories containing strongly associated words such as fruits, thus called Strong Categories (SC); four of the categories containing weakly associated words such as metals, thus called Weak Categories (WC); and finally, two Filler Categories (FX) containing words that were primarily strongly associated, however their associative strength was not taken into account in the data analysis (i.e., birds). All words were presented in the same random order to participants during the Learning phase of the study.

To summarize, the design was a 3 x 2 x 2 mixed factorial design with two between-subjects variables (Type of Eye Movements: H, V, or F: and Timing of the Eye Movement Task: before encoding or before retrieval), and one within-subjects variable (Word Association Strength: strong or weak).

Materials

The experiment had six phases: Edinburgh Handedness test, Learning Phase, Retrieval Practice Phase, Trivia Questionnaire, Final Test Phase, and the Eye Movement Task. The first phase of the study was the Edinburgh Handedness test. A modified version was utilized as a method of testing the handedness of participants to make sure they were strongly right-handed before continuing the experiment (see Appendix B). The rationale for using only strongly right-handed participants came from previous research showing that the effect of the eye movement task was only present in consistently handed participants.

The Learning Phase consisted of a list of 60 words drawn from 10 categories, with six exemplars in each category. Eight of the categories and their exemplars were taken from Anderson, Bjork, and Bjork (1994) and chosen based on average frequency scores from a pilot study of 10 participants completed before the research project. The associative strength of the eight categories was such that four categories were strongly associated (and thus recruited bottom-up processes), and four categories were weakly associated (and thus recruited top-down processes). The remaining two categories were filler categories from the study conducted by Lyle and Edlin (2014).

The study list was created as follows: There were six blocks of words, each block containing 10 words, with one exemplar from each category. To make each block, a random order of categories was determined, for example: birds, drinks, furniture, etc. The exemplars within each of these categories were randomly ordered as well. For the first block, a die was rolled and the number it landed on was used to count down the list from the first category (birds). The word chosen was not considered in the following blocks. Rolling the die again, the number was used to count down the list of the second category (drinks). The process was repeated until the first block of words was created with ten exemplar names, one from each category. The same method was used to make the remainder of the five blocks. Once the blocks had been made, the ten words within each individual block were randomly ordered using an online computer program.

In the Retrieval Practice phase, the same randomized list of category names used for the learning phase was utilized again (birds, drinks, furniture, etc.). A die was rolled and the number shown was used to count down the list until two Strong Categories (SC), two Weak Categories (WC) and one Filler Category (FX) were chosen, meaning only a total of five categories were practiced. A die was then rolled to choose the three exemplars from each of the selected categories, choosing a total of three exemplars for each category, giving a total of 15 exemplars. Participants saw the name of the category and first two letters of the exemplar (i.e., fruit – ba). These were termed practiced words from practiced categories (Pr+). The remaining words in those categories were termed as nonpracticed words within practiced categories (Pr-), and these were expected to be the most cognitively demanding words. Finally, there were nonpracticed words from nonpracticed categories (Nrp). The list of 15 words was presented a total of three times, each time according to a different random order. An online computer program was used to create these three randomized lists.

An unrelated trivia questionnaire was utilized after the retrieval practice phase with the purpose of providing participants with a 10-minute break.

In the final test phase, an online computer program was used to generate a random order for the 10 categories used in the study. The same order was presented to all participants.

There were three types of Eye Movement Task: Horizontal, Vertical and Fixation. In the horizontal eye movement task participants were shown a small black circle (font size 85) as it moved from the left to the right repeatedly on a white background screen at a distance of 29 inches from the participant's eyes. The distance from the center of the screen to the left and right sides, respectively, was 13.5º of visual angle. The circle moved across the screen once every 500 ms for a total duration of 30 s. The vertical eye movement task was the same as the horizontal, but the display screen was turned 90º to the left. The fixation task consisted of flashing the same black dot used in the previously mentioned tasks in the center of the screen. The black circle flashed on for the duration of 500 ms, with a 500 ms inter-stimulus interval between each flash of the black circle. The total duration was 30 s. Participants' eyes were recorded as they performed the eye movement task to ensure they moved their eyes according to the task instructions.

Procedure

As soon as the participants arrived to the research lab, they read through the informed consent form and given enough time to read through and ask any questions. (Please see Appendix A for a copy of the informed consent form). Each participant was informed of the voluntary nature of the study and their right to withdraw at any moment without repercussions. Once the participant agreed to take part in the experiment, they were given the Edinburgh Handedness Inventory to complete. (Please see Appendix B for a copy of the Edinburgh Handedness Inventory). To be considered a strongly right-handed person, the participant had to get a minimum score of +95 out of a maximum of +100. Participants who scored below a +70 were thanked for their time and kindly dismissed. These participants still received credit in their respective courses. Participants who scored a +70 or above, completed the rest of the experiment.

Participants assigned to the Before Encoding (BE) condition, performed their randomly assigned eye movement task after the completion of the Edinburgh Handedness test. In contrast, participants assigned to the Before Retrieval (BR) condition, performed the eye movement task immediately before the Final Test phase.

Participants in the Before Encoding condition were asked to place their head on a chin rest to prevent sudden movements of the head, which could have the possibility of leading to possible discrepancies in eye-tracking. After the eye-tracker was calibrated, participants were shown the eye movement task they were randomly assigned to on their monitor. An automatic ISCAN eye tracker was used to measure participants' direction of gaze during their assigned eye movement task. The eye tracker provided an image of the participants' screen (with the moving or flashing stimulus) with a superimposed cross to indicate the participants' moment to moment point of regard during the task. This enabled the researcher to check that the participant was following the moving or flashing stimulus, as instructed. The eye tracker's screen was recorded for later off-line monitoring of the participants' compliance with task instructions.

Once the eye movement task ended, the chin rest was removed and the participant continued on to the learning phase. In the learning phase, study items were presented as a pair consisting of the category name and the exemplar name (ex: fruit – orange). All word pairs were presented in the center of the computer monitor for the duration of five seconds, and there was a one second interstimulus interval between each word pair. The task lasted a total of six minutes. Participants were asked to study the words by relating the exemplar to the category name shown.

Following the learning phase, participants performed the retrieval practice phase. They were presented with a category name and the first two letters of an exemplar name within that category as a pair, one pair at a time. Participants were instructed to type the name of the exemplar that fit the two-letter cue on a textbox shown on the monitor from the words they had previously seen. They were given a total of 12 seconds to type each exemplar name. Each pair was shown a total of three times, for a total duration of nine minutes for the entire phase.

After completing the retrieval practice phase, participants filled out an unrelated questionnaire during their assigned 10-minute break.

If a participant was assigned to the Before Retrieval (BR) condition, they performed their randomly assigned eye movement task following the unrelated questionnaire. The same procedure as the Before Encoding eye movement tasks was followed for the Before Retrieval eye movement tasks.

Finally, all participants completed the Final Test phase, in which they were tested on the exemplar names they had learned during the learning phase. Participants were shown a total of 10 category names, shown one at a time. They were instructed to type as many of the exemplar names within the category shown that they were able to recall. This phase was self-paced, however participants could not go back to a category previously shown. All of the participants were shown the same random order of categories.

Upon completion of the Final Test phase, each participant was debriefed and thanked for their participation. Researchers answered any questions that arose, and escorted the participant out of the lab. Each participant completed the five phases of the study during a period of approximately 35 minutes.

The following table is a summary of task sequence for performance of the eye movement task at the two different possible times:

Table 1.

Summary of task sequences for the two eye movement timing conditions

Before Encoding	**Before Retrieval**
1. Informed Consent Form	1. Informed Consent Form
2. Edinburgh Handedness Inventory	2. Edinburgh Handedness Inventory
3. Eye Movement Task (Horizontal, Vertical or Fixation)	3. Learning Phase
4. Learning Phase	4. Retrieval Practice Phase
5. Retrieval Practice Phase	5. Trivia Questionnaire
6. Trivia Questionnaire	6. Eye Movement Task (Horizontal, Vertical or Fixation)
7. Final Test Phase	7. Final Test Phase

Note. This table shows the two different possible orders for participants depending on which timing condition they were assigned to (before encoding or before retrieval). The only difference between the two is that time at which the eye movement condition they were assigned to is performed: either before the learning phase or before the final test phase.

Results

Overall, the mean number of total words recalled by all participants in the study was 29.6 (*SD* = 7.6). In addition, for the strong categories, there was a mean proportion of 0.546 (*SD* = 0.243) nonpracticed words recalled in practiced categories, and there was a mean proportion of 0.500 (*SD* = 0.148) of nonpracticed words recalled from nonpracticed categories. In weak categories, there was a mean proportion of 0.275 (*SD* = 0.222) nonpracticed words recalled in practiced categories, and a mean proportion of 0.302 (*SD* = 0.156) nonpracticed words recalled in nonpracticed categories.

To investigate the first hypothesis, a 3 x 2 between-subjects Analysis of Variance (ANOVA) was conducted with the purpose of determining the effect of each type of eye movement task on mean recall. Figure 1 displays the mean number of total words recalled for the horizontal, vertical and fixation eye movement tasks. As shown in Table 3, the 3 (Eye Movement Task: Horizontal, Vertical or Fixation) x 2 (Timing of Eye Movement Task: Before Encoding vs. Before Retrieval) between-subjects ANOVA revealed no significant main effect of eye movement task, $F(2,60)=0.201$, $p=.819$. Overall, the horizontal eye movement task had a slightly higher recall performance (M = 30.2, SD = 7.6) compared to the vertical eye movement task (M = 29.0, SD = 8.1), and the fixation task (M = 30.1, SD = 7.4). As there was no main effect in the ANOVA, this shows that there was no significant difference in the memory performance as a function of the type of eye movement task.

To investigate the second hypothesis, a 2 x 2 x 2 mixed factor ANOVA was calculated with the purpose of examining the effect of horizontal eye movements or fixation on the recall of harder to remember words (Rp- = nonpracticed words from practiced categories) to easier to remember words (Nrp = nonpracticed words from nonpracticed categories). As shown in Table 5, the 2 (Item Type: Rp- or Nrp) x 2 (Word Association Strength: Strong or Weak) x 2 (Eye Movement: Horizontal vs Fixation) mixed factor ANOVA revealed no main effect of item type, $F(1,42)=.071$, $p=.791$. There was no significant interaction between item type and eye movement task, $F(1,42)=1.548$, $p=.220$. The ANOVA results revealed a main effect of word association strength, $F(1,42)=96.028$, $p<.001$. Analysis of this effect revealed that there was a statistically larger number of strongly associated words recalled (*M* = 14.4, *SD* = 3.09) in comparison to weakly associated words (*M* = 9.1, *SD* = 3.52), which shows there was a difference in word association strength in the categories, and thus different levels of difficulty in recall of these words. In addition, there was no significant interaction between word association strength and eye movement task, $F(1,42)=.485$, $p=.489$. Furthermore, the interaction between item type and word association strength also failed to reach significance, $F(1,42)=.680$, $p=.414$. Finally, there was no significant interaction between all three of the factors analyzed in this ANOVA (item type, word association strength and eye movement task), $F(1,42)=.00$, $p=1.00$.

To investigate the third hypothesis, a 3 x 2 between-subjects ANOVA was calculated to analyze the effect of eye movements occurring before encoding compared to before retrieval. Figure 2 shows the mean number of words recalled as a function of the type of eye movement task and the timing of when the eye movement task was performed. The ANOVA reported for the first hypothesis (as shown in Table 3) was also relevant for this hypothesis. This ANOVA revealed a significant main effect of eye movement timing, $F(1,60)=4.539$, $p=.037$. The participants performing an eye movement task before encoding remembered significantly more words (*M* = 31.8, *SD* = 7.8) in comparison to those performing the eye movement task before retrieval (*M* = 27.9, *SD* = 7.0). Finally, there was no significant interaction between the timing of the eye movement task and the type of eye movement task performed, $F(2,60)=.727$, $p=.488$.

Discussion

The current study investigated the effect of the Saccade Induced Retrieval Enhancement on the retrieval of episodic memories following horizontal, vertical, and no eye movement conditions. The most consistently reported finding in the SIRE literature concerns enhanced retrieval following horizontal eye movements which has been described by Christman, et al., 2003; Christman et al., 2005; Lyle et al., 2008; Lyle et al., 2012; Nieuwenhuis et al, 2013; Parker & Dagnall, 2007; Parker et al, 2008; and Parker et al., 2013.

Despite various studies showing its existence, this effect was not replicated in the present study, as there was no statistically significant difference in the performance between any of the eye movement types. The *Interhemispheric Interaction Hypothesis* states that horizontal eye movements singly produce SIRE in episodic memory by increasing the interaction between the two hemispheres of the brain (Christman et al, 2003), however, as SIRE was not replicated in the current study with horizontal eye movements, the results from the current study do not provide support for this *Interhemispheric Interaction Hypothesis*. This failure to replicate the SIRE phenomenon was surprising because the current study replicated the methodology of a study that did find the effect of SIRE following horizontal eye movements (i.e., Lyle & Edlin, 2014). The discrepancy between the results of the Lyle et al. study and the current study may be explained by suggesting that the SIRE effect itself is most probably a small effect. And thus, if it is indeed a small effect, it would then require a larger sample size for the effect to be observed in the data. From the results in the current study, it is proposed that a total of 66 participants may be too small of a sample size to observe the SIRE effect.

Another aspect examined in the current study was the effect of vertical eye movements on the retrieval of episodic memory. Again, there was no significant improvement of recall of total words following either horizontal or vertical eye movements. According to the *Interhemispheric Interaction Hypothesis*, vertical eye movements should not have any enhancement of memory retrieval (Christman & Butler, 2005). However, the *Top-Down Attentional Control Hypothesis* states that vertical eye movements, similar to horizontal eye movements, should improve performance of episodic memory tasks (Lyle & Edlin, 2014). As the current study did not find any significant difference between the performances of any of the eye movement conditions (HS: *M* = 30.2; VS: *M* = 29.0; and FX: *M* = 30.2), the findings do not support either of the hypotheses. The results of the present study add further uncertainty to the already mixed results in the literature (i.e., Parker & Dagnall, 2007; Lyle et al., 2008) regarding the influence of vertical eye movements on episodic memory. However, the involvement of vertical saccades in SIRE has not been as thoroughly researched as horizontal saccades, and so deserves more study. Further study may help distinguish whether the *Interhemispheric Interaction Hypothesis* or *Top-Down Attentional Control Hypothesis* more clearly explains the effect of SIRE.

The lack of vertical saccade enhancement of memory already casts sufficient doubt on the validity of the *Top-Down Attentional Control Hypothesis*. Another characteristic that casts further doubt on the support of this hypothesis is that the prediction that either horizontal or vertical eye movements would improve the recall of information that is harder to remember was not observed from the present results. Participants remembered strongly associated words significantly more than weakly associated words. This finding demonstrates that some of the words in the current study were harder to retrieve (weakly associated) than others. Thus the word list used was adequate for testing if eye movements would enhance the retrieval of harder to remember words. However, the analysis of the mean proportion of words recalled for different associative strengths revealed no effect of horizontal eye movements on the recall of each type of word. Thus making eye movements did not appear to bring information that is harder to remember into consciousness to a greater degree than did staying fixated. As the *Top-Down Attentional Control Hypothesis* states that making eye movements should bring into consciousness information that is more cognitively demanding, and this was not found in the current study, results do not provide support for this hypothesis. However, this failure to confirm the expectations of the *Top-Down Attentional Control Hypothesis* may be a function of low power rather than an inherent problem with the theory.

To examine the effect of eye movements on the recall of words with different association strengths discussed in the *Top-Down Attentional Control Hypothesis*, an interaction between eye movement type and word association strength was analyzed. To replicate past studies, only the horizontal and fixation groups were included in the analysis for the present study. Including only those two groups lowered the number of participants involved in the analysis, which could have lowered the power of the study even further and thus lowered the chances of the SIRE effect being observed in this analysis.

Another aspect of the literature that was investigated in the current study is the influence of making eye movements either before encoding occurs or before retrieval occurs on the retrieval of episodic memory. Only one study, an unpublished study conducted by Christman and Butler (2005) investigated this effect. In this study eye movements made before encoding impaired recall compared to eye movements before retrieval. The results of the current study actually showed the opposite effect: participants who performed eye movements before encoding had a significantly higher recall in comparison to those that made eye movements before retrieval.

The superior recall following the encoding condition compared to the retrieval condition of the present study can be interpreted in two ways: either performing eye movements prior to encoding enhanced memory retrieval (i.e., had a facilitative effect), or performing these eye movements before retrieval actually impaired memory retrieval (i.e., had a deleterious effect). If the latter is true, this may be explained by suggesting that performing the eye movements before retrieval may disrupt and distract participants. On the other hand, if the *Top-Down Attentional Control Hypothesis* were true, performing the eye movements before encoding would activate the attentional network system in the brain. This activation may possibly thus lead to more efficient encoding of information presented if this information is presented immediately following the eye movement task. If so, maybe this effect should be named a term first discussed by Lyle and Martin (2014) known as Saccade Induced Cognitive Enhancement, as the eye movements would then appear to increase cognition overall rather than retrieval specifically.

There are some possible strategies to improve our understanding of the SIRE phenomenon. Firstly, future studies should focus on including a much larger sample size so that if the SIRE effect is a small effect, a larger sample size would then allow for a greater chance of observing SIRE. Secondly, investigators should make certain all participants are native English speakers. Some of the participants in the current study reported that they did not speak English fluently. Thus for these participants, all of the words presented in the study may have been weakly associated, and so would have been equally difficult to retrieve. Weakly associated words are harder to remember, in theory because they are words that are less familiar in an individual's vocabulary. This would be especially true for nonnative speakers for whom all words included may not be as familiar and thus all weakly associated.

According to Parker et al. (2008), familiarity is an aspect of semantic memory rather than episodic memory. Thus, one might speculate is that the method used in the current study does not solely test for episodic memory, but contains some aspects of semantic memory as well. This speculation is further maintained by the fact that knowledge of a language should not affect the formation of episodic memory. However, some participants in the current study felt that they were at a disadvantage due to not speaking the language of the study fluently and so they were not as as familiar with the words as native speakers are. As familiarity may play an important role in the retrieval of the words of the study, it is suggested that the current study's methodology may not have accounted for the role that semantic memory may have played. If so, these inclusions of semantic memory may have affected the results and decreased the chances of the SIRE effect being seen in the results. In addition, the use of a paired-association verbal task may have led to tapping into both semantic and episodic memories.

The studies in the literature have all used different methodologies for testing the memory of participants, such as recognition tests (i.e., Parker & Dagnall, 2007), true recall and false recall tests (i.e., Lyle et al., 2008), and recall of episodic autobiographical memories (i.e., Christman et al., 2003). There may be discrepancies in the methods used in the literature as to whether they test for retrieval of only episodic memory, or if they also include aspects of other types of memory. Parker et al. (2008) discussed that recognition tests have two underlying processes, one which involves semantic memory (familiarity) and the other which involves episodic memory (recollection). This is an important distinction because various studies in the literature investigating SIRE in episodic memory have used recognition tests (i.e., Parker et al., 2008; Christman et al., 2003; Parker & Dagnall, 2007), and so may not properly account for the semantic (familiarity) aspect of the retrieval test. The involvement of semantic memory would invalidate the proposition that the SIRE effect only influences episodic memory. Thus researchers should first focus on developing a task that will solely test for episodic memory, so that all studies examining eye movements and SIRE may use this test and therefore may decrease the discrepancies in the results now found in the literature.

One strength of the current study that should be included in future studies is to include horizontal eye movements, vertical eye movements and fixation conditions. It is important to include all three conditions because there is mixed evidence of the influence of vertical eye movements specifically. Thus, to be able to determine their role in the production of SIRE, they should be included in the analysis for more accurate comparisons to horizontal eye movements and to fixation. This evidence would then allow more efficient discrimination between the two competing theories, and thus could lead to establishing which of the two theories best explains SIRE.

Furthermore, another important strength to add to future studies is to investigate the effect of performing eye movements before encoding or before retrieval on the recall of episodic memories. Including the current study, only two studies have investigated this effect, and both have contradictory results, thus suggesting the need for further study.

In conclusion, the current study investigated the effect of horizontal, vertical and no eye movements on the Saccade Induced Retrieval Enhancement of episodic memory. Results did not replicate the SIRE effect, and eye movements did not appear to enhance the retrieval of episodic memory, unless they were made prior to encoding. Because SIRE is not consistently found across all studies, it can be suggested that SIRE is a small effect, and it may have differential influence on retrieval depending on when and which type of eye movements are performed. This study has shown that a larger sample size should be used in studies of SIRE and that the timing of eye movement tasks should be studied because timing may have an effect on retrieval. Further research is needed to broaden the understanding of this effect and to allow us to draw a more explicit conclusion on the mechanism underlying this phenomenon. Research in this field is important because we can gain insight into how exactly our eye movements may have the chance to influence our memory. More importantly, it can allow us to understand the relation between two different systems: a motor system and our cognition. These two systems are not often connected to each other, and the effect of SIRE offers an association between the two. Obtaining more information regarding this phenomenon can help us better understand not only our cognition overall and its formation, but most importantly, factors that can influence it. These discoveries can then lead us to maybe one day improving our cognition.

This understanding may have clinical implications. The use of horizontal saccades for the enhancement of episodic memories is already a technique that is used in therapy for Posttraumatic Stress Disorder. If this effect is shown to influence memory in such circumstances, it may also be able to influence an individual's cognition under different conditions. A person's episodic memory is memory of their life, which contains information about their personality and the events that have led them to be the person they are in the present. Knowing of an effect that can positively influence the retrieval of these memories can be powerful, as there are diseases that exist in the world which affect this core element an individual's persona: their episodic memory. Thus, there may come a day in which the SIRE effect can be harnessed to enhance the memory of individuals with such conditions. Perhaps, SIRE may be shown to enhance the memory of patients with Alzheimer's disease sometime in the near future; restoring at least a small portion of the episodic memory lost that leads to cognitive dysfunction, and giving these patients a chance to tap into their memories.

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Table 2

Descriptive Statistics

Descriptive Statistics

Dependent Variable: Total Words Remembered

When Eye Movement task is performed	Type of Eye Movement Task	Mean	Std. Deviation	N
Before Encoding	Horizontal	31.1000	9.52715	10
	Vertical	32.4545	4.82418	11
	Fixation	31.7273	9.13336	11
	Total	31.7813	7.81535	32
Before Retrieval	Horizontal	29.4167	5.83809	12
	Vertical	25.4545	9.34199	11
	Fixation	28.5455	5.20315	11
	Total	27.8529	6.99841	34
Total	Horizontal	30.1818	7.58216	22
	Vertical	28.9545	8.09160	22
	Fixation	30.1364	7.43413	22
	Total	29.7576	7.60983	66

Note. This table shows the descriptive statistics of the total words remembered for horizontal, vertical and fixation eye movements by the timing of the eye movement task (before encoding or before retrieval). The horizontal eye movement group had a total mean of 30.2 (SD = 7.6), the vertical eye movement group had a total mean of 28.9 (SD = 7.4), and the fixation group had a total mean of 30.1 (SD = 7.4). In addition, the before encoding group had a total mean of 31.8 (SD = 7.8), and the before retrieval had a total mean of 27.9 (SD = 7.0).

Table 3

Two Factor Univariate Analysis of Variance – Between-Subjects

Between-Subjects Factors

		Value Label	N
When Eye Movement task is performed	1.00	Before Encoding	32
	2.00	Before Retrieval	34
Type of Eye Movement Task	1.00	Horizontal	22
	2.00	Vertical	22
	3.00	Fixation	22

Tests of Between-Subjects Effects

Dependent Variable: Total Words Remembered

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	361.941[a]	5	72.388	1.277	.286	.096	6.383	.421
Intercept	58381.934	1	58381.934	1029.609	.000	.945	1029.609	1.000
Timing	257.385	1	257.385	4.539	.037	.070	4.539	.554
Eye_Mov	22.776	2	11.388	.201	.819	.007	.402	.080
Timing * Eye_Mov	82.431	2	41.216	.727	.488	.024	1.454	.168
Error	3402.180	60	56.703					
Total	62208.000	66						
Corrected Total	3764.121	65						

a. R Squared = .096 (Adjusted R Squared = .021)

b. Computed using alpha = .05

Note. This table shows the results from a 3 (Eye Movement Task: Horizontal, Vertical or Fixation) x 2 (Timing of Eye Movement Task: Before Encoding or Before Retrieval) between-subjects ANOVA. There is no main effect of eye movement task, $F(2,60)=.201$, $p=.819$. There was a main effect of timing of eye movement task, $F(1,60)=4.539$, $p=.037$. There was no interaction of eye movement task or timing of eye movement task, $F(2,60)=.727$, $p=.488$.

Table 4

Descriptive Statistics

Descriptive Statistics

	Type of Eye Movement Task	Mean	Std. Deviation	N
SRpminusP	Horizontal	.5455	.23672	22
	Fixation	.5303	.21600	22
	Total	.5379	.22408	44
WRpminusP	Horizontal	.3106	.27360	22
	Fixation	.2576	.18349	22
	Total	.2841	.23178	44
SNrpP	Horizontal	.4924	.13341	22
	Fixation	.5303	.15547	22
	Total	.5114	.14444	44
WNrpP	Horizontal	.2992	.12509	22
	Fixation	.2992	.18123	22
	Total	.2992	.15389	44

Note. This table shows the descriptive statistics of mean proportion of words recalled in strong and weak categories for different item types for horizontal and fixation eye movement conditions. In the strong category, there was a total proportion mean of .5375 (SD = .224) for nonpracticed words in practiced categories (SRpminusP), and a total proportion mean of .5114 (SD = .144) for nonpracticed words in nonpracticed categories (SNrpP). In the weak category, there was a total mean proportion of .2841 (SD = .232) for nonpracticed words in practiced categories (WRpminusP), and a total proportion mean of .2992 (SD = .154) for nonpracticed words from nonpracticed categories (WNrpP).

Table 5

Mixed Factor ANOVA

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
ItemType	Sphericity Assumed	.001	1	.001	.071	.791	.002	.071	.058
	Greenhouse-Geisser	.001	1.000	.001	.071	.791	.002	.071	.058
	Huynh-Feldt	.001	1.000	.001	.071	.791	.002	.071	.058
	Lower-bound	.001	1.000	.001	.071	.791	.002	.071	.058
ItemType * Eye_Mov	Sphericity Assumed	.031	1	.031	1.548	.220	.036	1.548	.229
	Greenhouse-Geisser	.031	1.000	.031	1.548	.220	.036	1.548	.229
	Huynh-Feldt	.031	1.000	.031	1.548	.220	.036	1.548	.229
	Lower-bound	.031	1.000	.031	1.548	.220	.036	1.548	.229
Error(ItemType)	Sphericity Assumed	.839	42	.020					
	Greenhouse-Geisser	.839	42.000	.020					
	Huynh-Feldt	.839	42.000	.020					
	Lower-bound	.839	42.000	.020					
WordAssociation	Sphericity Assumed	2.388	1	2.388	96.028	.000	.696	96.028	1.000
	Greenhouse-Geisser	2.388	1.000	2.388	96.028	.000	.696	96.028	1.000
	Huynh-Feldt	2.388	1.000	2.388	96.028	.000	.696	96.028	1.000
	Lower-bound	2.388	1.000	2.388	96.028	.000	.696	96.028	1.000
WordAssociation * Eye_Mov	Sphericity Assumed	.016	1	.016	.635	.430	.015	.635	.122
	Greenhouse-Geisser	.016	1.000	.016	.635	.430	.015	.635	.122
	Huynh-Feldt	.016	1.000	.016	.635	.430	.015	.635	.122
	Lower-bound	.016	1.000	.016	.635	.430	.015	.635	.122
Error(WordAssociation)	Sphericity Assumed	1.044	42	.025					
	Greenhouse-Geisser	1.044	42.000	.025					
	Huynh-Feldt	1.044	42.000	.025					
	Lower-bound	1.044	42.000	.025					
ItemType * WordAssociation	Sphericity Assumed	.019	1	.019	.680	.414	.016	.680	.127
	Greenhouse-Geisser	.019	1.000	.019	.680	.414	.016	.680	.127
	Huynh-Feldt	.019	1.000	.019	.680	.414	.016	.680	.127
	Lower-bound	.019	1.000	.019	.680	.414	.016	.680	.127
ItemType * WordAssociation * Eye_Mov	Sphericity Assumed	.000	1	.000	.000	1.000	.000	.000	.050
	Greenhouse-Geisser	.000	1.000	.000	.000	1.000	.000	.000	.050
	Huynh-Feldt	.000	1.000	.000	.000	1.000	.000	.000	.050
	Lower-bound	.000	1.000	.000	.000	1.000	.000	.000	.050
Error(ItemType*WordAssociation)	Sphericity Assumed	1.179	42	.028					
	Greenhouse-Geisser	1.179	42.000	.028					
	Huynh-Feldt	1.179	42.000	.028					
	Lower-bound	1.179	42.000	.028					

a. Computed using alpha = .05

Note. This table shows results from a 2 (Item Type: Rp- or Nrp) x 2 (Word Association: Strong or Weak) x 2 (Eye Movement: Horizontal or Fixation) mixed factor ANOVA. There was no main effect of Item Type, $F(1,42)=.071$, $p=.791$. There was a main effect of word association, $F(1,42)=96.028$, $p<.001$. There was no interaction of item type and eye movement condition, $F(1,42)=1.548$, $p=.220$. There was no interaction of word association and eye movement condition, $F(1.42)=.635$, $p=.430$. There was no interaction of item type and word association, $F(1,42)=.680$, $p=.414$. There was no interaction of item type, word association and eye movement condition, $F(1,42)=.000$, $p=1.00$.

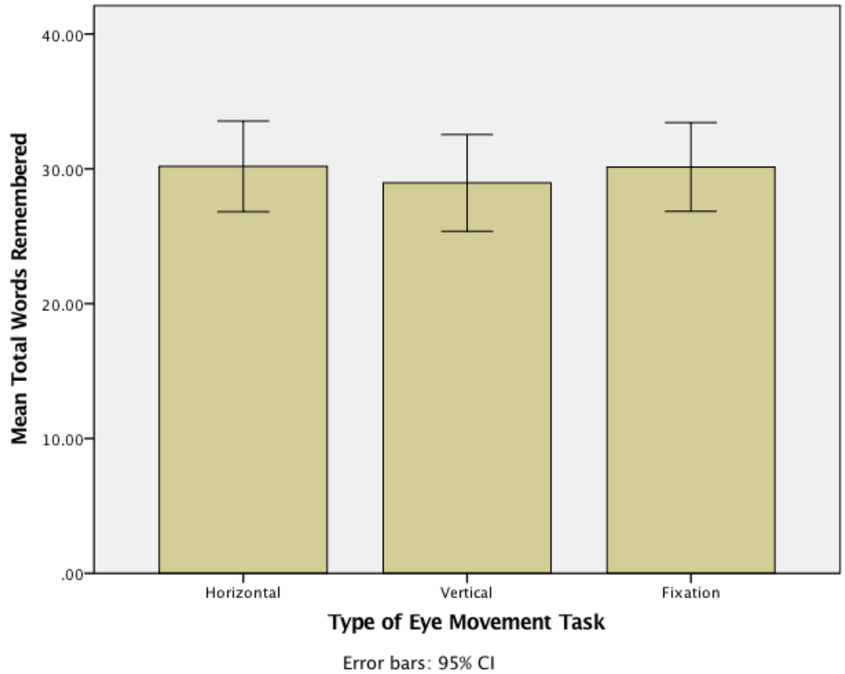

Figure 1. Mean values of number of total words remembered for horizontal, vertical and fixation eye movement conditions. There was no statistical difference between the eye movement condition groups. The error bars included in each column illustrate the standards errors.

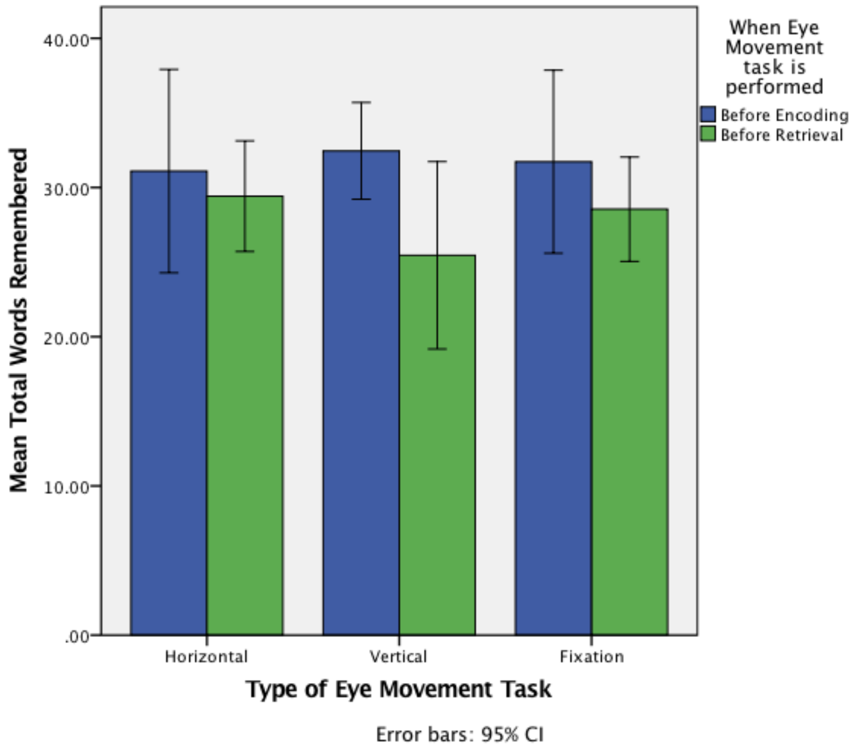

Figure 2. Means of total number of words remembered for horizontal, vertical and fixation eye movement conditions by the timing of the eye movement task (before encoding, or before retrieval). The before encoding group had a higher performance than their respective eye movement condition in the before retrieval group. The error bars included in each column illustrate the standards errors.

Appendix Material

Appendix A. Informed Consent Form

Informed Consent Form

Title of Project
Saccade Execution and Episodic Memory Retrieval

Researcher's Name(s) and Contact Information
Belen Martinez-Caro Aguado, phone: 312-774-0541; email: martinezcaro@mx.lakeforest.edu
Thesis Advisor: Naomi Wentworth, Ph.D., Department of Psychology, Lake Forest College, 555 N Sheridan Rd, Lake Forest, IL 60045, phone: 847-735-5256; email: wentwort@mx.lakeforest.edu

Purpose
The purpose of this study is to investigate the effect of eye movements on episodic memory retrieval.

Participants
Participants in this research study are strongly right-handed students at Lake Forest College of ages 18-23 years old who have been recruited from current psychology courses offered at Lake Forest College. Participants will receive extra credit in their respective courses. The exact value for the extra credit is left up to the discretion of the instructor of the course.

Procedure
The researchers will introduce themselves and explain what the equipment in the lab is for. You will read the informed consent form, and the researcher will answer any questions that may arise. If you decide to take part in the study, you will be randomly assigned to one of the conditions. Depending on which condition you are assigned to, you will perform specific eye movements at some point during the study or not. There will be an ISCAN eye tracker in front of the computer screen where the presentation will be shown, and this eye tracker will project the image it picks up onto the researcher's computer screen. The researcher's computer screen will be videotaped, and these files will be kept in a password-protected computer, which will be locked in the lab at all times. You will then begin the study. The first part of the study is the Edinburgh Handedness Inventory that will measure your right-hand handedness strength. You will then proceed to the second part of the study, which includes three phases. In the first you will be shown a list of words to learn by associating the exemplar name to the category name. In the second part you will practice the retrieval of some of the words previously shown to you. You will then take a 10 minute break in which you will fill out an unrelated questionnaire, and you will proceed to the final phase which is the testing phase for the words previously learned. This study should last approximately 30 to 40 minutes.

Voluntary Nature of the Study
Participation in this research project is completely voluntary. You may withdraw from this study at any point throughout the procedure without any sort of penalty. If at any point you decide to withdraw from this study, you may contact any of the people listed above.

Risks of Participation
There are no risks of participation in this research study. Some possible risks may include fatigue, boredom or frustration as would occur in any daily activity. If a researcher notices any distress while you are participating in the study, they will immediately stop the procedure.

Benefits of Participation
The participant will receive extra credit points in the class from which they were informed about the study and signed up to participate. The extra credit point value will be left up to the discretion of the instructor that informed the student.

Cost and Compensation of Participation
There are no costs of participation in the research project other than the time spent participating.

Privacy

All information and data collected during the study will be kept confidential. You will be assigned a participant number by the researchers, which will then be used to label any data files and data analysis files for the study, as well as the consent forms. The signed informed consent form and data files will be safely stored in Room 4 of Hotchkiss Hall at Lake Forest College, which will be locked at all times. After 5 years have passed since the completion of the study, the informed consent forms will be shredded and properly disposed of and all data files will be removed from all computers.

Questions, Suggestions, Concerns, or Complaints

Before you decided to participate in this research study, you may ask any questions regarding the experiment.

- If you have any questions, suggestions, concerns or complaints regarding this research study, you may contact Naomi Wentworth, wentwort@mx.lakeforest.edu
- If you have any questions about your rights as a participant in this study, you may contact Michael Orr, the Dean of Faculty at Lake Forest College, morr@lakeforest.edu

Statement of Consent

I have read the information provided in this document, I have asked any questions I may have and I have received answers for them. I am at least 18 years old and give my consent to participate in this research study.

____

Printed Name of Participant

____ __________________

Signature of Participant **Date**

Person Obtaining Consent:

I have to the best of my ability informed the participant of the purpose, risks and benefits of participating in this research study. I have responded to any of the questions that the participant may have asked. I have informed the participant that participation is voluntary and they may withdraw at any moment.

____ __________________

Name of Person Obtaining Informed Consent **Date**

Research Team:
Belen Martinez-Caro Aguado, martinezcaro@mx.lakeforest.edu
Naomi Wentworth, Ph.D., wentwort@mx.lakeforest.edu

Appendix B. Edinburgh Handedness Inventory

The Assessment and Analysis of Handedness: The Edinburgh Inventory

Please specify your preference for the use of hands in the subsequent activities.
If an activity is performed using both hands, the preferred hand to be evaluated will be specified in parenthesis.

The options are the following:

- 'Always Right/Left' for activities that you perform with one hand and would only perform with the other hand if pressed to do so.
- 'Usually Right/Left' for activities that you mostly perform with one hand, but may sometimes use the other hand to perform.
- 'No Preference' for activities you use both hands equally.

Mark an 'X' in the corresponding space, and only mark one space for each activity. Please respond to all the questions, and only leave a blank space if you have not used the object beforehand.

	Activities	**Always Left**	**Usually Left**	**No Preference**	**Usually Right**	**Always Right**
1	Writing					
2	Drawing					
3	Throwing					
4	Scissors					
5	Toothbrush					
6	Knife (without a fork)					
7	Spoon					
8	Broom (upper hand)					
9	Striking Match (match)					
10	Opening box (lid)					
	Total					

Overall Score __________

Appendix C. Words Used in The Study By Word Association Strength

Strong Categories:

Drinks – Vodka
Drinks – Rum
Drinks – Tequila
Drinks – Whisky
Drinks – Gin
Drinks – Bourbon

Fruits – Orange
Fruits – Banana
Fruits – Mango
Fruits – Strawberry
Fruits – Lemon
Fruits – Tomato

Sports – Basketball
Sports – Soccer
Sports – Football
Sports – Tennis
Sports – Baseball
Sports – Hockey

Insects – Beetle
Insects – Fly
Insects – Mosquito
Insects – Hornet
Insects – Grasshopper
Insects – Roach

Filler Categories:

Furniture – Desk
Furniture – Table
Furniture – Bed
Furniture – Chair
Furniture – Sofa
Furniture – Bookcase

Birds – Bluebird
Birds – Chicken
Birds – Robin
Birds – Falcon
Birds – Sparrow
Birds – Penguin

Weak Categories:

Professions – Critic
Professions – Accountant
Professions – Investor
Professions – Gardener
Professions – Scientist
Professions – Carpenter

Trees – Mimosa
Trees – Juniper
Trees – Birch
Trees – Spruce
Trees – Ash
Trees – Hickory

Metals – Francium
Metals – Pewter
Metals – Tungsten
Metals – Lithium
Metals – Chrome
Metals – Mercury

Fish – Muskie
Fish – Walleye
Fish – Yellowtail
Fish – Angler
Fish – Pike
Fish – Marlin