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Abstract

Handedness can be used as a marker for interhemispheric interaction, which can produce memory benefits. Bilateral saccadic eye movements can be used to manipulate levels of interhemispheric interaction. This study measured the effects of handedness and bilateral saccadic eye movement on memory using the Deese-Roediger-McDermott paradigm. This study predicted a memory advantage for left-handers and mixed-handers without eye movements and an advantage for right-handers with the eye movements. The results do not support these predictions but do suggest that handedness is a factor in episodic memory performance. The analyses for this study were run using A’ to compare false alarm rates for critical lures and for unrelated new items. Mixed-handers were less susceptible to the DRM paradigm, as the made fewer critical false alarms than both left-handers and right-handers. The bilateral saccadic eye movements increased the number of critical false alarms for left-handers but did not affect right-handers or mixed-handers. Reaction times data indicated that participants treated critical lures like old items.

The Effects of Handedness and Bilateral Saccadic Eye Movements on False Alarms in Recognition Memory

People tend to think of handedness is only related to common tasks like writing or throwing a ball, but hand dominance and its relationship with neural functioning have more far reaching consequences. Handedness can be defined as the general preference of one hand over the other for basic motor functions, and can vary in both strength and direction (Oldfield, 1971). In addition, the term handedness can apply to lateral preferences for tasks that do not involve the hands, such as kicking a ball and monocular vision. Handedness is somehow reflected in the brain, but there is no handedness area that we are aware of. We do know that handedness can affect the brain and mental processes in large part due to research on dyslexia, which is more common in left-handers than in right-handers (Geschwind, 1983). In addition, left-handers are more likely to have language lateralized in the right hemisphere or bilaterally organized than right-handers (Knecht et al., 2000). However, researchers as well as people in general do not fully understand the implications of handedness for cognitive processes, such as memory. The current study will examine the effects of handedness on episodic memory performance.

Interhemispheric Interaction

Interhemispheric interaction is the degree to which the left and right hemispheres of the brain communicate with each other via the corpus callosum (Witelson, 1985). The corpus callosum connects the two hemisphere of the brain and is responsible for the majority of interhemispheric interaction. Handedness is linked with the degree of interhemispheric interaction. The general pattern is that right-handers exhibit less interhemispheric interaction than mixed-handers and left-handers (Christman & Propper, 2001; Christman, Propper, & Brown, 2006; Christman, Propper, & Dion, 2004; Lyle, McCabe, & Roediger, 2008; Propper &

Christman, 2004; Propper, Christman, & Phaneuf, 2005; Witelson, 1985). There is evidence to suggest that the disparity in the degree of interhemispheric interaction found in left-handers and right-handers is due to differences in the size of the corpus callosum, with left-handed and ambidextrous individuals possessing larger corpus callosa than right-handed individuals (Witelson, 1985).

There are clear anatomical asymmetries associated with handedness, since the corpus callosum is larger in non-right-handed individuals than in right-handed individuals (Witelson, 1985). Many researchers use the term non-right-handers instead of left-handers, because it is difficult to find sufficient numbers of left-handed participants, and non-right-handers include mixed-handers. There are more specific variations in corpus callosum size that also take hemispheric laterality into account. Language lateralization in the right hemisphere is correlated with a larger corpus callosum. Individuals whose language capacities are lateralized to the left or bilaterally represented have smaller corpus callosa than individuals with right hemisphere language lateralization (Cowell, Kertesz, & Denenber, 1993). There is evidence for sex differences interacting with handedness to affect the size of the corpus callosum (Habib et al., 1991). Possibly because of the influence of hormonal differences, non-right-handed males have larger corpus callosa than right-handed males, but non-right-handed females have smaller corpus callosa compared to right-handed females (Habib et al., 1991).

Because of the evidence connecting non-right-handedness to increased levels of interhemispheric interaction, measure of handedness can be used to gage levels of interhemispheric interaction without any direct neurological measures. The benefits of non-right-handedness on episodic memory ability have been attributed to increases in interhemispheric interaction. Mixed-handed individuals exhibit superior recall of both lab-based and autobiographical episodic memories in comparison to strongly right-handed individuals (Propper et al., 2005). This result places the advantage of non-right-handedness with the mixed-handed group, but it remains unclear which non-right-handers have greater baseline levels of interhemispheric interaction and experience episodic memory benefits because of it. The next section reviews the observed relationship between handedness and episodic memory abilities.

Memory

Non-right-handedness is connected with advantages in many different areas of episodic memory. Although there do not seem to be differences in simple recognition based on handedness, there is evidence that there are differences in remember versus know judgments for recognition tasks (Propper & Christman, 2004). A remember judgment in recognition is the recollection of the specific aspects of an event. This is a recollection process that depends on a recall-like mechanism that involves the retrieval of associative information (Parker, Relph, & Dagnall, 2008). A know judgment in recognition does not require any specifics, just a semantic representation of the item. A know judgment is a familiarity process that produces a recognition decision based on automatic processes brought about by the matching of the test item to all other items stored in memory (Parker et al., 2008). According to a study by Propper and Christman (2004), mixed-handed individuals are more likely to report remember judgments and provide more accurate responses with remember judgments, while right-handers exhibit a greater number of know judgments and achieve a higher degree of accuracy when using know judgments.

The neurological processes behind episodic encoding and retrieval have been investigated using imaging technology. Evidence from PET scans has produced the Hemispheric Encoding/Retrieval Asymmetry model of prefrontal activation (HERA), such that encoding occurs in the left prefrontal regions of the cerebral cortex and retrievals takes places in the right prefrontal areas (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). The HERA model only applies to verbal episodic memory, and Tulving et al. (1994) acknowledge that there are varying patterns of prefrontal activation for different types of memory. Further research supports the HERA model and has found activations in the left Brodmann's Areas (BA) 44, 45, 9, and 46 during episodic encoding and activations in the right BA 10, 9, and 46 during episodic retrieval (Cabeza & Nyberg, 2000). Because episodic encoding and retrieval occur in opposite hemispheres, episodic memory processes require interhemispheric interaction. This is what makes episodic memory different from other types of memory in terms of hemispheric activity.

There is fMRI evidence of a stimuli based asymmetry for episodic memory that places the encoding of verbal material in the left hemisphere and encoding of facial information in the right hemisphere (Kelley et al., 1998). Word encoding requires activity in the left dorsal frontal cortex, face encoding requires activation of the right dorsal frontal cortex, and object encoding requires bilateral dorsal frontal activation (Kelley et al., 1998). These fMRI results have been used to argue against the HERA model, but they are not actually inconsistent with the HERA model's conclusions. The authors of the HERA model specifically state that their data all come from verbal tasks, and thus the proposed hemisphere asymmetry for encoding and retrieval only applies to verbal material (Tulving et al., 1994). The data from Kelley et al. (1998) and Tulving et al. (1994) both suggest that the encoding of verbal materials occurs in the left prefrontal cortex.

Source Memory

Source memory refers to the memory of aspects of an event that assist the individual in differentiating that event from other events and attributing a mental experience to an episodic memory (Mitchell, Johnson, Raye, & Greene, 2004). Source information attributions can be based on specific perceptual or temporal details as well as undifferentiated information like familiarity and recency (Mitchell et al., 2004). The source monitoring process evaluates mental information based on the differences in specific and undifferentiated information to determine if the mental experience is a retrieved episodic memory. Insufficient source monitoring results in increased false alarm rates, because the threshold for what can be considered an episodic memory is lowered (Mitchell et al., 2004). A false alarm occurs when a participant reports retrieving a memory that was never encoded. Ambiguous extrinsic context information could lead to a recollection process relying on the associative extrinsic information (i.e., information related to an aspect of the memory's presentation that is not an integral part of the memory itself) that is actually a failure of source monitoring (Parker et al., 2008).

Evidence from damage to the prefrontal cortex reveals a hemisphere asymmetry, which suggests that left prefrontal cortex processes source attributions based on specific features, and the right prefrontal cortex processes source attributions based on undifferentiated information (Mitchell at al., 2004). There is evidence that links source memory to interhemispheric interaction, as non-right-handers have been shown to outperform right-handers on source memory tasks (Lyle, McCabe, & Roediger, 2008). Lyle et al. (2008b) used two different source memory tasks, a see-hear test in which participants are asked to remember whether they saw a target word on a computer screen or heard a target word through headphones, and a read-anagram test in which participants had to identify if target words were presented normally or with two adjacent letters transposed. The results that non-right-handers outperformed right handers on both of these tasks is consist with the theory that source memory does indeed require interhemispheric interaction and that people with greater degrees of interhemispheric interaction will posses a greater ability for source memory than people with lesser degrees of interhemispheric interaction (Lyle et al., 2008b).

Episodic retrieval can be divided into production tasks (i.e., finding a memory based on a pattern of activation) and monitoring tasks (i.e., differentiating the source of that memory from other possible activations). Production processes occur primarily during the early pre-recovery and intermediate recovery phases of retrieval, whereas monitoring processes occur mainly during intermediate and late post-recovery phases of episodic retrieval (Cabeza, Locantore, & Anderson, 2003). Left ventrolateral prefrontal cortex (BA 45) activity during episodic retrieval is attributed to the semantic and generic operations of the production process. (Cabeza et al., 2003). This activation is guided by semantic memory processes, which lead the left hemisphere to accept lures related to studied scenes, words, faces, and visual patterns (Cabeza et al., 2003). Because the contribution of the left ventrolateral prefrontal cortex during episodic retrieval can be attributed to semantic memory assisting in episodic processes, it does not conflict with the HERA model. The HERA model proposes a fundamental asymmetry between semantic and episodic memory, and it asserts that semantic retrieval occurs in left prefrontal cortical regions (Tulving et al., 1994).

Right dorsolateral prefrontal (BA 44 and 56) and right anterior prefrontal (BA 10) activity during episodic retrieval is attributed to verification and checking operations necessary for monitoring processes (Cabeza et al., 2003). These monitoring processes reject the lures that can be accepted by the left hemisphere reproduction processes. Because recall requires more production than monitoring tasks and recognition requires more monitoring than production tasks, there is a hemisphere asymmetry for prefrontal activity during episodic recall and reproduction. The left prefrontal cortex demonstrates more activation during recall than recognition, and the right prefrontal cortex is more activated during recognition than recall (Cabeza et al., 2003). These asymmetries in memory processing provide further evidence that episodic memory tasks require interhemispheric interaction.

Deese-Roediger-McDermott Paradigm

Reproductive memory is the accurate rote production of material from memory, and reconstructive memory is the activate process of filling in missing elements while remembering (Roediger & McDermott, 1995). False recall and recognition is a common result of errors in reconstructive memory for meaning rich material, but some stimuli are more likely to elicit false memories than others (Roediger & McDermott, 1995). Deese (1959) studied extra-list intrusions (i.e., remembering words that were not presented in the studied list) and found that what you remember depends on the context of its presentation. Extra-list intrusions come from the associated context of the presented words, so word association norms are able to predict the occurrence of particular extra-list intrusions, with stronger word associations producing more intrusions (Deese, 1959). Deese (1959) generated word associations with a free response task that asked participants what word they thought of when presented with other words. The probability that a specific word will cause an extra-list intrusion can be predicted from the likelihood that word will occur as a free association response to the list of words (Deese, 1959).

Roediger and McDermott (1995) built on Deese (1959) to develop a method that demonstrates how false recognition of words semantically associated to a list of words occurs. The Deese-Roediger-McDermott (DRM) paradigm uses lists of semantic associates linked to a critical lure to elicit false memories from participants (Roediger & McDermott, 1995). The critical lures are semantic associates of their corresponding word list and prototypes that encourage schematic processing. The critical lures are falsely recognized at a higher rate than unrelated lures, and recognized at almost the same level as studied items (Roediger & McDermott, 1995). The degree of association between the critical lure and the word list affects participants' confidence in their memory decision, such that words with stronger semantic associations produce more confident recognition decisions (Roediger & McDermott, 1995).

The episodic memory benefits for non-right-handers may arise from a decrease in false alarm rates rather than an increase in hit rates (Christman et al., 2004). Using the DRM paradigm, Christman et al. (2004) were able to find source memory deficits in strong right-handers by analyzing the false alarm rates for lures. Falsely remembering that a lure was presented is a failure of source memory, because the participant cannot distinguish between seeing the word in a list and having the word activated through semantic networks after seeing other words in that semantic network. These results suggest that participants with a greater degree of interhemispheric interaction (either due to handedness or induced saccadic eye movements) had lower false alarm rates (Christman et al., 2004).

Bilateral Saccadic Eye Movements

Both non-right-handedness and bilateral saccadic eye movements are associated with increased levels of interhemispheric interaction. Bilateral saccadic eye movements are when the eyes move automatically from side to side, and these eye movements can be induced by presenting participants with images on a computer screen that are moving in a regular back and forth pattern (Christman, Garvey, Propper, & Phaneuf, 2003). Levels of interhemispheric interaction can be manipulated by inducing bilateral saccadic eye movements. Left or right eye movements selectively activate the contralateral hemisphere, and repeated left-right sequences activate both hemispheres (Christman et al., 2003; Propper & Christman, 2008). Saccadic eye movements are rapid, instinctive back and forth movements that generate activity in the frontal lobe regions that are active during episodic memory (Christman et al., 2003).

The link between saccadic eye movements and interhemispheric interaction came from research on Post-Traumatic Stress Disorder (PTSD), which found that people with PTSD experience recurrent and intrusive distressing memories of the traumatic event in addition to impaired retrieval of other episodic memories (Propper & Christman, 2008). Eye Movement Desensitization and Reprocessing (EMDR) therapy uses induced bilateral saccadic eye movements to enhance both the accuracy and amount of retrieved memories (Propper & Christman, 2008). This type of therapy has a great potential to be beneficial for people with PTSD, as it helps restore their memory capabilities to the way memory processes functioned before the trauma. Additionally, EMDR can enhance previously neglected aspects of memories that can help people retrieve less fragmented memories (Propper & Christman, 2008). The success of EMDR therapy at improving the dysfunctional episodic memory of individuals with PTSD led to the idea that saccadic eye movements could provide general episodic memory benefits (Propper & Christman, 2008).

In a study by Christman et al. (2006), both mixed-handed participants and participants who were in the bilateral saccadic eye movement condition reported retrieving personal episodic memories from earlier in life than participants who were right-handed or participants who were not in the eye movement condition. The age of the offset of childhood amnesia is a contentious issue in psychology, with some researchers arguing for the possibility of the offset of childhood amnesia at as young as 2 years (Usher & Neisser, 1993), and others claiming that these alleged memories come from external information later in life instead of actual memories from before the third birthday (Loftus, 1993). Recollecting early memories and establishing the offset of childhood amnesia appears to be an episodic memory task that requires and benefits from interhemispheric interaction.

The benefits of saccadic eye movements appear to be at the retrieval stage of episodic memory and are driven by enhanced source memory (Propper & Christman, 2008). Christman et al. (2003) found that bilateral horizontal saccadic eye movements selectively enhance episodic memories. Specifically, participants who engaged in the eye movements experienced a reduction in false alarms when they were asked to recount autobiographical memories of events recorded in journals (Christman et al., 2003). In a recognition memory paradigm, a false alarm is when a participant responds yes to an item when the correct response to that item is no. Other memory benefits of saccadic eye movements included improved recall and recognition for lists of words, better identification of the spatial location of studied stimuli, increased accuracy for the recall of paired associates, an earlier offset of childhood amnesia, more remember responses during recognition tests, and fewer false alarms of previously presented material (Propper & Christman, 2008).

Bilateral saccadic eye movements improve memory by enhancing recollection, but do not appear to influence familiarity processes. In addition, bilateral saccadic eye movements can enhance the recall of both intrinsic and extrinsic context information (Parker et al., 2008). Intrinsic context refers to incidental or intrinsic properties of the stimulus itself (e.g., color and type font), while extrinsic context is not an integral part of the stimulus but nevertheless related to an aspect of its presentation (e.g., location on a screen and position within a list) that can be crucial for memory processing (Parker et al., 2008). Individuals use both intrinsic and extrinsic information when they make memory decisions, and extrinsic context information has the potential to increase familiarity of an item that does not actually come from memory.

Because baseline levels of interhemispheric interaction vary with the degree and direction of handedness, saccadic eye movements should have different effects on different handedness groups (Lyle, Logan, & Roediger, 2008). For strongly right-handed individuals, saccadic eye movements have been found to decrease false recall, but for non-strongly right-handed individuals, saccadic eye movements have been found to increase false recall (Lyle et al., 2008a). Lyle et al. (2008a) found that vertical saccadic eye movements (in addition to horizontal eye movements) also increase interhemispheric interaction, because the bilateral motor activity of the repetitive saccades is associated with bilateral activation of the frontal eye field. The bilateral activation represents interhemispheric interaction.

These results suggest that saccadic (horizontal and vertical) eye movements enhance retrieval for strongly right-handed individuals by increasing interhemispheric interaction, but the same increase in interhemispheric interaction has negative effects for non-strongly right-handed individuals (Lyle et al., 2008a). Therefore, interhemispheric interaction may benefit retrieval only up to a point, and past that point, it may impair retrieval (Lyle et al., 2008a). Too much interhemispheric interaction may impair episodic retrieval and increase false alarm rates, because the extra activation reaches the schemas and semantic associations related to the information in memory. The activation of this extra information is confusing and creates a failure of source memory, which leads to the increased false alarm rate.

The current study will compare the effects of handedness and bilateral saccadic eye movements on performance on the DRM paradigm. The participants will encompass a full range of handedness scores in order to determine what groups experience episodic memory advantages and disadvantages. Both vertical and horizontal bilateral saccadic eye movements will be used to follow up on the results of Lyle et al. (2008a).

The predictions for this study reflect the proposed interaction between handedness, bilateral saccadic eye movements, and memory performance. Left-handers and mixed-handers are predicted to make fewer critical false alarms than right-handers in the control (no eye movements condition). In both the horizontal and vertical eye movement conditions, right-handers are predicted to make fewer critical false alarms than left-handers and mixed-handers. Across all eye movement conditions, left-handers and mixed-handers are predicted to have faster reaction times than right-handers due to increased levels of interhemispheric interaction. In addition, left-handers in the horizontal and vertical conditions are predicted to have faster reaction times than left-handers in the control condition. Reaction times are a critical part of memory performance and provide information about memory abilities that accuracy scores alone cannot. The effects for mixed-handers are predicted to be in the same direction as those for left-handers but are predicted to be less strong as those for left-handers.

Method

Participants

There were 82 participants in this study. Eighty participants were students attending Macalester College in St. Paul, MN. These participants participated for course credit in Introduction to Psychology, Cognitive Psychology, Research in Psychology I, or Research in Psychology II. The remaining 2 participants were Macalester faculty members who were included to increase the number of left-handed participants. Left-handed participants were directly recruited (through my friends and classmates) to participate in order to have a sufficient number of left-handed participants.

Materials

This study took place in Professor Lea's cognitive psychology lab in the psychology department at Macalester College. Each participant used a PC computer and a keypad to complete the study. This study used E-Prime 2 software. The words used as stimuli were 90 words taken from the semantically related lists developed by Roediger and McDermott (1995). All of the words were presented as visual stimuli during the study phase and at test. Handedness was assessed using the Edinburgh Handedness Inventory (see Appendix 1), which asked participants to identify their hand preference for 10 tasks (e.g., writing and striking a match) as well as two questions about foot and eye preference (Oldfield, 1971). Horizontal and vertical saccadic eye movements were induced using the visual stimuli developed by Lyle, Logan, and Roediger (2008). The filler task was 15 practice GRE math problems taken from the 2010 Princeton Review GRE prep book (see Appendix 2).

Procedure

Participants met the experimenter in the cognitive psychology lab individually. All of the participants were asked to sign an informed consent form, which provided information about the study (see Appendix 3). Participants were asked to read the instructions for the EHI and invited to ask any questions. Participants were encouraged to mime the tasks on the EHI to help them be as accurate as possible while indicating their hand preferences. The experimenter gave on-screen instructions for the saccadic eye movements and the memory task. The experimenter answered any questions the participants asked.

This study used the DRM paradigm to investigate false alarm rates. Participants were presented with 6 lists of 15 words that are semantically related to a single critical word (e.g., sleep) and will be presented with each list separately (see Appendix 4). After presentation, participants did as many of the 15 practice GRE math problems as they could in 10 minutes.

Then, participants engaged in horizontal saccadic eye movements, vertical saccadic eye movements, or no eye movements. The experimenter watched the participants' eye to ensure that they were engaging in the proper eye movements. Immediately following the eye movement condition, participants were given the recognition test. The items on the recognition test were organized into 6 blocks that corresponded to the 6 presentation lists, such that the fist test block contained items from the first presentation list. Each block contained 3 studied words, 3 unrelated and non-studied words, and the critical lure for that list. Participants were asked to indicate whether they saw each word before. Every participant was given a debriefing form (see Appendix 5) and thanked for their participation at the end of the study.

Results

Participants were divided into three handedness categories based on the laterality quotients obtained from the EHI. There are no standard categories based on EHI scores, so I created groups that made sense based on previous research (e.g., Propper & Christman, 2004; Lyle, Logan, & Roediger, 2008). Left-handers were defined by laterality quotients between -88.89 and 20 (n = 24), mixed-handers were defined by laterality quotients between 35.29 and 69.23 (n = 23), and right-handers were defined by laterality quotients between 71.43 and 100 (n = 27). The mean laterality quotient was 31.80 and the median laterality quotient was 56.35. This sample of handedness is distinct from most others that lean more heavily towards the strongly right-handed end of the scale, with reported medians of 80 (Christman, Propper, & Brown, 2006; Christman, Propper, & Dion, 2004; Lyle, Logan, & Roediger, 2008) or as high as 95 (Lyle, McCabe, & Roediger, 2008). All analyses were performed using these three handedness groups. Five participants were excluded from the analysis for not following directions during the experiment, and three other participants were excluded as outliers with extreme accuracy scores beyond four times the semi-interquartile range from the median. These participants were outlier, because they were much more accurate than the other participants, which suggests a previous exposure to the DRM and thus an awareness of which items were critical lures.

The data consisted of accuracy scores and reaction times for the three types of recognition items: old (seen at presentation), new (not seen at presentation), and critical lure (semantic associate of old items). Recognition accuracy was operationalized as A' using the corrected method of signal detection analysis developed by Snodgrass and Corwin (1988)[1]. The signal detection analysis was used to compare hits, false alarms for new items (unrelated false alarms), and false alarms for critical lures (critical false alarms). In addition to calculating A', a new statistic, Weinberg's A' Lure Difference (WALD), was calculated to demonstrate the distance between the unrelated false alarm rate and the critical false alarm rate. The standard DRM prediction for false alarms is that participants will make more critical false alarms than unrelated false alarms. The WALD statistic indicates whether this prediction holds true as well as how much separation there is between the two false alarm rates. Therefore, using WALD provides a measure of how much difference there was between unrelated new items and critical lures. WALD was calculated by subtracting the A' value for the critical false alarms from the A' value for the unrelated false alarms. ANOVAs were conducted on the A' values for accuracy as well as the reaction times.

The analyses were run based on predictions for both accuracy and reaction times that reflected the interaction between handedness and bilateral saccadic eye movements. Left-handers and mixed-handers were predicted to have fewer critical false alarms than right-handers

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in the control condition (no eye-movements), while right-handers were predicted to have fewer critical false alarms than left-handers in both the vertical and horizontal eye movement conditions. Left-handers and mixed-handers were predicted to have the fastest overall reaction times and even faster reaction times for the horizontal and vertical conditions due to increased levels of interhemispheric interaction. For all of these predictions, the effects for mixed-handers were predicted to be in the same direction as those for left-handers but not as strong. The predictions for accuracy were stronger than the predictions for reaction times. The results did not support these predictions but did yield some interesting comparisons.

Because of the complex nature of the results, I will present the results in separate sections. The first section consists of analyses derived from the predictions stated in the introduction. However, since none of the predictions were supported, I will then present a second set of analyses designed to understand the present data set in Appendix 6.

Accuracy

There was no apparent difference between the horizontal and vertical conditions, so these were collapsed into a single eye movement condition for all further analyses. Recall that the experimental design was a 3 (Handedness: left, mixed, or right) X 2 (Eye Movement Group: control or eye movements) X 2 (False Alarm Type: unrelated vs. critical lure), with the first two variables varying between-subjects and the last varying within-subjects. Left-handers and mixed-handers were predicted to have higher A’ values for critical lures (critical A’) and thus make fewer false alarms than right-handers in the control condition. Right-handers were predicted to have higher A’ values and thus make fewer false alarms than left-handers and mixed-handers in the eye movement conditions.

Figure 1 presents the means tested in this analysis of the accuracy data. Across both eye movement conditions, the A' was higher for unrelated items (unrelated A') compared to the critical A'. Since A' is a measure of discrimination (specifically the ability to discriminate old from new items), this means that participants made fewer false alarms for unrelated items than for critical lures. This trend produced a significant main effect for false alarm type, *F*(1, 65) = 60.296, *p* < .001. This main effect, however, was qualified by a significant false alarm type by handedness group interaction, *F*(2, 65) = 3.749, *p* = .029 that is shown in Figure 2. Left-handers consistently made more critical false alarms than unrelated false alarms, *t*(22) = 6.232, *p* < .001, as did right-handers, *t*(26) = 6.588, *p* < .001. Mixed-handers made more critical than unrelated false alarms as well, but this trend was not very strong, *t*(20) = 2.127, *p* = .046. The higher critical A' rate for mixed-handers also produced a significant main effect of handedness group, *F*(2, 65) = 3.834, *p* = .027. Multiple comparisons using LSD revealed a marginally significant comparison between mixed-handers and left-handers, *p* = .056, as well as a marginally significant comparison between mixed-handers and right-handers, *p* = .062. These results demonstrate that mixed-handers made more false alarms overall (i.e., both unrelated and critical) and left-handers and right-handers.

Figures 3a and 3b depict A' rates for handedness group by eye movement condition (collapsed to two levels: eye movements or control). Panel A presents A' for critical lures, and Panel B gives A' for unrelated new items. Handedness appears to interact with eye movement group in Panel A; this interaction was marginally significant, *F*(2, 65) = 2.685, *p* = .076. Left-handers in the control condition made more critical false alarms than left-handers in an eye movement condition, *t*(21) = - 2.330, *p* =.030. Mixed-handers made the same amount of critical false alarms in the control condition and in the eye movement conditions, *t*(19) = .961, *p* = .349.

Like the mixed-handers, the right-handers also made the same amount of critical false alarms in the control and eye movement conditions *t*(25) = .371, *p* =.714. None of the handedness groups exhibited any differences in the amount of unrelated false alarms by eye movement condition. The participants' handedness seems to have affected how their behavioral responses to the bilateral saccadic eye movements for the critical lures.

The WALD scores were used to interpret the differences between false alarms for unrelated items and the false alarms for the critical lures. The DRM predicts that the critical lures will produce significantly more false alarms than the unrelated items, and the WALD analysis supported this prediction. Figure 5 depicts the effects on WALD based on handedness (left, mixed, or right) and eye movement group (control or no eye movements). Higher values of WALD indicate a greater difference between unrelated and critical false alarms, and these high values mean that participants were treating new items and critical lures differently.

There was a significant main effect for handedness, *F*(2, 65) = 3.749, *p* =.029, which indicates that handedness had a differential effect on the treatment of new items and critical lures. WALD scores for left-handers and mixed-handers were marginally different, *p* = .056, and WALD scores for mixed-handers and right-handers were marginally different, *p* = .063. The more interesting trend is the marginal interaction between eye movement group and handedness, *F*(2, 65) = 2.594, *p* = .082. As shown in Figure 5, left-handers had significantly higher WALD scores in the control condition than in the collapsed eye movement conditions, *t*(21) = 2.147, *p* = .044.

Reaction Times

To test the hypothesis that handedness groups (left, mixed, or right) differentially affected reactions times for the different types of recognition items, I submitted the reaction times data to a 3 (Handedness: left, mixed, or right) X 3 (Eye Movement Condition: horizontal, vertical, or control) X 3 (Recognition Item Type: old, new, or critical lure) ANOVA, with the first two variables varying between-subjects and the last varying within-subjects. Figure 6 presents the means tested in this analysis. Across the eye movement conditions, the responses to new items were significantly slower (mean = 1130.69 ms) than the responses to both the old items (mean = 994.32 ms), $p < .001$, and the critical lures (mean = 982.19 ms), $p < .001$. Figure 6 depicts this significant main effect of recognition item type, $F(1.703, 124) = 13.523$, $p < .001$. Old items did not differ significantly from the critical lures, $p = .554$. Figure 6 also demonstrates a marginal main effect for handedness group, $F(2, 62) = 3.030$, $p = .056$. This trend appears to follow the pattern of mixed-handers responding more quickly (mean = 870.78 ms) to the critical lures than left-handers (mean = 1061.80 ms) and right-handers (mean = 1001.03 ms).

Discussion

This study examined the effects of handedness and bilateral saccadic eye movements on false alarms in the DRM paradigm to further the understanding of cognitive implication of handedness and interhemispheric interaction. The results of this study add to the growing body of research on the cognitive implications of handedness. Even though the effects of handedness and bilateral saccadic eye movements found in this study do not follow patterns found in previous research, handedness and interhemispheric interaction definitely affect our cognitive processes. As expected from previous research using the DRM paradigm, participants made more critical false alarms than unrelated false alarms. Interestingly, this effect was mitigated by handedness, as mixed-handers exhibited close to the same amount of critical and unrelated false alarms.

The induced bilateral saccadic eye movements served as a manipulation of interhemispheric interaction, as the bilateral movement produces activity that rapidly switches back and forth between the two hemispheres. The prediction that eye movements would increase the amount critical false alarms for left-handers and mixed-handers but decrease the amount critical false alarms for right-handers was not supported. However, the effects of the eye movements were different based on the handedness groups. For left-handers, eye movements increased the number of critical false alarms. For mixed handers and right-handers, eye movements did not alter the amount of critical false alarms. Because eye movements affected critical false alarms, the neural activity associated with the eye movements appears to influence semantically associated information that contributes to source memory processes.

Left-handers and mixed-handers were predicted to have faster reaction times than right-handers, and eye movements were predicted to further increase the speed of the responses. These predictions were not supported, but the reaction time data do provide evidence for the separation of processes involved in making memory decisions about new items and critical lures. The reaction time data suggest that participants treated new items and critical lures differently. Overall, participants responded more quickly to both old items and critical lures than to new items. The lack of difference between old items and critical lures indicates that participants treated critical lures as old items and did not hesitate to make their response. This trend in reaction times was marginally affected by handedness, as mixed-handers responded faster to critical lures than both left-handers and right-handers. Therefore, mixed-handers are more likely to treat critical lures like old items than right-handers or left-handers.

The WALD analysis was used to measure the difference in discrimination sensitivity between critical and unrelated false alarms. Critical false alarms and unrelated false alarms were definitely distinct, and the WALD statistic allowed for a comparison of the difference between critical and unrelated false alarms across groups. Left-handers exhibited a substantial difference in WALD between the control and eye movement conditions, with WALD scores higher in the control condition. The interhemispheric interaction present in the left-handers because of a combination of higher baseline levels of interhemispheric interaction and the induced eye movements appears to have lessened the difference between critical and unrelated false alarms.

The WALD statistic is a valuable extension to signal detection analysis, as it can be used to summarize the distance between two A^1 distributions. As demonstrated by this study, WALD analysis is a useful tool for research using the DRM paradigm. WALD can be used whenever there are two types of A^1 values in an experiment. A potential use of WALD is for source memory tasks that ask participants to distinguish between two different sources of their memories. An example of this type of task is a see-hear test, which consists of a combination of visual and auditory presentation and asks participants whether they saw or heard the stimulus at test. WALD would be useful in determining if seeing or hearing the stimuli makes a difference for source memory performance.

Unlike most other studies, this study used three handedness groups (left, mixed, and right) to examine effects of handedness. The use of a full range of handedness in handedness research is critical. So much is still unknown about handedness, thus it is essential to look for effects with as much data as possible. In addition, this study reports differential effects for mixed-handers who are frequently not studied as a distinct group. Most previous research used only two handedness groups: strongly right-handed individuals and everyone else. Lyle, McCabe, and Roediger (2008) had a very narrow strong right-handed group (LQs of 95 and above) and a very broad non-strong right-handed group (LQs of 90 and below). Lyle, Logan, and Roediger (2008) divided their participants into strong right-handers (LQs of 80 and above) and non-strong right-handers (LQs below 80). Propper and Christman (2004) defined strongly right-handed participants as those with LQs of 75 and above and designated participants with LQs between 45 and 70 as mixed-handed. Christman, Propper, and Dion (2004) and Christman, Propper, and Brown (2006) divided their participants into mixed-handers and right-handers, with mixed-handers defined as participants who scored a 75 or below on the EH and right-handers defined as participants who scored 80 and above on the EHI. This list could continue, but it already demonstrates how a variety of handedness categories are used and how individuals with lower LQs are lumped into a single large group. There is clearly diversity in the non-right-handed category, and it is unclear what groups within that large category are driving the effects.

Handedness researchers should develop standardized handedness categories that will give clear definitions of left-handed, mixed-handed, and right-handed. It is currently unclear what it means to belong to any given handedness group, as these groups change across studies. Standardized groups would make it much easier to compare different studies, as it would provide consistency. The effects found for mixed-handers suggest the possibility of nonlinear correlations between laterality quotients and memory abilities. The only way to investigate this possibility is to find participants who represent all levels of handedness. Therefore, researchers must work hard to bring mixed-handers and left-handers into the lab.

The differences between the results of this study and previous results led me to carefully examine any possible difference between this study and previous studies. This study used the DRM paradigm as Roediger and McDermott (1995) originally developed it. The presentation lists were the six lists with the strongest critical lure effects, and both the presentation and test phases were exactly modeled after Roediger and McDermott (1995). Bilateral saccadic eye movements were induced using the moving dots developed by Lyle, Logan, and Roediger (2008). Their E-Prime program was directly inserted into the program for this study, and participants were seated at the correct distance to maintain the same visual angle. The EHI developed by Oldfield (1971) was used to assess the degree and direction of the participants' handedness. The EHI is the standard measure for handedness. Because of these consistencies, the results of this study probably represent a psychological effect that simply requires additional investigation.

There were some limitations to this study. The 'yes' and 'no' response keys were always in the same place on the keypad (i.e., 'yes' was on the right and 'no' was on the left). Some of the left-handed participants reported feeling like 'yes' and 'no' were on the wrong sides. The induced eye movements were also not as precise as they could have been. Participants sat at a measured distance from the screen, but their heads were not steadied in a chin rest. The experimenter watched the participants' eyes to check for bilateral saccadic eye movements, but an eye tracker would have been useful to guarantee the true presence of bilateral saccadic eye movements.

Further research is needed to determine how handedness and interhemispheric interaction affect memory and other cognitive processes. Improved and standardized handedness groups will help clarify handedness effects. Functional magnetic resonance imaging (fMRI) is a useful tool that may be able to demonstrate the patterns of interhemispheric interaction associated with handedness as well as induced bilateral saccadic eye movements. Determining the cognitive implications for handedness and interhemispheric interaction could potentially help people improve their memory capacities. Methods to improve memory are particularly important for the aging population that is at risk for Alzheimer's and dementia.

Individuals cannot change their handedness, but it would be possible for them to alter levels of interhemispheric interaction. Induced bilateral saccadic eye movements are a good start, but recent fMRI research has demonstrated the people can actually be trained to willfully alter their brain activity (deCharms et al., 2005). Feedback from Real-time fMRI (rtfMRI) to train healthy participants and chronic pain patients to control activity in the rostral anterior cingulated cortex (rACC) and thus their perception of pain (deCharms et al., 2005). This exciting research suggests that individuals can be similarly trained to control activity in other areas of the brain. Potentially, people could be trained to increase levels of interhemispheric interaction with the help of rtfMRI feedback and maybe experience some episodic memory benefits.

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Footnote

[1] The A’ statistic is a variation on the d’ statistic that is a measure of accuracy that uses signal detection theory. Signal detection theory uses of combination of sensitivity and bias to account for participants’ responses. Sensitivity indicates the participants’ ability to discriminate between old and new items and is the measure of accuracy we are interested in. We must account for bias, which is how likely participants are to respond “yes” or “no” when they are unsure of the correct answer. Signal detection analysis adjusts straight accuracy data to account for response bias and indicate the participants’ ability to discriminate between old and new items. This is done statistically by presenting false alarm rates in terms of hit rates as A’ (or d’) values. Signal detection analysis thus accounts for participants responding “yes” to every item or “no” to every item by demonstrating that these participants are not discriminating between old and new items, and thus have very low accuracy. Signal detection analysis is good measure of accuracy, because it assesses discrimination ability, which directly reflects what the participants are being asked to do at test.

Figure 1. Mean A' values for the collapsed eye movement groups (control/no eyemovements vs. eye movements.

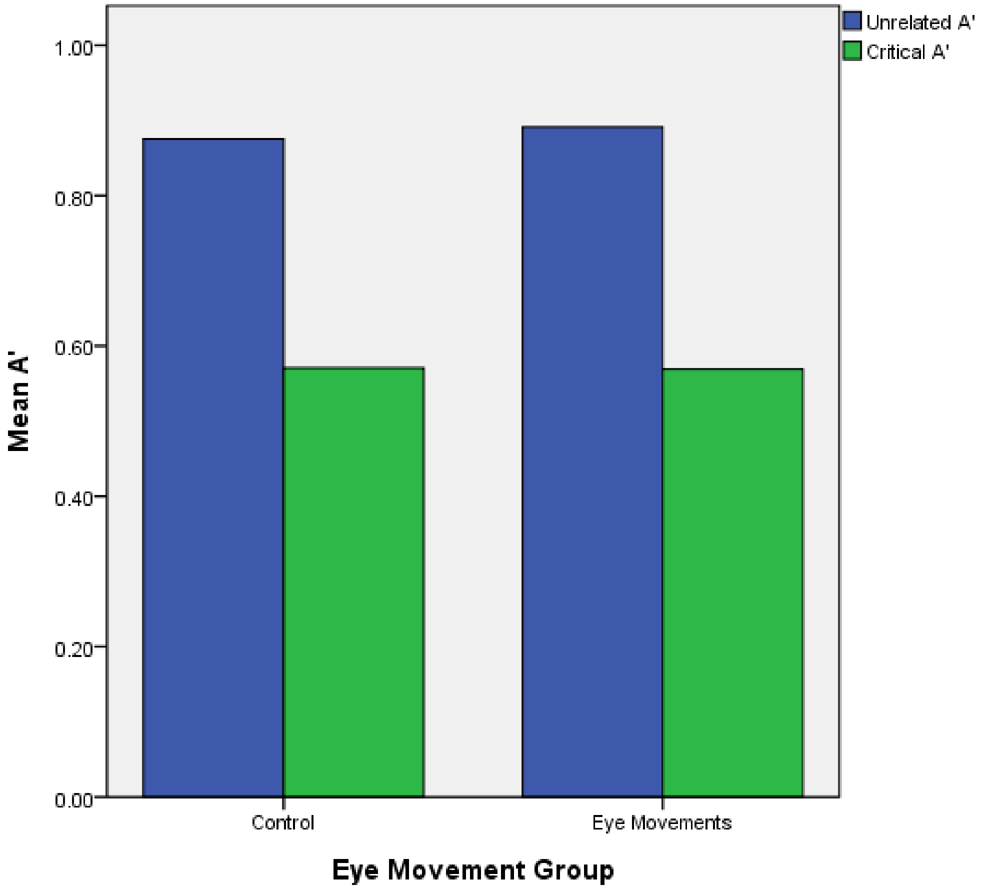


Figure 2. Mean A' values for the three handedness groups (left, mixed, and right).

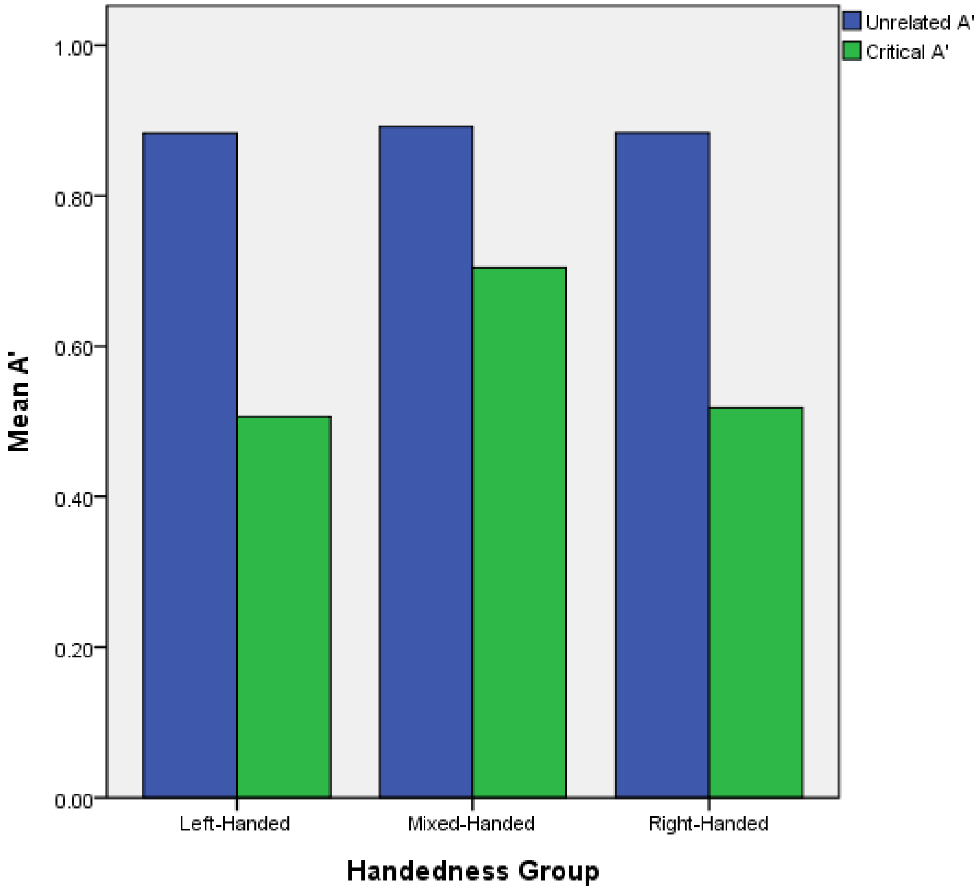
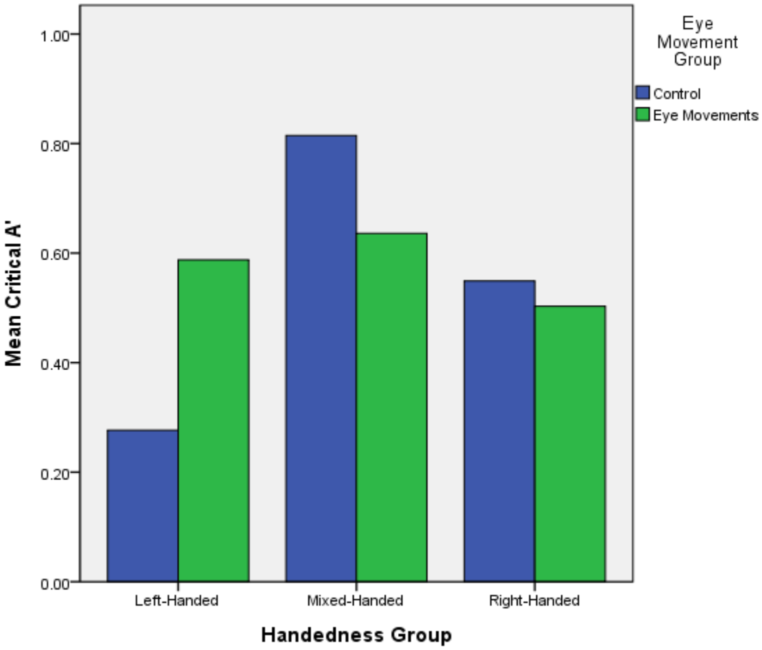


Figure 3

a) Mean critical A' values for the eye movement conditions for each of the three handedness groups.



b) Mean unrelated A' values for the eye movement conditions for each of the three handedness groups.

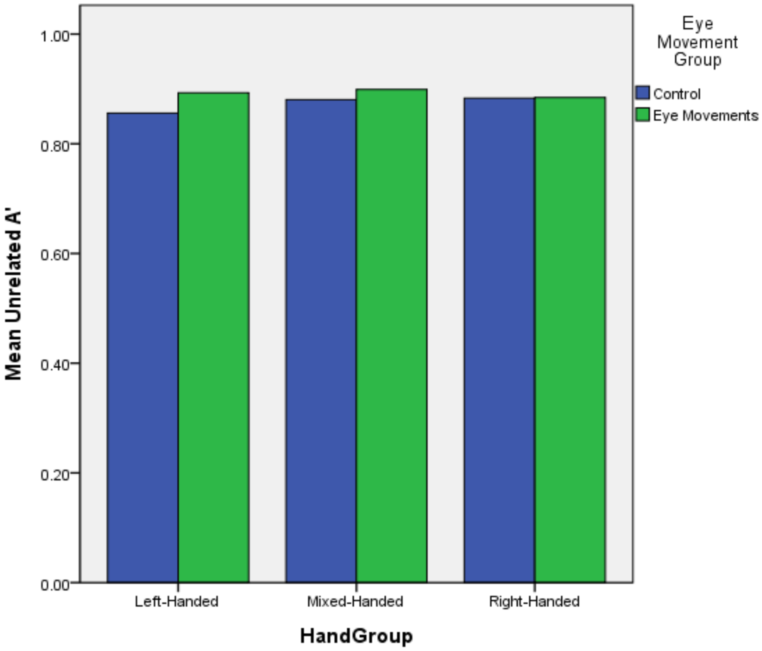


Figure 4. Mean WALD values for the eye movement conditions for each of the three handedness groups.

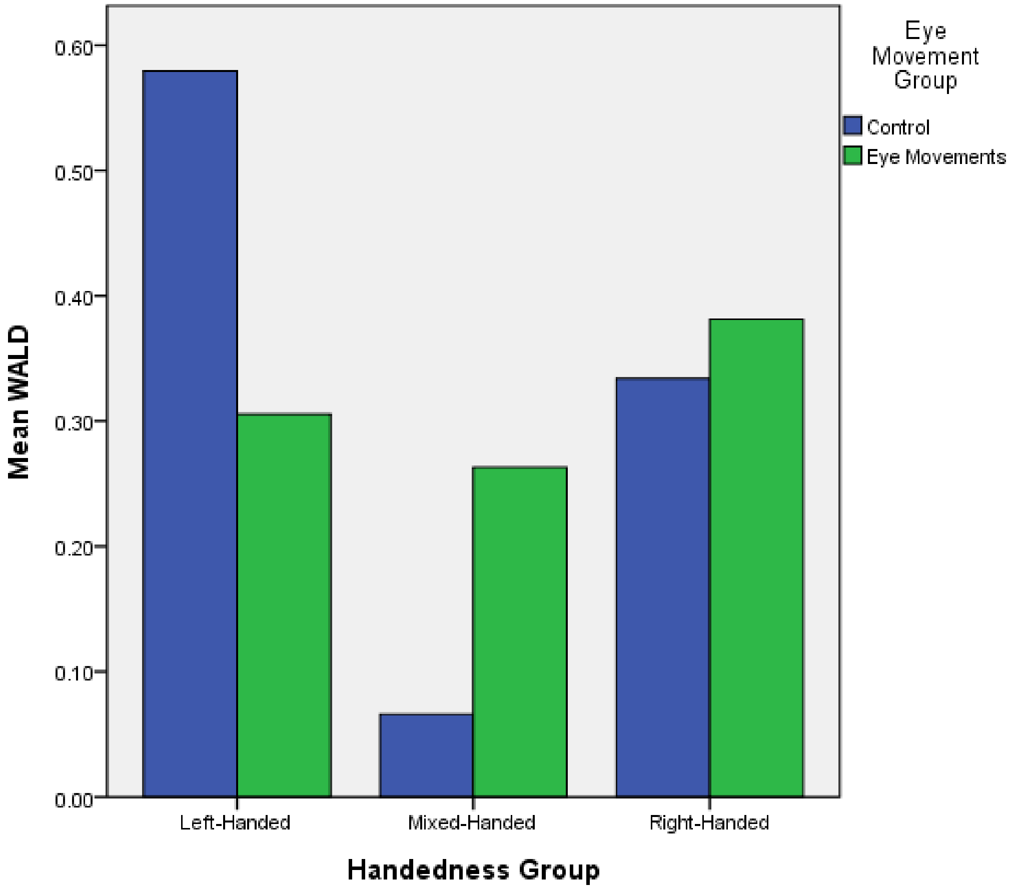
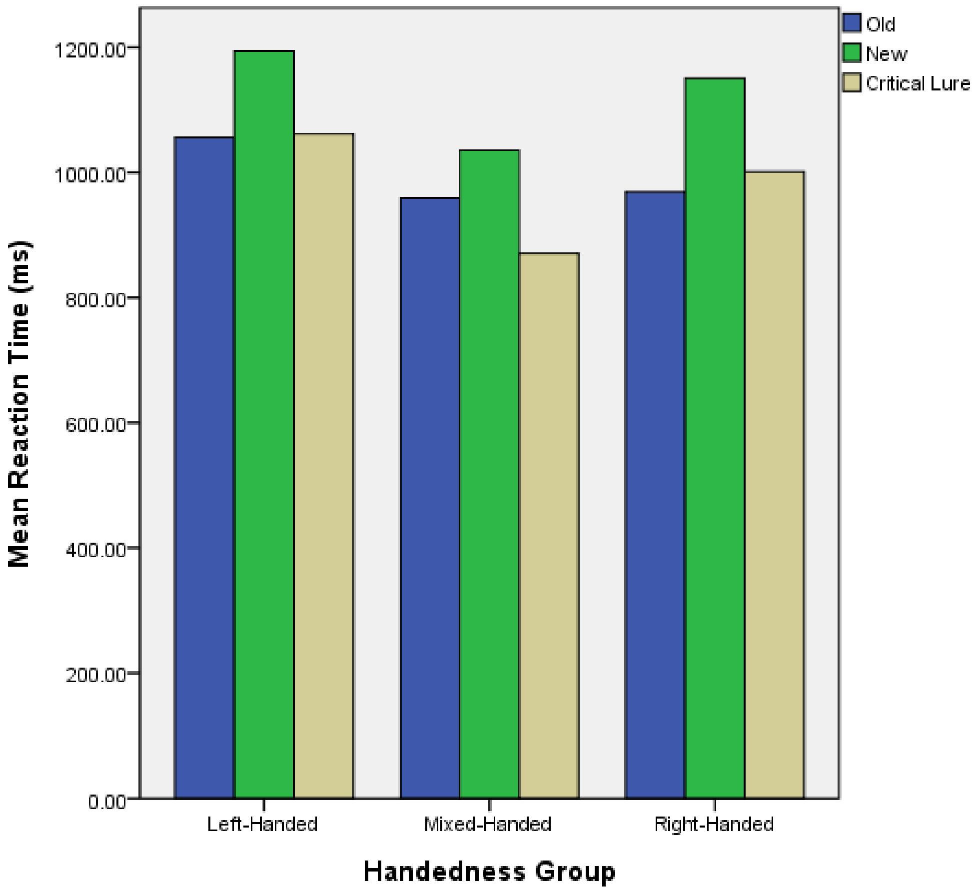


Figure 5. Mean reaction times in milliseconds for old items, new items, and critical lures for each of the three handedness groups.



Appendix 1

Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities by ***putting + in the appropriate column.*** Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, ***put + +.*** If in any case you are really indifferent ***put + in both*** columns. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		Left	Right
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening Box (lid)		
11	Which foot do you prefer to kick with?		
12	Which eye do you use when using only one?		

Appendix 2

Please complete as many of these problems as you can to the best of your ability. You can use as much scratch paper as you need.

1. If $k = 6$ X17, then which of the following is a multiple of k?

a) 68
b) 78
c) 85
d) 136
e) 204

2. What is the value of $(4 + a)(4 – b)$ when $a = 4$ and $b = - 4$?

a) – 64
b) – 16
c) 0
d) 16
e) 64

3. The illumination E, in footcandles, provided by a light source of intensity l, in candles, at a distance D, in feet, is given by $E = 1/D^2$.
For an illumination of 50 footcandles at a distance of 4 feet from a source, the intensity of the source must be

a) 50 candles
b) 200 candles
c) 800 candles
d) 1,600 candles
e) 2,500 candles

4. If $x + y = z$, then, $x^2 – 2xy + y^2 =$

a) $4z$
b) $yz – yx$
c) z^2
d) $z^2 + 4(x + z)$
e) $z^2 + yz + x^2$

5. $12m^2 – 8m – 64 =$

a) $4(3m +8)(m – 2)$
b) $4(3m – 8)(m + 2)$
c) $4(3m – 2)(m + 8)$
d) $4m^2 – 64$

e) $4m - 64$

6. What is the greatest possible value of integer n if $6^n < 10,000$?

a) 5
b) 6
c) 7
d) 8
e) 9

7. In the equation $ax + b = 26$, x is a constant. If $a = 3$ when $b = 5$, what is the value of b when $a = 5$?

a) – 11
b) – 9
c) 3
d) 7
e) 21

8. An office supply store charged $13.10 for the purchase of 85 paper clips. If some of the clips were 16 cents each and the remainder were 14 cents each, how many of the paper clips were 14 cent clips?

a) 16
b) 25
c) 30
d) 35
e) 65

9. In the set of numbers {12, 5, 14, 12, 9, 15, 10), f equals the mean, g equals the median, h equals the mode, and j equals the range. Which of the following is true?

a) $f > g > h > j$
b) $g = h > f > j$
c) $f = h > g > j$
d) $g > h > f = j$
e) $j > f > g = h$

10. Which of the following CANNOT be an integer if the integer k is a multiple of 12 but not a multiple of 9?
a) $k/3$
b) $k/4$
c) $k/10$
d) $k/12$
e) $k/36$

11. Which of the following is equivalent to $(3a – 5)(a + 6)$?

I. $(3a + 5)(a – 6)$
II. $– 5(a + 6) + 3a(a + 6)$
III. $3a^2 – 30$

a) II only
b) III only
c) I and II only
d) II and III only
e) I, II, and III

12. If the dimensions of a rectangular crate, in feet, are 5 by 6 by 7, which of the following CANNOT be the total surface area, in square feet, of two sides of the crate?

a) 60
b) 70
c) 77
d) 84
e) 90

13. In the set of positive, distinct integers $\{a, b, c, d, e\}$ the median is 16. What is the minimum value of $a + b + c + d + e$?

a) 26
b) 48
c) 54
d) 72
e) 80

14. A professor is choosing students to attend a special seminar. She has 10 students to choose from and only four may be chosen. How many different ways are there to make up the four students chosen for the seminar?

____

15. How many square tiles, each with a perimeter of 64 inches, must be used to completely cover a bathroom floor with a width of 64 inches and a length of 128 inches?

____

Appendix 3

Consent Form
Handedness and Memory

You are being asked to participate in a study on the relationship between handedness and recognition memory being conducted by Lisa Weinberg and her research advisor, Prof. Brooke Lea. This study consists of a recognition memory task and a questionnaire that evaluates the degree and direction of an individual's handedness. Handedness refers to an individual's general lateral tendencies for motor tasks that require the use of one side of the body. Therefore, this includes many tasks beyond which hand you use to write. The risk associated with your participation is minimal, but it is possible that you may experience some discomfort. You are free to decline to participate in this study, and you are able to leave the study at any time for any reason without penalty.

Students enrolled in Introductory Psychology will receive .5 credit hours for participating in this study. All other participants will be entered in a prize lottery sponsored by the Psychology Department. The grand prize is a $50 gift card (subject to US taxes) or a book of your choice with a value of up to $50; smaller prizes include flash drives and other gifts valued at between $5 and $10.

Your participation in this study will be a valuable contribution to the psychological understanding of handedness and recognition memory.

All of the information you provide during the course of this study will be kept under the strictest confidence. Your identity will not be disclosed under any circumstances and will have no connection to this study.

If you have any questions or concerns about your participation, please contact Lisa Weinberg (lweinberg@macalester.edu) or Prof. Brooke Lea (lea@macalester.edu) at any time.

Thank you for participating in this study. The time and effort you put into this study are highly appreciated.

By signing your name below, you are agreeing to participate in this study.

Name Date

Appendix 4

Word Lists (critical lure in bold)

CHAIR
Table
Sit
Legs
Seat
Couch
Desk
Recliner
Sofa
Wood
Cushion
Swivel
Stool
Sitting
Rocking
Bench

MOUTAIN
Hill
Valley
Climb
Summit
Top
Molehill
Peak
Plan
Glacier
Goat
Bike
Climber
Range
Steep
Ski

NEEDLE
Thread
Pin
Eye
Sewing
Sharp
Point
Prick
Thimble
Haystack
Thorn
Hurt
Injection
Syringe
Cloth
Knitting

ROUGH
Smooth
Bumpy
Road
Tough
Sandpaper
Jagged
Ready
Coarse
Uneven
Riders
Rugged
Sand
Boards
Ground
Gravel

SLEEP
Bed
Rest
Awake
Tired
Dream
Wake
Snooze
Blanket
Doze
Slumber
Snore
Nap
Peace
Yawn
Drowsy

SWEET
Sour
Candy
Sugar
Bitter
Good
Taste
Tooth
Nice
Honey
Soda
Chocolate
Heart
Cake
Tart
Pie

Appendix 5

Debriefing Form
Effects of handedness and saccadic eye movements on false alarms for critical lures

The study you just completed examines that relationship between handedness, saccadic eye movements, and false alarms in recognition memory. Saccadic eye movements are the rapid instinctive back and forth eye movements that occur without any conscious thought. Both handedness and saccadic eye movements are associated with increased levels of interhemispheric interaction in the brain. The recognition memory task you completed follows the Deese-Roediger-McDermott paradigm. You were presented with lists of words that were semantically related to a non-presented critical word (e.g., sleep) and then asked if you saw the critical lure. False alarms are when individuals incorrectly report that they recognize the critical lure. Greater interhemispheric enhances recognition memory and decreases the rate of false alarms.

If any portion of this study caused any discomfort or raised any questions, please feel free to contact Lisa Weinberg (lweinberg@macalester.edu) or Professor Brooke Lea (lea@macalester.edu) at any time. You can also contact Macalester's Health and Wellness Center (located in the Leonard Center) at 651-696-6275 or health@macalester.edu. The hours for the Health and Wellness Center are Mon. & Fri from 8:30-4:30, Wed. from 12:30-4:30, and Tues. & Thurs. from 9:00-5:00.

The results of this study will be available at the end of the semester. If you would like to see the results of the study, please contact the researcher (Lisa Weinberg) or her research advisor (Brooke Lea).

Thank you for your participation.

Appendix 6

The analyses presented here include an analysis of my data based on handedness groups that correspond to those used in previous research (e.g., Lyle, Logan, & Roediger 2008 and Propper & Christman, 2004). My participants' laterality quotients were distinct from those found by other researchers, so I wanted to investigate the possibility that my results diverged from previous research because of differences in laterality quotients. In addition to applying new handedness groups to my data, I split the data by laterality quotient so that I only analyzed the 10 most extremely left-handed participants and the 10 most extremely right-handed participants.

Altered Handedness Groups

To test the possibility that my unusual handedness groups accounted for my unusual results, I divided my participants in two new handedness groups: strong right-handers (SR) with LQs greater than 80 and non-strong right-handers (nSR) with LQs less than 80. I then submitted the accuracy data to a 2 (Handedness: SR or nSR handers) X 3 (Eye Movement Condition: horizontal, vertical, or control) X 2 (False Alarm Type: unrelated vs. critical) ANOVA, with the first two variables varying between-subjects and the last varying within-subjects. As in the analyses using the three handedness groups (left, mixed, and right), there was a significant main effect of false alarm type, $F(1, 65) = 38.452$, $p < .001$ but not other significant main effects or interactions (*p's* > .05). The A' value for unrelated false alarms (.888) was higher than the A' value for critical false alarms (.586). Since A' is a measure of discrimination, this result indicates that participants were better at discriminating unrelated new items from old items than critical lures from old items. Therefore, participants made more critical false alarms than unrelated false alarms. These results correspond to the results for accuracy from previous analyses.

To test if the participants with extreme laterality quotients would demonstrate a different pattern of results, I extracted the 10 most extremely left-handed participants and the 10 most extremely right-handed participants and analyzed them separately. The extremely left-handed (ELH) group consisted of laterality quotients from -88.89 to -75, and the extremely right-handed (ERH) group consisted of laterality quotients from 87.5 to 100. I submitted the accuracy data to a 2 (Extreme Handedness Group: ELH or ERH) X 3 (Eye-Movement Condition) X 2 (False Alarm Type: unrelated vs. critical) ANOVA, with the first two variables varying between-subjects and the last varying within-subjects. Consist with the other analyses, there was a significant main effect of false alarm type, $F(1, 14) = 29.277$, $p < .001$, but no other main effects or interactions were significant. Keeping with the previously reported pattern, participants made more critical false alarms (mean A’ = .503) than unrelated false alarms (mean A’ = .882).