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Hemispheric Asymmetries in the Activation and Monitoring of Memory Errors

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Abstract

Previous research on the lateralization of memory errors suggests that the right hemisphere's tendency to produce more memory errors than the left hemisphere reflects hemispheric differences in semantic activation. However, all prior research that has examined the lateralization of memory errors has used self-paced recognition judgments. Because activation occurs early in memory retrieval, with more time to make a decision, other memory processes, like strategic monitoring processes, may affect memory errors. By manipulating the time subjects were given to make memory decisions, this study separated the influence of automatic memory processes (activation) from strategic memory processes (monitoring) on the production of false memories. The results indicated that when retrieval was fast, the right hemisphere produced more memory errors than the left hemisphere. However, when retrieval was slow, the left hemisphere's error-proneness increased compared to the fast retrieval condition, while the right hemisphere's error-proneness remained the same. These results suggest that the right hemisphere's errors are largely due to activation, while the left hemisphere's errors are influenced by both activation and monitoring.

Keywords

false memory; lateralization; semantic activation; source monitoring

1. Introduction

False memories constitute events that are remembered that never occurred, or occurred much differently than they are remembered. False memories are best known to the general public as a potential consequence in eyewitness settings (Wells, et al., 2000) or psychotherapeutic techniques like recovered memory therapy (Shobe & Kihlstrom, 1997). However, their occurrence is also important in understanding the mechanisms of human memory. Much is still unclear about the fundamental processes of memory, and by closely evaluating the origin and maintenance of false memories, we can better understand the nature of memory processes. Furthermore, a thorough understanding of the mechanisms underlying false memories can lead to techniques to minimize their effects.

False memory is commonly studied with the Deese/Roediger-McDermott (DRM) Paradigm (Deese, 1959; Roediger & McDermott, 1995). Subjects study a list of words (e.g., *sour*,

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candy, sugar, bitter, good, taste, tooth, and nice) that are all related to a single unrepresented *lure word* (e.g., *sweet*). Following this study period, subjects are asked to either recall or recognize the words on the list. False memory arises when subjects falsely believe that unstudied lure words such as *sweet* were presented in the study phase.

Recently, the study of false memories using the DRM paradigm has been extended to examine the disparities in error rates between the brain's hemispheres in order to understand the semantic activation processes that occur in each hemisphere (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Fabiani, et al., 2000; Faust, et al., 2007; Ito, 2001; Westerberg & Marsolek, 2003). Studies have shown that the right hemisphere produces more lure errors than the left hemisphere (Bellamy & Shillcock, 2007; Westerberg & Marsolek, 2003). Further, Westerberg and Marsolek (2003) found that participants were more confident in rejecting the lure words presented to the left hemisphere than the right hemisphere.

In general, researchers have interpreted these findings as support for a prominent theory of semantic processing, fine-coarse coding theory (Beeman, 1998; Jung-Beeman, 2005). This theory suggests there are differences in semantic networks between the brain's hemispheres, such that the left hemisphere activates a relatively fine semantic network, while the right hemisphere activates a relatively coarse semantic network. The left hemisphere's fine semantic network quickly focuses on the dominant or contextually-relevant meaning of a concept and inhibits the concept's subordinate meanings. In contrast, the right hemisphere activates a diffuse semantic network that includes several alternate meanings of a concept. Because the right hemisphere's semantic networks are more diffuse than those in the left hemisphere, they are more likely to enable the activation of distantly related meanings when a concept is encountered. The right hemisphere's tendency to produce more lure errors than the left hemisphere in the DRM paradigm can be explained by the fine-coarse coding theory. Specifically, due to the diffuse semantic networks in the right hemisphere, studying words associated with a lure item will be more likely to activate the lure's representation in the right hemisphere than the left hemisphere, leading the right hemisphere to make more errors (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Fasut, et al., 2007; Ito, 2001; Westerberg & Marsolek, 2003).

Fine-coarse coding theory describes hemispheric differences in DRM lure errors in terms of semantic memory activation differences between the brain's hemispheres. However, theories of false memory typically propose that there are two processes that underlie lure errors (Brainerd, et al., 1995; Roediger, et al., 2001). For simplicity, we describe the constructs posited by activation-monitoring theory (Roediger et al., 2001) because, like fine-coarse coding theory, it proposes semantic memory activation plays a role in producing lure errors. In addition, activation-monitoring theory proposes that people sometimes employ strategic monitoring processes to determine whether or not a memory is authentic. These monitoring processes typically have the effect of reducing lure errors because subjects can evaluate a variety of types of memorial information and determine whether a test item was experienced as part of a specific encoding episode or context. Thus, activation-monitoring theory suggests that lure error rates result from both semantic memory activation and monitoring processes while only semantic memory activation is used to explain false memory by fine-coarse coding theory.

Importantly, evidence favors two-factor theories of false memory over those that argue a single factor (e.g., semantic memory activation) underlies false memory (e.g., Arndt & Gould, 2006; Benjmain, 2001). Further, prior studies of hemispheric differences in false memory (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Faust et al., 2008; Ito, 2001; Westerberg & Marsolek, 2003) have not taken specific steps to dissociate activation- and monitoring-based influences on lure errors. Thus, although it is possible that hemispheric

asymmetries in memory errors are only caused by differences in semantic memory activation between the brain's hemispheres as fine-coarse coding theory suggests (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Ito, 2001; Westerberg & Marsolek, 2003), it is also possible that those asymmetries arise from both activation and monitoring processes, or solely from monitoring processes (Faust, et al., 2008).

The possibility that monitoring processes can explain part or all of hemispheric differences in false memory is supported by evidence that the right hemisphere evaluates less specific information than the left hemisphere (Dobbins et al., 2004; Mitchell & Johnson, 2009). Specifically, the right hemisphere evaluates item familiarity, while the left hemisphere monitors memory for contextual and semantic information (Dobbins et al., 2004). Given these differences in monitoring abilities between the hemispheres, monitoring processes can explain why the right hemisphere produces more lure errors than the left hemisphere. Specifically, since left hemisphere monitoring processes evaluate more detailed information, the left hemisphere will be able to limit lure errors better than the right hemisphere. Thus, because both activation and monitoring processes differ between the brain's hemispheres, and both activation and monitoring can explain hemispheric differences in false memory, a full understanding of hemispheric differences in false memories requires separating their contributions to false memory. This separation of activation and monitoring processes was the primary goal of the present study.

Critical to the present investigation of hemispheric differences in false memory is that semantic memory activation and memory monitoring processes tend to become available at different time points during retrieval (Heit, et al., 2004). Semantic memory activation is generally characterized as being available early in memory retrieval because it is a reflection of automatic access to a concept's representation in semantic memory (Neely, 1977). Monitoring, on the other hand, generally requires conscious and intentional deliberation because a person is attempting to access and retrieve evidence from memory that an event was encountered in a particular encoding context. As a result, monitoring processes are typically only available later in retrieval. In order to separate the contribution of activation- and monitoring-based processes to hemispheric differences in memory errors, we manipulated retrieval time in addition to the visual field of test item presentation. Specifically, subjects were cued to respond 500 ms after the onset of the test item in the fast retrieval condition, and 2500 ms after the onset of the test item in the slow retrieval condition. Given that semantic memory activation is available early in retrieval and monitoring is increasingly available as retrieval proceeds in time (Heit et al., 2004), lure error rates in the fast retrieval condition should mainly reflect the influence of activation, while lure error rates in the slow retrieval condition should reflect the effects of both activation and monitoring. Thus, lure errors in the fast retrieval condition should provide an assessment of how activation influences hemispheric differences in false memory. Similarly, because activation influences performance in both the fast and slow retrieval conditions, but monitoring only influences performance in the slow retrieval condition, the *difference* between lure errors in the fast and slow retrieval conditions should provide an assessment of how monitoring processes influence hemispheric differences in false memory. We now turn to specify the expected outcomes from this study if hemispheric differences are driven a) only by activation-based processes, b) only by monitoring-based processes, or c) if hemispheric differences in false memory are due to a combination of activation and monitoring processes.

If activation alone produces hemispheric differences in false recognition, as fine-coarse coding theory and previous research suggest (Bellamy & Shillcock, 2007; Ben-Artzi, 2009; Ito, 2001; Westerberg & Marsolek, 2003), we would expect the results in the fast retrieval condition to parallel the results in the slow retrieval condition. Based on fine-coarse coding

theory's premise that the left hemisphere has more focused semantic networks while the right hemisphere has more diffuse semantic networks, the right hemisphere should produce more errors than the left hemisphere in the fast retrieval condition. Further, when participants are given more retrieval time to employ monitoring strategies, this hemispheric difference in lure errors should not change.

If monitoring alone produces hemispheric differences in lure errors, we would expect the hemispheres to produce similar levels of lure errors in the fast retrieval condition, and that hemispheric differences in lure errors would only emerge in the slow retrieval condition. This prediction occurs because monitoring processes are only able to influence lure error rates when participants have time to deliberate. Based on the respective monitoring capabilities of each hemisphere, the left hemisphere's detail-based monitoring should produce a greater decline in error rates between the fast and slow retrieval conditions compared to the right hemisphere's familiarity-based monitoring. This will result in more lure errors in the right compared to the left hemisphere -- the pattern seen in most prior research (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Ito, 2001; Westerberg & Marsolek, 2003).

Finally, if hemispheric asymmetries for memory errors reflect a combination of activation and monitoring processes, the data will show differences in error patterns between hemispheres in the fast retrieval condition, and the size or direction of that difference will change in the slow retrieval condition. The strongest evidence that both activation and monitoring contribute to hemispheric differences in false recognition would take the form of hemispheric differences that exist in the fast retrieval condition reversing in the slow retrieval condition. Such an outcome would suggest that there is a difference in semantic memory activation across the hemispheres, which produces the hemispheric differences in the fast retrieval condition, and a countervailing hemispheric difference in monitoring processes that reverses the hemispheric difference in false memory in the slow retrieval condition. For example, if the left hemisphere made more errors in the fast retrieval condition, but the right hemisphere made more errors in the slow retrieval condition, that outcome would suggest that 1) activation of lure representations is greater in the left hemisphere than the right hemisphere, but 2) monitoring processes operate more effectively to limit lure errors in the left hemisphere than the right hemisphere. This enables the left hemisphere's lure error rates to fall below those of the right hemisphere when both activation and monitoring processes influence performance.

In addition to manipulating the visual field of test item presentation and retrieval time, we manipulated mean backward associative strength (MBAS; Deese, 1959; Roediger et al., 2001). MBAS represents the mean probability that a list of associates will produce a lure word in free association. In order to manipulate MBAS, we constructed high MBAS word lists and low MBAS word lists for each lure, and each person studied either the high or low MBAS list for each lure. MBAS influences lure error rates, such that when a lure's strong associates are studied (e.g., *trout*, *tuna*, *salmon*, and *bait* for the lure item *fish*), lures are judged as studied more often than when a lure's weak associates are studied (e.g., *line*, *lobster*, *lake*, and *mussel* for the lure item *fish*; Arndt & Gould, 2006; Roediger et al., 2001). Semantic activation theories of false memory suggest this outcome occurs because weak associates are less semantically related to the lure making them less likely to activate the lure during study (Roediger et al., 2001).

The purpose of this manipulation was to further test fine-coarse coding theory's explanation of hemispheric differences in false memory and to evaluate the generality of the results found in prior studies of hemispheric differences in false memory. Specifically, the broad semantic networks in the right hemisphere should make it more likely that the right

hemisphere will activate lures following the study of both high MBAS and low MBAS word lists. This should cause the right hemisphere to be more error-prone than the left hemisphere for both high- and low-MBAS word lists. Additionally, prior studies have generally used standard DRM word lists, which typically include a mixture of both high and low MBAS associates. Thus, our manipulation of MBAS in this study will enable us to examine whether prior findings were due to studying a lure's high MBAS associates, its low MBAS associates, or both. In essence, the manipulation of MBAS provides a more fine-grained test of fine-coarse coding theory and examines the empirical generality of prior findings documenting hemispheric differences in false memory.

2. Experiment

2.1. Participants

Ninety-six Middlebury College students participated in the study. Participants were native English speakers and right-hand dominant as indicated by a laterality quotient of at least +75 on the Edinburgh Handedness Inventory (Hellige, 1993; Oldfield, 1971). The mean laterality quotient was +86.

2.2. Materials

Ninety-six sets of 16 items each (referred to as *themes* below) were selected from Nelson, et al. (1998). The study items for each theme were chosen because they produced the same lure in free association (Nelson, et al., 1998). For each theme, eight of the items produced the lure in free association with a probability greater than 0.10 (high MBAS associates) and eight of the items produced the lure in free association with a probability between 0.02 and 0.10 (low MBAS associates). Thus, each theme had a high MBAS associate word list and a low MBAS associate word list. There were no repeated words across all 96 themes, and lures were not repeated among studied items.

2.3. Procedure

We tested each participant individually. At the beginning of the experiment, we informed each participant that he or she would see a list of words and should try to remember as many of the words as possible. During the study phase, the subjects were asked to focus on a central fixation point on the computer screen for 700 ms. This was immediately followed by a word presented centrally on the screen for 1500 ms. The fixation point appeared in between each of the study words for 700 ms. Each study list contained words from four different themes. For two of the themes in a given study list, the eight high MBAS associates of a lure were studied. For the other two themes, the eight low MBAS associates of a lure were studied. There were 12 study lists, such that each participant studied a total of 24 high MBAS themes and 24 low MBAS themes over the course of the experiment. Items within each study list were blocked by theme, the presentation order of the items within each theme was randomized anew for each participant, and the order of the themes within each study block was randomized anew for each participant.

A visual old-new recognition test followed each study list. Participants were instructed to respond "old" if they had studied the word in the immediately preceding study list, or "new" if they had not. To make these responses, participants were asked to press the "Z" key with their left index finger, or the "M" key with their right index finger. The keys that corresponded to the old and new responses were counterbalanced across participants.

During the recognition test, the stimuli were presented to either the left visual field/right hemisphere (LVF/RH) or the right visual field/left hemisphere (RVF/LH). Subjects were seated so that their eyes were approximately 50 cm from the screen, and stimuli were

presented so that the center of the test words appeared at approximately 3.3° of visual angle, with the innermost edge of the word appearing at a visual angle of at least 1.1° . Participants were asked to focus on a central cross that appeared for 700 ms and was immediately followed by a test word presented for 170 ms. This presentation time was chosen to allow full visibility of the word but limit eye movement to re-fixate on the word. This ensured the stimulus reached the target hemisphere first, and the subject's response was reflective of processes in that hemisphere (Bellamy & Shillcock, 2007; Westerberg & Marsolek, 2003).

In the fast retrieval condition, participants were cued to answer by an auditory beep 500 ms after the onset of the test item, and in the slow retrieval condition, participants were cued to answer 2500 ms after the onset of the test item. Participants were instructed to respond within 300 ms of hearing the beep, and the time it took them to respond was displayed on the screen after each trial. If they did not respond within 300 ms after the beep, a warning appeared on the screen that displayed their time and the message "Too Slow!" in red. A blank screen was shown for 2000 ms after each response was provided. In order for the participants to become accustomed to responding after the beep and within the appropriate time window, they were presented with one practice round of 32 studied words and 32 test words before the 12 study-test blocks. None of the words used for the practice study and test lists were used in the 12 study-test blocks.

The recognition test for each study list consisted of 16 words. One studied item and the corresponding lure from each of the four studied themes were tested, and one item and the lure from each of four themes not studied were tested. The unstudied words were picked from the 48 themes not presented to the participants during any of the study lists. The two items from each theme (studied/unstudied item and its corresponding lure) were tested in the same visual field and in the same retrieval time condition (fast vs. slow). Thus, in each test list, the items from each theme were tested in one of the four conditions formed by the combination of visual field (left vs. right) and retrieval time (fast vs. slow). The test items were presented randomly so the participants were unable to predict which visual field and retrieval time would be tested on each trial. Across participants, each theme was presented equally often in the eight conditions formed by combinations of fast and slow retrieval, high and low MBAS word lists, and visual field of presentation. As a consequence of each study list containing only four themes, all eight conditions were tested across each pair of study-test blocks.

3. Results

Mean response times, reported in Table 1, revealed that, on average, participants responded well within the 300 ms time frame after they were cued. We created a separate data set where we removed all trials with response times above 400 ms and both data sets showed the same qualitative patterns. The analyses of the complete data set were used because they included more observations per person, which maximized the power of our statistical analyses. Analyses were performed using 2 (MBAS: high vs. low) $\times 2$ (retrieval time: fast vs. slow) $\times 2$ (hemisphere: left vs. right) within-participants ANOVAs. All results were considered significant at an alpha level of 0.05.

We measured false memory using d' as our primary measure (referred to as *lure d'* hereafter). Lure d' was computed by treating the lure false alarm rate when lures' associates were studied as a hit rate and the lure false alarm rate when lures' associates were not studied as a false alarm rate (Arndt & Hirshman, 1998). Therefore, lure d' provides a measure of how much lure errors exceed the baseline probability of a false alarm occurring when the lure's associates were not studied. It is particularly important to adjust for baseline error rates in the case of the present study's data because the tendency to judge a test item

“old” was lower in the slow retrieval condition ($M=0.087$) compared to the fast retrieval condition ($M=0.130$).

Lure d' is presented in Figure 1 as a function of MBAS, hemisphere, and retrieval time. There was a significant effect of MBAS ($F(1,95) = 210.264$, $MSE = 0.579$, $p < 0.001$), indicating that participants produced significantly more errors in the high MBAS condition than the low MBAS condition. There was also a significant interaction between hemisphere and retrieval time ($F(1,95) = 5.566$, $MSE = 0.349$, $p = 0.020$). Lure d' was higher in the right hemisphere than the left hemisphere when retrieval was fast while lure d' was higher in the left hemisphere than the right hemisphere when retrieval was slow. The analyses further indicated a trend towards a 3-way interaction between MBAS, retrieval time, and hemisphere ($F(1,95) = 3.466$, $MSE = 0.406$, $p = 0.066$). Visual inspection of Figure 1, as well as the trend toward a 3-way interaction, suggests that the interaction between hemisphere and retrieval time was driven by performance in the high MBAS condition. In order to explore the patterns suggested by the three-way interaction, separate 2×2 ANOVAs for the high MBAS condition and the low MBAS condition were conducted. This breakdown revealed a significant interaction between hemisphere and retrieval time in the high MBAS condition ($F(1,95) = 6.940$, $MSE = 0.437$, $p = 0.010$), but not in the low MBAS condition ($F(1,95) = 0.015$, $MSE = 0.262$, $p = 0.903$). No main effects were reliable in either of the 2×2 ANOVAs conducted on the high and low MBAS conditions (largest $F(1,95) = 1.52$ for the main effect of retrieval time in the low MBAS analyses). These outcomes suggest that when high MBAS word lists were studied, the right hemisphere made more errors than the left hemisphere when retrieval was fast ($t(95) = 2.01$, $p = .047$), while the left hemisphere made more errors than the right hemisphere when retrieval was slow ($t(95) = 2.04$, $p = .044$). Importantly, the reversal in lure error rates across the brain's hemispheres was driven by an *increase* in lure errors between the fast and slow retrieval conditions in the left hemisphere ($t(95) = 2.39$, $p = .019$), coupled with a non-significant decrease in lure errors between the fast and slow retrieval conditions in the right hemisphere ($t(95) = 1.27$, $p = .207$). In contrast, no such differences in lure error rates occurred across the brain's hemispheres or as a function of retrieval time when low MBAS items were studied.

While lure d' provides the critical data for evaluating the factors underlying the production of false memories in the brain's hemispheres, we also evaluated peoples' general memory ability by analyzing d' computed from hits to studied items and false alarms to unstudied items (*old-new* d' ; Figure 2). This analysis produced significant main effects of MBAS ($F(1,95) = 33.156$, $MSE = 0.299$, $p < 0.001$) and retrieval time ($F(1,95) = 21.482$, $MSE = 0.455$, $p < 0.001$), as well as a significant interaction between hemisphere and retrieval time ($F(1,95) = 4.200$, $MSE = 0.283$, $p = 0.043$). The main effect of MBAS indicated that participants were better at discriminating between studied words and unstudied words in the high MBAS condition compared to the low MBAS condition. The main effect of retrieval time indicated that participants were better able to discriminate between studied words and unstudied words in the slow retrieval condition compared to the fast retrieval condition. Finally, the interaction between hemisphere and retrieval time signified that the left hemisphere was better able to distinguish between studied and unstudied words in the fast retrieval condition whereas the hemispheres did not show strong differences in their ability to distinguish between studied and unstudied items in the slow retrieval condition.

4. Discussion

Consistent with most prior work using centralized presentation, we found that lure errors were greater following study of a lure's high MBAS associates than its low MBAS associates (e.g., Arndt & Gould, 2006; Gallo & Roediger, 2003). Building on this prior work, we found that differences in lure error rates as a function of MBAS occurred for both

of the brain's hemispheres. Regarding hemispheric differences in false memories within the high MBAS condition, we found that lure error rates were greater in the right hemisphere than the left hemisphere when retrieval was fast, replicating prior studies (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Ito, 2001; Westerberg & Marsolek, 2003). Extending prior findings, when retrieval was slow, the right hemisphere maintained similar error rates compared to the fast retrieval condition while the left hemisphere's error-proneness increased to the point that it made more errors than the right hemisphere.

In comparing our results to prior studies, it is important to note that studies that found the right hemisphere produced more lure errors than the left hemisphere used conditions that were similar to the fast retrieval condition in the present study. Prior studies encouraged participants to respond as quickly as possible on each trial which resulted in response times for lures being less than 1000 ms (Ben-Artzi et al., 2009; Westerberg & Marsolek, 2003).¹ In our fast retrieval condition, participants were cued to respond 500 ms after the onset of the test item, and were allowed up to 300 ms to make a response. This produced response times in our fast retrieval condition that were less than 800 ms. Thus, the response times of these prior studies were much closer to those in our fast retrieval condition than our slow retrieval condition where responses were not accepted until 2500 ms post-stimulus. It can be concluded then, that the data from our fast condition replicated prior results showing that the right hemisphere made more errors than the left hemisphere (Bellamy & Shillcock, 2007; Ben-Artzi, et al., 2009; Ito, 2001; Westerberg & Marsolek, 2003). Additionally, the interpretation of those results is supported by the results from our fast retrieval condition. Namely, that hemispheric differences found in prior studies are largely based upon hemispheric differences in semantic memory activation.

The addition of the slow retrieval condition provided a means with which to extend prior findings, to assess the generality of effects found in the fast retrieval condition, and to assess the contribution of monitoring processes to hemispheric differences in false memory. Overall, the lure d' data patterns in the slow retrieval condition did not replicate those in the fast retrieval condition, suggesting that hemispheric differences in false memory are more complex than prior research has documented. Importantly, the fact that the left hemisphere made more errors in the slow retrieval condition than the right hemisphere, while the opposite outcome occurred in the fast retrieval condition, suggests that both activation and monitoring processes contribute to the lateralization of false memories.

4.1. Theoretical Implications

As noted above, the results from the fast retrieval condition support the conclusions of prior studies that when retrieval occurs quickly, hemispheric differences in lure error rates reflect differences in semantic memory activation across the brain's hemispheres (Bellamy & Shillcock, 2007; Ben-Artzi, et al, 2009; Faust, et al., 2007; Ito, 2001; Westerberg & Marsolek, 2003). The right hemisphere's higher error rates in the fast retrieval condition supports the explanation of hemispheric differences in lure errors posited by fine-coarse coding theory. The theory distinguishes between the semantic networks in each hemisphere, noting that the left hemisphere engages in relatively fine semantic processing, while the right hemisphere engages in relatively coarse semantic processing. In explaining false memory, this theory suggests that the brain's hemispheres differentially activate lure representations, such that the right hemisphere's diffuse semantic networks are more likely to activate lures' representations than the left hemisphere's fine semantic networks.

¹The lure response times were slower than 1000 ms in Experiment 2 of Westerberg and Marsolek's (2003) study, but they required confidence judgments on a 1–6 scale. Thus, it likely took people longer to type their response compared to the first experiment where they only had to respond old vs. new.

However, the results of this study suggest a possible limit to how well fine-coarse coding theory describes the semantic activation patterns underlying false memory. We found no differences in error rates between the brain's hemispheres in either the fast or slow retrieval conditions when low MBAS items were studied. Given the theory's claims, we should have observed greater errors in the right hemisphere when low MBAS associates were studied because the right hemisphere's more diffuse semantic networks should have enabled activation of lure representations to some degree. Further, it should have been very unlikely that the left hemisphere's fine semantic networks would activate the lure's representations when low MBAS associates were studied. This outcome suggests that the fine-coarse coding theory may be limited to describing the semantic activation patterns that influence hemispheric differences in false memory when strongly-related associates are studied. Further, since prior studies found a significant difference in lure error rates between the hemispheres using study lists that were likely composed of both high and low MBAS associates, our data suggest that the results found in prior studies were primarily due to the effects of studying a lure's high MBAS associates.

Results in the slow retrieval condition suggest that lure errors are underlain by sources of memorial information other than the semantic memory activation described in fine-coarse coding theory such as monitoring processes. Specifically, when participants had more time to respond in the slow retrieval condition, the error rates in the right hemisphere remained the same (or perhaps decreased somewhat) relative to the fast retrieval condition, while the error rates in the left hemisphere increased. This change in lure error patterns from the fast retrieval condition to the slow retrieval condition indicates that when participants have the ability to employ monitoring processes, the right hemisphere's tendency toward false memory does not change, while the left hemisphere's tendency toward false memory *increased*. This pattern suggests that when it is given time to evaluate a lure with monitoring processes, the left hemisphere finds additional evidence indicating lure words were studied beyond that provided by semantic memory activation. In contrast, the right hemisphere does not find additional evidence indicating lures were studied, nor does it find evidence to reject lures.

These results are consistent with prior theorizing about hemispheric specialization in monitoring processes. In particular, evidence from fMRI studies suggest that the right hemisphere performs heuristic evaluations of less specific information such as evaluating item familiarity, while the left hemisphere evaluates more specific information such as contextual information (Dobbins et al., 2004; Mitchell & Johnson, 2009). If the right hemisphere is mostly using familiarity to determine if lure items were studied, the memorial evidence supporting lure errors produced by the right hemisphere is largely available early in retrieval (Yonelinas, 2002), and lure error rates in the right hemisphere will not be affected much by increased retrieval time. In contrast, if the left hemisphere evaluates information such as context and source, memorial evidence supporting lure errors in the left hemisphere is not fully available until later in retrieval. Although such monitoring processes typically reduce memory errors (Roediger, et al., 2001), our data provide evidence that in the DRM paradigm, employing monitoring-like processes can *increase* lure errors. If the left hemisphere is monitoring for information such as encoding context, the fact that lure errors increased from fast to slow retrieval conditions suggests that when the left hemisphere is given time to evaluate contextual or source information, it finds evidence that lures were encountered in the same encoding context as studied items. This then strengthens people's belief that the lure was studied (Arndt, 2006; 2010).

Although it may seem paradoxical to claim that monitoring processes can increase lure errors, there is evidence in the literature that supports 1) the finding that lure errors can increase with retrieval time (Arndt, 2006; Arndt, in press; Benjamin, 2001), 2) the notion

that employing monitoring processes can increase false memory (Hicks & Marsh, 2001), and 3) the claim that people retrieve detailed knowledge of the context in which a lure's associates were encoded when a lure item is tested (Arndt, 2010; Arndt, 2012; Arndt, in press; Hicks & Hancock, 2002; Hicks & Starns, 2006; Roediger, et al., 2004). Specifically, Arndt (2006; in press) found that lure d' increased with retrieval time using centralized study and retrieval. Similarly, Benjamin (2001; Experiment 2) found that lure false alarms increased with retrieval time when study items were presented once. Further, research has documented that when people were given a source monitoring test, and thus were likely to employ monitoring processes, they were *more* likely to endorse lure items as studied compared to a condition where they were simply given an old-new recognition test that relied to a greater extent on lure item activation (Hicks & Marsh, 2001). Thus, employing monitoring processes can increase, rather than decrease, lure errors in the DRM paradigm.

In addition, several prior results demonstrate that lure items can inspire retrieval of encoding context even though lures were not directly perceived during encoding (see Arndt, 2012 for a review). First, people were disproportionately likely to attribute lure items to the source that was used to study a lure's associates when they were given a source monitoring test (Hicks & Hancock, 2002; Roediger et al., 2004). Second, when the strongest half of a lures associates were presented in one voice and the weakest half of its associates were presented in a second voice, people were more likely to believe the lure was experienced in the voice used to present its strong associates during encoding (Hicks & Hancock, 2002; Hicks & Starns, 2006). Third, when the strong half of a lure's associates were studied in one font and the weaker half of the lure's associates were studied in a different font, testing the lure in the font used to show its stronger associates produced more memory errors than testing the lure in the font used to show its weaker associates (Arndt, 2006). Fourth, and finally, testing a lure in the same font used to present its associates during study (the *match* condition) produced more lure errors compared to testing a lure in a font that was shown during encoding but was used to present a different lure's associates during study (the *mismatch* condition; Arndt, 2010).

Each of these results suggests that when a lure is tested, the results of memory search access detailed information about the encoding context that was present when a lure's associates were studied. This leads people to believe the lure was experienced in that same encoding context. For example, consider the finding that people believed lure items were presented in the voice used to present lures' strong associates more often than they believed lure items were presented in the voice used to study their weak associates (Hicks & Hancock, 2002; Hicks & Starns, 2006). In order for this to occur, memory retrieval for lure items must be sensitive to both the strength of the relationship between a lure and its associates, as well as the voice that was present when those associates were encoded. Similarly, in order for lure errors to be greater in a font match condition compared to a mismatch condition, memory retrieval accompanying lure items must access the exact font that was used to present the lure's associates when they were encoded (Arndt, 2006; 2010). The results from the present study, where the left hemisphere produced more lure errors when it was given the time to engage monitoring processes, fits with these prior studies and indicates that the retrieval of encoding context is a product of the left hemisphere's monitoring processes. Thus, the present results converge with those from fMRI studies that suggest that the left hemisphere monitors for context and source (Mitchell & Johnson, 2009). Furthermore, they suggest that the left hemisphere's monitoring processes can produce increases in lure errors in addition to their documented role in producing accurate source monitoring.

4.2. Alternative theoretical explanations

There are at least two alternative explanations of the present results that are important to consider. First, it is possible that the slow retrieval condition allowed both hemispheres to

contribute relatively more to performance than they did in the fast retrieval condition. If this were the case, lateralization in the fast retrieval condition would primarily reflect the contribution of a single hemisphere, while performance in the slow retrieval condition would reflect the contribution of both hemispheres to a greater degree. While we cannot fully discount this hypothesis, facets of our data argue against it. Specifically, if one of the primary driving forces in the slow retrieval condition is that both of the brain's hemispheres contributed to performance more than in the fast retrieval condition, we would expect hemispheric differences found in the fast retrieval condition to lessen or disappear in the slow retrieval condition. In contrast to this expectation, left hemisphere lure errors were *lower* than right hemisphere lure errors in the fast retrieval condition, but were *higher* than right hemisphere lure errors in the slow retrieval condition. Thus, hemispheric differences in memory retrieval processes contributed to performance in the slow retrieval condition to the point that we observed a double dissociation between lure errors in the fast and slow retrieval conditions.

A second possibility is that there are hemispheric differences in how retrieval is constrained (Jacoby, Shimizu, Daniels, & Rhodes, 2005).² Jacoby, et al., (2005) demonstrated that people are able to constrain the source information they retrieve from memory in preparation for evaluating an item on a memory test rather than searching for and evaluating the source details of a test item after it has been identified and processed. As applied to the current findings, one could suggest that the left hemisphere is primarily responsible for constraining retrieval prior to items being presented. For example, the left hemisphere could attempt to constrain retrieval to focus only on memories that are associated with encoding context, which is consistent with data showing the left hemisphere monitors for source and encoding context (Dobbins, et al., 2004; Mitchell & Johnson, 2009). As a consequence, in the fast retrieval condition, the left hemisphere will attempt to constrain retrieval to only items that are associated with encoding context, while the right hemisphere will not be able to constrain retrieval to the same degree. Such a difference in the ability to constrain retrieval provides an explanation for why the right hemisphere produced more errors than the left hemisphere in the fast retrieval condition. Further, the hypothesis that the left hemisphere constrains retrieval to access memories associated with the encoding context from the study list can explain why lure errors in the left hemisphere increased between the fast and slow retrieval conditions. As noted above, there is ample evidence that lures inspire retrieval of encoding context. Thus, if the left hemisphere constrains retrieval to items that are associated with encoding context, it has the potential to produce more lure errors as retrieval time increases, because increased retrieval time allows more contextual information to be retrieved.

In sum, the hypothesis that the hemispheres differ in their ability to constrain retrieval seems capable of explaining the present results, and it does so in a similar manner to that proposed by activation-monitoring theory. Although we are unable to discount this hypothesis, it is important to note that it has not been extensively applied to false memory phenomena, nor have there been investigations of hemispheric differences in constrained retrieval to our knowledge. Thus, evaluating the viability of the constrained retrieval hypothesis to understanding false memory phenomena and hemispheric differences in memory performance remains a question for future research to examine.

4.3. Future research

This was the first study to examine hemispheric differences in false memory using a retrieval time manipulation. The results illustrated activation and monitoring differences

²We thank an anonymous reviewer for this suggestion.

between the brain's hemispheres which suggests a new perspective on the memory processes underlying hemispheric asymmetry in memory errors. Because our results suggest monitoring processes increase lure error rates, future research could further examine the disparate monitoring capabilities of the brain's hemispheres, as well as the effect those monitoring processes have on the hemispheres' tendencies to produce memory errors using a source memory task. For example, stimuli could be presented centrally in different colors at encoding. At test, words could be presented to either visual field and subjects could be asked to make source memory judgments regarding whether they had studied the word as well as the color in which the word was studied. It may also be beneficial to conduct an examination of how each hemisphere is influenced by study-test match effects. Thus, subjects could be asked to determine if a test word was presented in the color in which it was studied. Based on this study's results and the results of prior studies, we expect that the left hemisphere will make more lure errors than the right hemisphere when lateralized judgments involve such monitoring for contextual information.

4.4. Conclusion

Overall, this study revealed an additional mechanism contributing to hemispheric asymmetries in memory error production compared to the mechanisms posited in the extant literature. Specifically, the lure d' analyses revealed that in the fast retrieval condition, the right hemisphere made more errors than the left hemisphere. However, in the slow retrieval condition, the error rates in the right hemisphere stayed relatively constant compared to the fast retrieval condition while the error rates in the left hemisphere increased to the point that they were higher than those in the right hemisphere. This difference in error patterns between the fast and slow retrieval conditions indicates that both activation and monitoring influenced each hemisphere's error-proneness differently. In particular, the errors produced by the right hemisphere seem to be produced mainly by activation, while the errors produced by the left hemisphere seem to be produced by both activation and monitoring. By providing a more detailed look into the mechanisms driving error production between each hemisphere, the present study's results suggest the importance of dissociating activation and monitoring processes in order to fully understand hemispheric differences in false memory.

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Highlights

- We studied false memory effects in the brain's hemispheres
- Right hemisphere produced greater false memory when retrieval was speeded
- Left hemisphere produced greater false memory when retrieval was slow
- Right hemisphere false memories were driven by semantic activation
- Left hemisphere false memories were driven by semantic activation and monitoring

Figure 1.

Lure d' for the Fast Retrieval condition (top panel) and the Slow Retrieval condition (bottom panel) as a function of Mean Backward Associative Strength (MBAS) and Hemisphere

Figure 2. Old-new d' for the Fast Retrieval condition (top panel) and the Slow Retrieval condition (bottom panel) as a function of Mean Backward Associative Strength (MBAS) and Hemisphere

Mean of median response times (in milliseconds) after being cued to respond for associates and lure items. Response times are presented as a function of Studied Status, MBAS, Hemisphere, and Retrieval Time.

Table 1

	Studied Status							
	Old				New			
	High MBAS		Low MBAS		High MBAS		Low MBAS	
	RH	LH	RH	LH	RH	LH	RH	LH
Retrieval Time								
Speeded								
Associate	251	222	218	238	160	193	211	220
Lure	280	233	220	218	209	210	204	201
Unspeeded								
Associate	142	151	175	146	139	151	196	137
Lure	156	182	170	160	145	148	157	160