Comparing the Cognitive Mechanisms of False Memories with the Misinformation and DRM Paradigms

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ABSTRACT

Many methodologies have been used to generate false memories, with the misinformation (MI) paradigm and the Deese-Roediger-McDermott (DRM) paradigm being the most commonly studied. The MI paradigm generates false memories based on retroactive interference across episodes, while the DRM paradigm generates false memories based on semantic similarities across stimuli. Since current research is ambiguous about whether the processes for different types of false memories are similar, the purpose of this project was to compare the neural mechanisms between MI and DRM false memories. We used a novel paradigm to limit methodological differences, while maintaining the defining characteristics of each paradigm. We made ERP predictions for false memories in both paradigms based on four current cognitive theories of false memories: fuzzy-trace theory, spreading activation/monitoring theory, global matching models, and source of activation confusion (SAC) model. We found no LPC, FN400, or N2 neural differences between the two types of false memories. This result is discussed in the context of the theories and the implications about our understanding of false memories. Our results support that there may not be mechanistic differences in false memory recollection when paradigms to produce the false memories are similar.

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GENERAL AUIDENCE ABSTRACT

Many methodologies have been used to generate false memories (or retrieval of an incorrect detail of an experienced event), with the misinformation (MI) paradigm and the Deese-Roediger-McDermott (DRM) paradigm being the most commonly studied. The MI paradigm generates false memories based on incorrectly described details provided by the experimenter across episodes, while the DRM paradigm generates false memories based on semantic similarities across lists of words. Since current research is ambiguous about whether the processes for different types of false memories are similar, the purpose of this project was to compare the MI and DRM false memories. We used a novel paradigm to limit differences driven by different methods, while maintaining the defining characteristics of each paradigm. The four current memory theories informed our event-related potential (time-locked electroencephalogram) predictions. The four theories are fuzzy-trace theory, spreading activation/monitoring theory, global matching models, and source of activation confusion (SAC) model. We found no late positive component (an ERP component indicating recollective processes), FN400 (an ERP component indicating familiarity processes), or N2 (an ERP component indicating conflict) differences between the two types of false memories. This result is discussed in the context of these theories and the implications about our understanding of false memories. Our results support that there may not be differences in false memory recollection when paradigms to produce the false memories are similar

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Table of Contents

List of Tables

List of Figures

Introduction

The cognitive mechanisms of false memories provide insight into the representations and processes used by the human memory system. False memories often occur for: words that are semantically similar to studied words (Deese, 1959; Roediger & McDermott, 1995), confabulated events (Bruck, Ceci, & Hembrooke, 2002; Hyman & Billings, 1998; Porter, Yuille, & Lehman, 1999; Ost, Vrij, Costall, & Bull, 2002; Hirst et al., 2015), details of an event that were later misinformed (for a review, see Frenda, Nichols & Loftus, 2011; Braun, Ellis & Loftus, 2002; Loftus & Pickrell, 1995), and contextual details of similar stimuli (Karanian & Slotnick, 2014). More research is needed to determine if there are mechanisms that are common to multiple types of false memories (Wade et al., 2007; Pezdek & Lam, 2007). The current project investigates two false memory paradigms: the misinformation (MI) effect and the Deese-Roediger-McDermott (DRM) paradigm, with the goal of understanding whether the false memories in those paradigms have common or distinct underlying mechanisms.

The MI paradigm creates false memories through retroactive interference. Specifically, participants are presented with information during a second encoding session that contradicts the information from the first encoding session (for a review, see Frenda et al., 2011). The detail from the first encoding session that is later contradicted is known as the "critical item" (Stark, Okado, & Loftus, 2010). The contradictory information presented during the second encoding session is known as "misinformation" (Loftus & Hoffman, 1989). This MI may take one of several forms: misleading questions that contain contradictory information (i.e., 'what color was the car that passed the yield sign?' if the critical item was a stop sign), narrative descriptions containing contradictory information, or instructions to guess if an event cannot be recalled (Porter, Bellhouse, McDougall, Brinke, & Wilson, 2010; English & Nielson, 2010; Pansky, Tenenboim & Bar, 2011; Campbell, Edwards, Horswill & Helman, 2007; Roediger & Geraci, 2007; Zaragoza, Payment, Ackil, Drivdahl, & Beck, 2001). A false memory in the MI paradigm occurs when participants are asked to recognize or recall details from the first event (the critical item) but incorrectly retrieve the misleading information that was exclusively experienced during the second event. MI has sometimes been referred to as episodic false memory because it is driven by misattribution of information from one event to a prior event (Stark et al., 2010).

DRM false memories are created through semantic associations between multiple list items. Participants are asked to study a list of semantically-related words, such as "bed, rest, awake, tired, dream, wake, snooze, blanket, doze, slumber, snore, nap, peace, yawn, and drowsy" (Roediger, Watson, McDermott, & Gallo, 2001). The word with the strongest semantic association to the other list words remains unstudied (in the previous example: sleep) and is known as the "critical lure" (Roediger et al., 2001). A false memory in the DRM paradigm occurs when participants are asked to recognize items from the studied list but incorrectly identify the unstudied critical lure as a studied list item. DRM false memory has sometimes been referred to as semantic false memory, because it is driven by the semantic similarities among studied items (Guinther & Dougher, 2010).

Cognitive Theories of False Memories

Dual process theories of memory agree that recognition is driven by two separate retrieval pathways, familiarity and recollection (Yonelinas, 2002). Familiarity is a memory judgment based on the perceived strength of the item being recognized, as compared to the expected strength of that item if it had not been experienced in the study context (Yonelinas, 2002). Although early models of false memories assumed they were exclusively a product of familiarity, more recent findings suggest that they can also arise from recollection processes

(O'Neill & Diana, 2017; Karanian & Slotnick, 2014; Dennis, Johnson, & Peterson, 2014). Recollection is a memory judgment based on retrieval of contextual details from an encoding event, rather than just the strength of the item itself. In ERP studies, these different retrieval processes are associated with distinct components: the late positive component (LPC; parietal sites) for recollection and the FN400 (frontal sites) for familiarity (Curran & Hancock, 2007).

Many memory models have the potential to explain false memories in the DRM and MI paradigms. Although these models may not make specific predictions for differences between MI and DRM false memories, predictions can be deduced through extrapolation. Fuzzy trace theory (FTT) is a model of memory that proposes the creation of two distinct traces during encoding: gist and verbatim (Brainerd, Wright, Reyna, & Mojardin, 2001; Reyna & Brainerd, 1995; Reyna, Corbin, Weldon, & Brainerd, 2016). Gist traces contain information about the overall meaning or schema of a studied event, while verbatim traces contain specific details. In terms of retrieval processes, verbatim memory can be interpreted as indicative of recollection processes, while gist can be interpreted as indicative of familiarity processes. FTT has not previously been applied to contrast DRM and MI false memories although it makes predictions for each paradigm individually; FTT proposes that DRM false memories are a result of gist traces (Reyna et al., 2016). However, Reyna and colleagues argue, "misinformation effects *also* tap verbatim memories," (Reyna et al., 2016, p. 3). We interpret this to mean that the verbatim traces that are created during the second encoding session can also sometimes be recollected (in the absence of context information differentiating between the two encoding sessions) and thereby produce false recollection. Although it is unclear whether verbatim trace directly represents recollection, we argue verbatim traces represent recollection, while gist traces represent familiarity. Thus, when comparing the retrieval processes that lead to false memories in the two paradigms, FTT predicts that MI false memories should be associated with recollection to a greater degree than DRM false memories and therefore should produce a larger LPC component. FTT would not propose differences in the contribution from familiarity to these two types of false memories, so no differences should be seen in the FN400 component. For a summary of all predictions by all cognitive models, see Table 2.

Another set of memory theories that can account for MI and DRM false memories are the spreading activation/monitoring theories of false memories (Howe, Wimmer, Gagnon, & Plumpton, 2009; Roediger et al., 2001). These theories propose that when encoding stimuli, neural and semantic activation spreads probabilistically to semantic and situational associates. The probability of spreading is also known as the associative strength. Repeated probable activation spreading in the DRM paradigm (due to test words all being semantically related to the critical lure) accumulates to an overall high associative strength. When a strong associate (such as the critical lure) is sufficiently strengthened by this spreading, participants may implicitly generate this associate (such as the critical lure in the DRM paradigm). For example, when the word "rest" is encoded, participants additionally generate "bed, sleep, nap, snore, and tired". The words activated are dependent on the participant's semantic networks, the strength of the ties between the words, and the frequency of co-occurrence of the words for the participant (Collins & Loftus, 1975). In the DRM paradigm, the cumulative activation drives DRM false memories. During retrieval, this can lead to implicit or covert generation (depending on threshold of the participant). Therefore, the participants accept the critical lure as a studied item. If an implicit generation occurs, critical lure decisions (false memories) are based on familiarity. If a covert generation occurs, participants may believe that the context of the critical lure is experimenter-generated, rather than self-generated. The proposed mechanism for MI false memories is similar in that they are thought to occur when the item's encoding context fails to be recollected. In the MI paradigm, if the encoding context was session two rather than session one that item should be rejected. Therefore, failures of context retrieval drive DRM and MI false memories (Ayers & Reder, 1998) but DRM false memories can also be driven by familiarity-based recognition. Spreading activation/monitoring theories can therefore be interpreted as predicting that there should be no differences between recollection components for DRM ad MI false memories (LPC), but DRM false memories are more likely driven by familiarity (seen in greater FN400).

Global matching models, such as MINERVA2, propose that stimuli are encoded as a set of separate features (Coane, McBride, Termonen, & Cutting, 2016; Arndt & Hirshman, 1998). During retrieval, the probe stimulus is compared to the features stored in memory. If the match between the probe's features and the stored features is sufficiently strong, the stimulus is accepted as recognized (Arndt & Hirshman, 1998). DRM critical lures are accepted as recognized due to the fact they share feature overlap with each of the items in the list shown at study (Coane et al., 2016). Therefore, we interpret MINERVA2 as predicting that false memories in the DRM paradigm must reach the same level of familiarity as true memories. The ERP familiarity correlate, the FN400, should not differ when true and false memories are compared. The predictions by MINERVA2 for MI false memories are less clear. Clark argues that MINERVA2 explains MI false memories as a product of similarities between MI and the critical item (Clark, 1997). Although the MI may share some features with the critical item, it is unlikely the feature overlap is as high as in DRM false memories (which benefit from the summation of the list items). Therefore, we interpret MINERVA2 as proposing that MI false memories will have lower familiarity strength (indicated by the FN400) compared to both true memories and DRM false memories, but higher familiarity strength compared to correctly rejected new stimuli.

The source of activation confusion (SAC) model of memory proposes that three interassociated nodes influence memory encoding (Diana, Reder, Arndt, & Park, 2006; Park, Reder, & Dickison, 2005; Schunn, Reder, Nhouyvanisvong, Richards, & Stroffolino, 1997). The concept or word node represents the actual studied item. The experimental context node represents experimental-specific context (such as laboratory room) (Diana et al., 2006). The specific context node is also created in some contexts; this node represents information specific to the trial or run (such as an emotion or experiment-driven similarity across certain trials). These nodes become bound together during the encoding session of the study. Successful retrieval of the item during test is a result of strong familiarity with the concept or word node or recollection of the bound event with experimental context as well as the concept or word node (Diana et al., 2006). False memories occur in the SAC model due to one of two mechanisms: strong familiarity for the concept with no contextual retrieval or atypical activation of the episode node driven by feature or conceptual match without activation of the concept node. Recollection of false memories in the DRM paradigm would occur due to a thematic node (specific context node) being created during encoding (since each DRM list item has a strong thematic overlap with the rest of the list words). If the critical lure matches the theme node, its activation would lead to atypical activation of the experimental node *without* activation of the concept node. Thus, like true memories, DRM false memories can result from either familiarity or recollection processes. Therefore, SAC predicts similar LPC and FN400 effects for DRM false memories and true memories. However, since no thematic node would be created for the MI paradigm, and therefore the recollective mechanism for false memories is not available, we would expect greater recollection for DRM compared to MI false memories. SAC predicts a larger LPC for DRM compared to MI false memories, but similar FN400 effects.

Previous False Memory Neural Findings

Previous neural experiments provide insight into the mechanisms of MI and DRM false memories. The MI paradigm has proved difficult to study in neuroimaging paradigms due to small trial numbers. The paradigm relies on participants being *unaware* that the MI provided is intentionally contrasting information (Loftus, 2005). Therefore, for each scenario, few MI details can be given and only a portion of those details result in false memory. Okado and Stark (2005) developed a MI paradigm for fMRI scanning that used complex scenes as the original event. The complex scenes were more detailed than typical MI scenarios and therefore allowed the introduction of more MI (Loftus, 2005). This study identified differential encoding activation for true and false memories. Specifically, higher activation in the medial frontal gyrus, anterior cingulate, and superior frontal regions during the first encoding session predicted subsequent true memories as compared to subsequent false memories (Okado & Stark, 2005). Stark, Okado, and Loftus (2010) then examined the neural correlates of MI during retrieval. Interestingly, they found no frontal or parietal activation differences (which are normally associated with memory performance) between true and false memories in this paradigm. Only early visual regions (BA17, BA18) showed greater activation for true compared to false memories (Stark et al., 2010).

Consistent with the MI findings, the DRM paradigm has also demonstrated increased activation in early sensory regions during retrieval of true memories compared to false memories (Fabiani, et al., 2000). Many studies have replicated this finding (Meek, Phillips, Boswell, & Vendemia, 2013; Schacter et al., 1996; Gallo, 2010; Baym & Gonsalves, 2010). Also similar to the MI paradigm, some regions of activation are common to both true and false memories, including general frontal and temporal regions (for a full list of regions, see Garoff-Eaton, Slotnick & Schacter, 2006). Differences between true and false memories are less consistent across studies and some argue may be due to methodological discrepancies (Schacter, 2002). Previous research on false memories created by the DRM paradigm show false memories have greater activation in the medial prefrontal cortex (Straube, 2012), orbitofrontal cortex (Cabeza, Rao, Wagner, Mayer, & Schacter, 2001), and bilateral prefrontal cortex (Schacter, Buckner, Koutstaal, Dale, & Rosen, 1997; Goldmann et al., 2003 [frontal leads on EEG]; Slotnick & Schacter, 2004) than true memories. True memories show greater activation in the anterior temporal lobe (Boggio et al., 2009 [T3 of EEG International 10/20 System]), posterior parahippocampal gyrus (Kim & Cabeza, 2007; Cabeza et al., 2001), and inferior temporal lobe (Kim & Cabeza, 2007) compared to false memories.

These previous fMRI findings have led to a sensory reactivation theory of false memories. This theory hypothesizes that the presence of sensory stimuli produces specific sensory cortex activation during the encoding of true memories that is not available during false memory creation. This encoding activation then can be reinstated during retrieval of the memory and thereby distinguish between true and false memories (Nyberg, Habib, McIntosh, & Tulving, 2000; Slotnick & Schacter, 2006). The proposed reactivation has been demonstrated in visual, auditory, motor, and olfactory regions (Slotnick & Schacter, 2006). Slotnick and Schacter argue that the reactivation represents implicit memory, since it does correlate to behavioral responses (2006). Interestingly, distinct reactivation for true memories is confined to early visual regions (BA17 and BA18: Slotnick & Schacter, 2004). Later higher level, visual regions (BA19 and BA37) are activated similarly for true and false memories (Slotnick & Schacter, 2004), suggesting that false memories are not dependent on previously encountered stimuli, but on projections from the medial temporal lobe to the visual cortex.

Previous ERP Findings

Previous ERP studies of memory inform our predictions in false memory paradigms. To our knowledge, there have been only two studies that have examined true versus false memories in the MI paradigm with ERP data (Kiat & Belli, 2015; Meek et al., 2013). Kiat and Belli (2015) found that true memories had larger mean amplitude for the late positive component (LPC) when compared to false memories (500 to 600ms at parietal electrodes). Higher LPC amplitudes are correlated to greater recollection memory performance (Curran & Cleary, 2003; Johansson & Mecklinger, 2003). Therefore, Kiat and Belli's finding implies that true memories rely on recollection to a greater degree than false memories in the MI paradigm. Interestingly, they found no differences in LPC amplitude between incorrectly accepted MI and correctly rejected MI, which further supports the conclusion that recollection processes are not involved in the paradigm's false memory retrieval. Meek and colleagues also found higher amplitudes for true versus false memories in the LPC time window, although at occipital electrodes (2013), supporting the sensory reactivation theory in ERP data.

Several previous ERP studies of the DRM paradigm have been conducted. However, differences in LPC amplitude are found inconsistently when comparing true and false memories (no differences: Goldmann et al., 2003; Düzel et al., 1997; differences: Curran, Schacter, Johnson, & Spinks, 2001). This suggests that recollection may make a significant contribution to DRM false memories, perhaps to a greater degree than MI false memories. This finding has not been tested with a direct comparison of the two paradigms.

The frontal old-new effect (known as the FN400) occurs between 300 and 500ms and correlates with familiarity strength, distinguishing between familiar and unfamiliar stimuli (Curran & Cleary, 2003). More negative FN400 amplitudes are associated with unfamiliar stimuli. Kiat and Belli's (2015) MI ERP studies did not find FN400 differences when comparing true and false memories. This suggests that false memories relied on familiarity to the same extent as true memories in the MI paradigm. Taken with the LPC results, we interpret their results to indicate false memories in MI are primarily driven by familiarity. Likewise, previous DRM ERP studies have found no evidence that the FN400 differentiates between true and false memories (Düzel et al., 1997; Curran et al., 2001). Combined with the LPC results, this suggests that DRM false memories are driven by both recollection and familiarity. A direct comparison of the two paradigms would provide evidence about the relative strength of familiarity in each paradigm.

One possibility, suggested by Curran and Cleary (2003), is that the FN400 is driven by semantic priming. Therefore, we might find that DRM false memories lead to higher FN400 amplitudes based on the increased semantic similarity during DRM encoding compared to MI encoding. For that reason, we predict the FN400 will be more positive for DRM compared to MI false memories.

The frontal N2, a negative-going component occurring between 250 and 300ms post-stimulus, has been implicated in conflict or incongruence during presented stimuli (for a review, see Folstein & Van Petten, 2008). Previous studies have found a more negative amplitude for incompatible stimuli (such as in the flanker task, when the distractor arrows point opposite of the target arrow) compared to compatible stimuli (when the surrounding arrows point similarly to the target arrow). Furthermore, general mismatch in presented stimuli (such as during oddball task) also elicits a more negative N2 amplitude (Folstein & Van Petten, 2008). N2 differences have been found for intentional forgetting compared to remembering, such that successful intentional forgetting was associated with more negative N2 amplitude (Mecklinger, Parra, & Waldhauser, 2009; Waldhauser, Lindgren & Johansson, 2012). We propose that retrieval of MI may cause a cognitive mismatch or incongruence signal, since the participant has received both the MI and the critical item, which directly conflict with each other (i.e. was it a stop sign or a yield sign?). In the DRM paradigm, the critical lure is thematic of the entire list and hence congruent, which should not lead to conflict. Therefore, we predict more negative N2 amplitudes for MI true and false memories compared to DRM true or false memories.

Comparisons between DRM and MI

Two previous studies directly compared behavioral data for MI and DRM and concluded that there is no common mechanism for the two paradigms. Ost and colleagues found no significant correlation in a within subject design between rate of DRM false memories and MI effect scores (Ost et al., 2013). Although the authors argue that their resulting correlation was not due to lack of power, as indicated by "standard post-hoc power correlations" (Ost et al., 2013, p.5), the participants received only 3 MI details and 5 DRM lists. This led to an average of 1.8 MI false memories and 3.4 DRM false memories. Zhu and colleagues did find a small, but significant, positive correlation (r = 0.12) between DRM (M = 6.6) and MI (M = 3.8) false memories; nevertheless, they concluded that DRM and MI false memories "generally involved different mechanisms and that their shared mechanism might be the global discrimination ability" (Zhu, Chen, Loftus, Lin, & Dong, 2013, p. 837). They based their interpretation on the fact that MI false memories are negatively correlated with MI true memories, while DRM false memories are positively correlated with DRM true memories.

There is also support for common mechanisms for false memories. Specifically, the significant correlation between MI and DRM false memories coupled with the fact there is overlap in the traits of participants who have false memories on both paradigms suggest there may be common underlying mechanisms between the two paradigms. For example, participants with low working memory (Zhu et al, 2010; Peters, Jelicic, Verbeek, & Merckelbach, 2007), older adults, and younger children (Frenda et al., 2011; Smith, Hunt, & Dunlap, 2015; Balota et al., 1999) have higher false memories in both paradigms.

Task Differences and Current Experiment

Although the surface features of MI and DRM paradigms are usually very different, we have identified only three defining differences between the paradigms: directly conflicting information across encoding episodes, amount of semantic similarity among items, and the source from which false information is generated. The presentation of MI during the second encoding session provides directly conflicting information to the first encoding session in the MI paradigm through retroactive interference. At encoding session one, a specific detail is studied (e.g. stop sign), but at encoding session two, within the same context (e.g. a specific car accident), a directly conflicting detail is studied (e.g. yield sign). Interference occurs retroactively when participants believe the MI (yield sign) was part of the original event, rather than the critical item (stop sign). In contrast, the DRM paradigm does not contain directly conflicting information. Each study item is experienced only once and, although similar items are presented throughout the list, the items need not "overwrite" previous items as they do in the MI paradigm.

The DRM paradigm is defined by semantic similarity across multiple events with the activation during each event spreading to a strongly associated item, thereby potentially creating a false memory. The semantic similarity is stronger for the DRM paradigm compared to the MI paradigm. Each list item in the DRM paradigm relates to a critical lure and shares that semantic similarity with the other items related to that same critical lure. In the MI paradigm, experimenter-provided MI is only semantically related to the critical item (i.e. stop and yield signs both fit the context of a car accident, but are not necessarily strong associates of other items in the scenario). Thus, across the encoding session, DRM contains higher semantic similarity compared to MI.

Finally, the paradigms are defined by different sources for the falsely remembered information. In the MI paradigm, the falsely remembered details are provided by the experimenter (or someone else in an authoritative role). In contrast, the DRM paradigm relies on (in different theoretical accounts) either participants' conscious internal generations of the critical lures during encoding or on their own misattribution of its nonconscious activation.

To understand the relation between the cognitive mechanisms of the MI and DRM paradigms, the goal of the current project is to re-design the paradigms such that surface differences in methodology are minimal while the three defining differences between MI and DRM are maintained. We identified four non-defining differences between how the tasks are usually conducted that we will hold constant across the tasks. First, the MI paradigm spans two separate encoding sessions: the original event and the event containing MI. In contrast, the DRM paradigm generally uses one encoding session. We controlled this factor by dividing the DRM lists into two parts such that half of each list is studied in each of the two encoding sessions. This preserves the defining features because the DRM information is consistent across encoding sessions (due to its semantic similarity within the list) while the MI events conflict, but still creates two encoding sessions for each paradigms.

Second, MI and DRM paradigms typically use different types of stimuli. The MI paradigm uses a cohesive event with multiple details by using stories as its stimulus. Each critical item and MI detail is then bound to the larger story. The story is typically presented in two different modalities: a video or series of photographs during the first encoding session and a descriptive narrative or questions during the second session. The DRM paradigm uses individual words that have semantic overlap and each word is an independent event, presented either as auditory or visual stimuli. We controlled the nature of the encoding stimuli across paradigms by creating visually-presented story narratives for the first encoding session and visually-presented summaries of those narratives for the second encoding session. Thus the MI paradigm trials consisted of stories of events with 5 critical items in each story that conflicted with the MI items in the summary[1]. The DRM paradigm consisted of stories of events with 5 DRM list words in each story. The summary contained 5 new DRM list words that were consistent with the original story (such that the participant studied 10 DRM list words all together). Rather than studying non-contextualized lists of words, participants studied stories that contained individual list items.

Finally, MI and DRM paradigms typically use different retrieval tasks. In the MI paradigm, the task is usually a forced-choice recognition procedure such that one of the available responses is the critical item and another is the MI. In the DRM paradigm, the test is usually a single-item recognition procedure such that participants are asked to decide whether an individual item is novel or was studied, sometimes asking them to record their confidence about the judgment. We controlled the nature of the retrieval task across paradigms by using a single-item recognition procedure that asked participants to decide whether an individual item was studied in the original narrative while attempting to ignore the summary narrative. Although this

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[1] Although using narratives for the original event in the MI paradigm is unusual, a previous study successfully used this modality (Pansky et al., 2011).

does not provide a direct contrast between original information and MI information we can infer the participants' comparative judgments from their individual judgments to some degree.

By matching the surface features across tasks we were also able to measure false memory for MI-type lures derived from the DRM stories. That is, because the DRM list words changed in the summary, we can examine differences in false memory for self-generated and other-generated lures within the DRM paradigm if we compare critical lures (self-generated) to list items from the summary (other-generated). Furthermore, we were able to measure false memory for DRM-type lures derived from MI stories. Specifically, we can examine semantically related words thematic of the MI story and compare to false memories due to retroactive interference. The experimental conditions resulting from these paradigmatic changes are described in detail in Table 1. Of particular interest to this experiment were the following conditions: MI narrative item hit (MI True Memories), MI summary item false alarm (MI False Memories), DRM narrative item hit (DRM True Memories), DRM summary item false alarm (MI-styled DRM False Memory), DRM unstudied critical lures (DRM False Memories), MI or DRM studied non-critical word hits (True Memory), and non-critical lure false alarms (Unrelated False Alarms).

Summary and Hypotheses

The purpose of the current project is to directly compare the cognitive mechanisms of MI and DRM paradigms. Although MI and DRM paradigms have both been traditionally used to create false memories, it is unclear whether the resulting false memories are due to similar cognitive mechanisms. Previous studies directly comparing these paradigms have not used biological measures. Previous psychophysiological findings suggest that specific ERP components should be of interest in this project. We hypothesize:

1. Replication of Kiat and Belli's findings of higher LPC amplitudes in MI true memories compared to MI false memories, but we predict similar amplitudes for DRM true memories compared to DRM false memories.
2. Larger occipital amplitude for true compared to false memories in both paradigms, supporting the sensory reactivation theory.
3. More positive FN400 amplitude for DRM compared to MI false memories.
4. Larger N2 amplitude in the MI paradigm compared to the DRM paradigm, due to retrieval of conflicting information.

Methods

Participants

Participants were 27 undergraduate students at Virginia Tech. Two participants were excluded for not following directions. Both participants pressed the escape button, exiting from the test session program, after approximately 20 minutes of the test session. One participant was excluded for memory accuracy less than chance (M= .43, excluding false memory trials) and another for excessive noise in EEG recordings (average ERP across electrodes was more than two standard deviations higher in amplitude than the other participants).

Stimulus Creation

As previously described, we created story and summary stimuli for both DRM and MI paradigms. An example of a story and summary to elicit MI can be found in Appendix A. An example of a story and summary to elicit false memories through the DRM paradigm can be found in Appendix B. Stories were 10 to 15 sentences and described characters performing events. There were no significant differences in the amount of sentences for each paradigm (t(43)

= 1.22, p = 0.23). Summaries were 5 to 10 sentences and accurately described the original story except for the 5 specific details changed in MI trials (e.g. soda to lemonade, see Appendix A) or 5 new list words used in DRM trials (e.g. drowsy to tired, see Appendix B). The number of sentences was also matched for the summaries (t(43) = 0.03, p = 0.98). We then searched for these words in any of the stories, such that each one of these words (450 words total, 100 critical items, 100 MI, 250 DRM list items) appeared only once across the stories and summaries. We also assured the 50 critical lures and 40 DRM-styled MI critical lures did not appear in any of the stories or summaries. At least 4 undergraduate research assistants read the stories for grammar and clarity. The stories and summaries were used in a pilot study (N= 7 participants) to check overall performance level and number of false memories created. Because the levels of DRM false memories were low (M = 12) with 30 total stories, we increased the number of stories to 45 and piloted two additional participants.

Materials

Participants read 45 experimenter-created stories and summaries. Of these stories, 20 included MI critical items and 25 included DRM lists. A different number of MI and DRM stories were used, because the MI narratives included 5 modified details changed between the story and summary, whereas a DRM story was tied to only two critical lures (the critical lure and the next highest associative word). However, the proportion of false memories previously found through the DRM paradigm (50%, Roediger et al., 2001; Roediger & McDermott, 1995; Zhu et al, 2013) is higher than in the MI paradigm (30%, Kiat & Belli, 2015; Stark et al., 2010; Zhu et al., 2013). Our pilot data suggested the chosen trial numbers would create comparable numbers of DRM and MI false memories.

Procedure

After the informed consent, participants were told the goal of the experiment is to examine retrieval processes when complex contextual details are given (such as a story). They were asked to read 45 separate stories. Participants were told "Please read the stories carefully with the goal of trying to identify individual words during the test session." The stories were displayed on the computer screen individually, in their entirety. The trials were self-paced to account for differences in reading speeds. After reading the entire story, participants were asked to rate the story's vividness. The participants pressed 1 for extremely vivid through 4 for not at all vivid on the keyboard. Once participants responded, the next story appeared. The presentation order of the stories was randomized with intermixed MI and DRM stories.

After completion of all stories, participants were given 2 minutes to work on a Sudoku puzzle. Sudoku puzzles were printed from http://www.puzzles.ca/sudoku.html. See Appendix C for an example of a Sudoku puzzle. The participants were asked to complete as much as they could. The task served as a distractor task so that participants could not practice the stories by repetition. Additionally, we expected a break to decrease the chance of the participant directly noticing the differences between the stories and summaries. Distractor tasks without verbal materials are often used in MI paradigms (Ackil & Zaragoza, 1998; Vornik, Sharman, & Garry, 2003; Campbell et al., 2007; English & Nielson, 2010). At the end of 2 minutes, participants began the next set of experimental trials. During the second phase of encoding, participants were asked to read 45 summaries of the original stories. Participants were told the purposes of the summaries are twofold: to refresh their memories for the original stories and to test the effectiveness of summaries written from memory by undergraduates in a previous study. Participants were asked to rate the vividness of each summary before continuing to the next summary with each trial being self-paced. Summaries were also randomized and intermixed between the two paradigms.

Following the second phase of encoding, the elastic cap and electrodes were applied for EEG data collection. Participants were distracted during this time by conversation with undergraduate research assistants. Once the electrode were applied, participants were reminded that they would be tested on individual words from the stories and asked to make their judgments based on stimuli that were presented during the story section of the experiment, rather than based on the summaries. For each test item, participants were asked to rate their confidence that the presented word was studied between 1-6, with 1 representing "sure old" and 6 representing "sure new". To begin each trial, participants had a blink interval of 750ms, followed by a fixation interval of 200ms. The test stimulus was then presented simultaneously with the onset of a 2000ms recording window, as well as up to a 8000ms extended response window. If participants responded before the end of the extended 8000ms window, the next trial began immediately. Participants were tested on 762 words total. Of these words, 120 were DRM list words from stories, 120 were DRM list words from summaries, 100 words were MI critical items from stories, 100 were MI changed items from summaries, 50 were unstudied DRM critical lures, 150 were novel unstudied words, 40 were DRM-style MI lures, and 82 were studied words that were not critical items from the MI or DRM paradigms. There were no significant differences between the word lengths in each condition ($F(8,753)= 0.96$, $p = 0.47$). After completion of the test trials the elastic cap and external electrodes were removed. Participants were then asked to complete a short debriefing form (given in Appendix D). The participants were then debriefed about the true purpose of the experiment, asked if they had any questions, and encouraged not to discuss the experiment with other students until data collection was complete. From beginning to end, the experiment lasted between 1.5 and 3.25 hours, due to variability in reading speed, with an average of 2.5 hours. However, there was no difference in reaction time between MI and DRM conditions (t(433)= -1.204, p = .229).

ERP

Electrophysiological data was recorded during the retrieval task using a BioSemi ActiveTwo system with 32 active Ag/AgCl electrodes mounted in an elastic cap according to the international 10/20 system. Four additional electrodes were added to the face to monitor for horizontal and vertical eye movements. Two electrodes recorded from the left and right mastoids which were averaged to create a reference channel. A sampling rate of 1024 Hz with offline filtering between 0.1 and 30 Hz qA was used. The data were processed using the ERPLAB toolbox (Lopez-Caderon & Lock, 2014) within EEGLAB (Delorme & Makeig, 2004), run via MATLAB (2012a). Averaged mastoids were used to re-reference EEG recordings. Although participants were asked to limit eye blinking to the prestimulus period, manual eye blink identification was used to reject trials that contained artifacts due to blinking. Additional artifacts (including muscle or movement artifacts) were also identified using visual inspection. Bins were created through ERPLAB using condition number and participant response. Only artifact-free trials were averaged within each condition. Although a conservative analysis threshold of 15-artifact free trials was proposed (as recommended by Luck, 2005), three participants would have been excluded with this threshold due to low trials numbers in the false memory bins. We therefore used a more liberal threshold of 10-artifact free trials for only the trials of interest (DRM true memory, DRM false memory, MI true memory, MI false memory), which allowed us to retain all participants. Although this created trials with lower than 10 for an exploratory condition (DRM-styled MI false memories), this condition was not analyzed in any of the ANOVAs without aggregation. For full trial numbers, see Table 3.

Analysis windows and electrode configurations for hypothesized effects were identified from previous studies. Specifically, the N2 was measured from 250 to 300ms in electrodes FP1, FP2, AF3, AF4, F7, F8, F3, F4, FZ, FC5, FC1, FC2, FC6, C3, CZ, and C4 (Folstein, & Van Petten, 2008). The FN400 was measured from 300 to 500ms in electrodes F7, F3, FZ, F4, F8, AF3, AF4, FP1, and FP2 (Curran & Cleary, 2003). The LPC was measured from 500 to 800ms in electrodes P3, P4, P7, P8, CP5, CP1, CP2, CP6, PO2, and PO3 (Curran & Cleary, 2003; Wang et al., 2016). In addition, an omnibus ANOVA was used to test for other differences across the recording interval and all 32 electrodes. Greenhouse-Geisser procedures were used to account for violation of sphericity. As per previous research, the procedure was only used when ANOVA numerator degree of freedom were greater than one (Goldmann et al., 2003).

Results

Behavioral Results

Participants were able to dissociate studied, non-critical old items from new items, with a hit rate of 68.15% (*SD* = 10.38%). They accepted unrelated false alarms at a rate of 22.26% (SD = 13.54). DRM critical lures were accepted (DRM false memory) at a rate of 64.64% (*SD* = 16.43%). MI details were accepted (MI false memory) at a rate of 42.98% (*SD* = 15.98%). Both false memory rates were significantly higher than false alarms to novel new items (*M* = 22.26%, $t(22)=9.55$, $p < .001$ for DRM and $t(22) = 4.74$, $p < 0.001$ for MI). Mean accuracy levels for each condition are reported in Table 3. The correlation between DRM false memories and MI false memories was positive and significant ($r(23) = 0.63$, $p < 0.001$). Noticing the purpose of the study in the debriefing form did not predict percentage of false memories in the MI paradigm (t(22) = 0.29, p = 0.78) or DRM paradigm (t(22) = 0.66, p = 0.51). Ratings between the conditions differed significantly for all conditions except DRM true memories and DRM false memories (t(1257) = -0.40, p = 0.69). Lower ratings indicated higher confidence that participant viewed the word. Old items were given the lowest average ratings of 2.67. True and false DRM memories were rated an average of 2.97 and 2.94, respectively. True and false MI memories were rated an average of 3.28 and 3.89 respectively. The MI-styled DRM false memories (a novel condition) were rated an average of 3.58 and the DRM-styled MI false memories (our second novel condition) was rated an average of 3.92. New words were rated an average of 4.73. Interestingly, DRM false memories were rated lower than MI false memories (t(1257) = -14.08, p < .001). Our created conditions also were significantly different from the conditions in the corresponding paradigm. For example, our MI-styled DRM false memories were rated significantly lower than MI false memories (t(2516) = -6.73, p < .001). Our DRM-styled MI false memories were rated significantly lower than DRM false memories (t(1003) = -10.76, p < .001). DRM conditions were rated lower than MI conditions (t(6064) = -12.66, p < .001). This supports that DRM conditions benefited from increased semantic similarity in the stories and summaries compared to MI conditions.

ERP Results

First, we examined the classic old-new effect in old (True Memory) versus new (Correct Rejection) memories. This set a baseline for the rest of our study and assured we could interpret our results. All F-values and degrees of freedom were taken from the Greenhouse-Geisser procedure, to account for correlation between electrodes. We first ran a 2 (True Memory, Correct Rejection) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) repeated-measures ANOVA for the FN400 (300 to 500ms). There was no significant interaction between condition and electrode

(F(3,74) = 1.05, p = 0.38). There was also no main effect of condition (F(1,22) = 0.04, p = 0.85), but there was a main effect of electrodes (F(3,58) = 4.10, p = 0.01). To test the LPC old-new effect, we ran a 2 (True Memory, Correct Rejection) X 10 (P3, P4, P7, P8, CP5, CP1, CP2, CP6, PO2, PO3) repeated-measures ANOVA. There was a significant interaction between condition and electrode (F(3,75) = 1.67, p = 0.02). There was also a main effect of condition (F(1, 22) = 4.73, p = 0.04) (Figures 2a 2b), but not electrodes (F(2,44) = 4.10, p = 0.21). Therefore, an old/new effect was found in LPC, but not FN400. See Figures 1 and 2 for graphical representation of the ERP data.

To test any unpredicted effects between the false memories without biasing a particular time window or electrode configuration, we first ran an omnibus repeated-measures ANOVA. The 5 (0-200ms, 200-400ms, 400-600ms, 600-800ms, 800-1000ms) X 2 (MI false memory, DRM false memory) X 32 (electrodes) ANOVA did not show a significant three-way interaction effect (F(7,150) = 0.86, p = 0.54). There was also no significant interaction of condition and electrodes (F(4,80) = 0.78, p = 0.53) nor time bin and condition (F(2,42) = 0.09, p = 0.91), but there was a significant time bin and electrode interaction (F(2,54) = 3.44, p < .001). There was also no main effect of condition (F(1,22) = 0.13, p = 0.73).

Our first hypothesis was that LPC differences would be found in MI true versus false memories, but not DRM true versus false memories. To test this hypothesis, we first compared MI conditions with a 2 (MI true memory X MI false memory) X 10 (P3, P4, P7, P8, CP5, CP1, CP2, CP6, PO2, PO3) repeated measures ANOVA. Contrary to the prediction, there was no interaction between condition and electrode (F(3,61) = 1.37, p = 0.26) nor were there main effects of condition (F(1,22) = 0.30, p = 0.59) or electrode (F(3,66) = 2.33, p = 0.08) (see Figures 5 and 6). We then ran a 2 (DRM true memory, DRM false memory) X 10 (P3, P4, P7, P8, CP5, CP1, CP2, CP6, PO2, PO3) repeated measures ANOVA to test the effect in DRM paradigm. The interaction between condition and electrode was not significant ($F(4,86) = 1.37$, $p = 0.25$). Furthermore, there were no main effects of condition ($F(1,22) = 1.57$, $p = 0.83$) or electrodes ($F(3,60) = 2.25$, $p = 0.10$) (see Figures 7 and 8).

Our second hypothesis involved occipital differences in true versus false memories, supporting the sensory reactivation theory, without specific predictions for the time period at which effects might occur. We ran a 5 (0-200ms, 200-400ms, 400-600ms, 600-800ms, 800-1000ms) X 2 (false memory, true memory) X 5 (O1, O2, Oz, PO3, PO4) repeated measures ANOVA. We found no significant interaction ($F(4,89) = 1.10$, $p = 0.36$) or main effect of time bins ($F(2,53) = 1.81$, $p = 0.17$), conditions ($F(1,22) = 0.74$, $p = 0.40$), or electrode ($F(2,49) = 0.91$, $p = 0.42$). Therefore our data did not reveal evidence of sensory reactivation theory (see Figure 9).

Our third hypothesis was that the FN400 for DRM false memories would have a more positive amplitude compared to MI false memories. Therefore, we ran a 2 (DRM false memory, MI false memory) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) repeated-measures ANOVA. There was no significant interaction between condition and electrode ($F(2,54) = 0.81$, $p = 0.47$). There was also no main effect of condition ($F(1,22) = 0.01$, $p = 0.97$), but there was a significant effect of electrodes ($F(2,45) = 4.78$, $p = 0.01$) (see Figures 3 and 4). We tested the within MI and DRM conditions as well. For DRM effect repeated-measures 2 (DRM true v DRM false memories) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) ANOVA, there was not a significant interaction effect, ($F(2,48) = 1.14$, $p = 0.33$). There was also no main effect of condition ($F(1,22) = 0.09$, $p = 0.76$), but there was a significant effect of electrodes ($F(2,48) = 5.60$, $p = 0.01$). We then ran the MI repeated-measures 2 (MI true v MI false memories) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) ANOVA. There was no significant interaction, ($F(3,62) = 0.49$, $p = 0.68$). There was also no significant effect of condition ($F(1,22) = 0.20$, $p = 0.66$), but there was a significant effect of electrodes ($F(2,48) = 4.13$, $p = 0.02$). To examine if this finding was due to lack of power, we combined DRM-like MI false memories with DRM false memories (both unstudied words that are semantically related) and MI-like DRM false memories (both summary presented words). We reran the 2 (DRM false memories, DRM true memories) X 9 repeated-measures ANOVA with the new conditions. Again, there was no significant interaction effect for the DRM repeated-measures ANOVA ($F(4,78) = 0.75$, $p = 0.55$). There was also no significant effect of condition ($F(1,22) = 0.49$, $p = 0.49$) but there was a significant main effect of electrode ($F(2,45) = 4.95$, $p = 0.01$). The MI 2 (MI false memories, MI true memories) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) repeated-measures ANOVA showed a significant interaction effect ($F(2,54) = 3.24$, $p = 0.04$). The main effect of electrodes was also significant ($F(2,47) = 5.01$, $p = 0.01$), but the main effect of conditions was not significant ($F(1,22) = 1.46$, $p = 0.24$).

For the fourth hypothesis, we examined N2 for the MI versus the DRM paradigms. We ran a 2 (averaged MI conditions [MI True Memory, MI Miss, MI False Memory, Rejection MI], averaged DRM conditions [DRM True Memory, DRM Miss, DRM False Memory, Rejection Critical Lure]) X 16 (FP1, FP2, AF3, AF4, F7, F8, F3, F4, Fz, FC5, FC1, FC2, FC6, C3, Cz, C4) repeated-measures ANOVA. The interaction effect was not significant, ($F(4,79) = 0.73$, $p = 0.56$). There was also no significant effect of condition ($F(1,22) = 0.20$, $p = 0.66$), but there was a significant effect of electrodes ($F(3,59) = 11.35$, $p < .001$).

To test the four cognitive theories described, we ran comparisons of FN400 and LPC between MI true memories, MI false memories, DRM true memories, and DRM false memories. We therefore ran a 4 (DRM true memories, DRM false memories, MI true memories, and MI false memories) X 9 (F7, F3, Fz, F4, F8, AF3, AF4, FP1, FP2) repeated-measures ANOVA to examine FN400 (300 to 500ms). There was no significant interaction effect ($F(5,120) = 0.87$, $p = 0.51$). Furthermore, there was not a significant effect of condition ($F(2,50) = 0.14$, $p = 0.90$), but there was a significant effect of electrodes ($F(2,47) = 5.08$, $p = 0.01$). We also ran a 4 (DRM true memories, DRM false memories, MI true memories, and MI false memories) X 10 (P3, P4, P7, P8, CP5, CP1, CP2, CP6, PO2, PO3) repeated-measures ANOVA to examine LPC (500 to 800ms). We found no significant interaction ($F(5,116) = 1.23$, $p = 0.30$). Furthermore, we found no significant main effect of condition ($F(2,47) = 0.19$, $p = 0.84$) or electrode ($F(3,57) = 2.47$, $p = 0.08$). For graphical representation of the ERP data, see Figures 10 and 11.

Discussion

The aim of the current study was to compare the cognitive mechanisms in the MI and DRM paradigms when methodological surface feature differences were minimal. To our knowledge, this is the first study that has directly examined neural differences between MI and DRM paradigms. The paradigm we used was novel, such that we attempted to create a single procedure that could incorporate both paradigms. To do this, we identified factors that were paramount to each of the paradigms. The fundamental factors of the MI paradigm are the use of conflicting information, two study sessions, and other-generated misinformation. The fundamental factors of the DRM paradigm are testing unstudied words and strong semantic similarities between the list and critical lure. The results revealed behavioral differences in false memories; specifically, DRM critical lures were judged to be old more frequently than MI. We did not find neural differences between true and false memories in either paradigm. Furthermore, and contrary to our predictions, we found no differences between false memories in the two paradigms.

Our correlation (*r* = 0.63) matches the direction of Zhu and colleagues' significant correlation (*r* = 0.12) between MI and DRM false memories (Zhu et al., 2013). However, our correlation was much stronger than previously reported. There were two methodological reasons we found stronger correlations. First, we benefited from having 50 possible false memories in the DRM condition and 100 possible false memories in the MI condition. Second, our paradigms matched in as many ways as possible, decreasing the number of methodological differences, which may influence correlations. One indication that our strong positive correlation was valid was that there were no significant differences in ERP across the paradigms. This supports that the mechanisms may be more similar than the literature previously suggested.

Our ERP data revealed the classic LPC difference between old and new responses. Specifically, old responses had a higher amplitude than new responses in the 500 to 800ms time window in preselected parietal electrodes. Generally, memory studies have also found differences in the FN400 between new and old words as a signal of familiarity-based differences (Stóżak, Bird, Corby, Frishkoff, & Curran 2016; Wang et al., 2016; Daltrozzo, Wioland, & Kotchoubey, 2012; Curran & Hancock, 2007; Guillaume & Etienne, 2015). However, our results showed no such differences between old and new words in the FN400 component. This suggests that the paradigm might have minimized familiarity as a factor, leading participants to rely heavily on recollection during the retrieval task. There is a distinct possibility that new words may have had unforeseen semantic associations to the stories. For example, one new word was the word "gauze". This could have been semantically related to a story involving an injury or the story involving the DRM list for doctor for some participants.

Therefore, our finding of no differences in FN400 between the MI and DRM paradigms might not be surprising. The first reason this study may have minimized the relevance of familiarity in the conditions of interest is that none of these conditions were novel during test for the participant. Specifically, all DRM true memories, MI true memories, and MI false memories were seen during the experiment (either in story or summary). The DRM false memories, while not studied, were semantically similar to studied words. There is evidence that semantically similar words may activate the FN400 in the same way that familiar words would (Voss & Federmeier, 2010; although for opposite findings, see Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012). The high level of familiarity for lures at test might have led participants to rely on contextual details for retrieval.

The second reason this study may have minimized the relevance of familiarity is study modality. Participants had to distinguish between two encoding sessions that used the same stimulus modality. Specifically, we asked participants to "ignore the summaries when making their memory judgments and only respond if they remembered the word presented during the story (first) encoding session". Other misinformation paradigms have distinguished between encoding sessions using differences in encoding modality (i.e. session 1: video, session 2: verbal narratives). The only previous study that used narratives for original events included a one-day delay between the story and the MI encoding sessions, which would increase the role of familiarity in distinguishing the sessions. It also used misleading questions to introduce the MI resulting in a slightly different format for session two than session one (Pansky et al., 2011). Therefore, we acknowledge that our study design may have led participants to depend on recollection to a greater degree than previous studies and therefore had no reliance on familiarity. To support that participants did not rely on familiarity when making their memory judgments, we ran post-hoc repeated-measures ANOVAs for accepted versus rejected stimuli in the MI and DRM conditions in the FN400. The interaction of the MI conditions and electrodes was not significant (F(2,54) = 0.73, p = 0.66). The main effect of condition was also not significant (F(1,22) = 0.13, p = 0.73), but the main effect of electrodes was significant (F(2,53) = 4.14, p = 0.02). The interaction of the DRM conditions and electrodes was not significant (F(4,86) = 1.38, p = 0.25). The main effect of condition was also not significant (F(1,22) = 0.11, p = 0.74), but the main effect of electrodes was significant (F(2,42) = 4.13, p = .03). This supports that decisions by participants in our paradigm did not depend on familiarity.

Our results support Schacter's assertion that there are no differences in ERP data between true and false memories (2002). Although this was acknowledged in his book, no studies were cited that directly provided support of such a statement. It is highly probable that this result stems from the fact that null results are more difficult to publish than positive results (Rosenthal, 1979). Rosenthal describes the problem as a "file drawer problem" because these results are filed away and never examined again. However, publishing these results would allow for better understanding of the false memory mechanisms. Previous ERP studies that have found differences in neural correlates between true and false memories in both paradigms should be reviewed to examine methodological differences, which may have caused differences in activation. For example, lateralization, adding deception tasks, use of only central electrodes, and use of good performers versus bad performers all have been methods that elicited differences between true and false memory ERP components (Fabiani et al., 2000; Meek et al., 2013; Goldmann et al., 2003; Curran et al., 2001).

Review of Cognitive Theories

As previously discussed, the null differences between old versus new items made the FN400 null results for true versus false memories difficult to interpret. However, LPC differences were found between old and new items. There were no differences in LPC activity between DRM and MI false memories. Furthermore, there were no differences in LPC activity between true and false memories, regardless of the paradigm. One possibility for the non-significant findings is that our conditions did not have enough power to statistically identify differences between the paradigms. However, the average trial numbers were 44 in MI true memories, 32 in MI false memories, 57 in DRM true memories, and 26 in DRM false memories (for full trial numbers, see Table 1). This means that the trials should have been sufficiently powered. Another possibility was the task was too difficult for participants, resulting in reliance on guessing. However, with an accuracy rate of 73%, this seems unlikely. Also, because we found LPC differences between old and new items, we can infer that participants were able to distinguish between conditions.

Existing cognitive theories that propose mechanisms for false memories were used to make ERP predictions for the typical recollection and familiarity components. FTT predicted no FN400 differences but a greater LPC in MI compared to DRM false memories. Our results were consistent with the FN400 prediction; however, the LPC prediction was not supported. It is possible that our interpretation of verbatim traces as directly mapped to recollection processes is not accurate and therefore FTT would not predict differences in LPC (Reyna et al., 2016). Specifically, Reyna and colleagues argument that verbatim traces can lead to MI false memories implies that verbatim traces do not contain episode-differentiating details (such as context, here: encoding session number) (2016). Thus, false memories in FTT theory may be the result of purely familiarity-based processes. In the DRM paradigm the context of self-generation is misremembered and in MI paradigm the encoding session number is misremembered. Another possibility is that although FTT predicts false memories *can* result from verbatim traces, generally these memories result from gist traces (similar to DRM false memories). This would imply that there would be no differences in either component. To clarify this one-to-one mapping of recollection and verbatim traces, future studies must test these processes' neural correlates. Consequently, FTT should better define verbatim memory based on these neural traces. It is possible that verbatim "literal, precise memory representations" do not contain contextual details (Reyna et al., 2016, p.1). However, previous findings support that contextual details can be retrieved with false memories (therefore, implying recollection), which would contradict this interpretation of FTT (O'Neill & Diana, 2017).

Spreading activation/monitoring theories of false memories predicted no differences in LPC, but greater FN400 components for DRM compared to MI false memories. Our results were consistent with the LPC prediction. However, the results were not consistent with the predicted FN400 differences. If, as argued earlier in the discussion, our study discouraged reliance on familiarity-based processing, it remains uncertain if experimental designs dependent on familiarity would find differences. Future studies should test familiarity-based false memories and recollective-based false memories in separate but similar paradigms. This would allow clarification on familiarity versus recollection in false memories. Specifically, future studies could utilize the Remember/Know task (Yonelinas, 2002) to split participants judgments on false memories due to reliance on familiarity and recollection. Through this design, researchers could then test both familiarity-based and recollective-based false memories.

MINERVA2 predicted higher DRM FN400 compared to MI. However, this prediction may also not be properly evaluated due to the lack of differences in FN400 throughout the experiment. MINERVA2 model proposes all memory types are based on one process. Therefore, finding differences in the LPC during old versus new stimuli suggest there are two components of memory, which contradicts MINERVA2 predictions in general memory.

SAC predicted no differences between DRM true and false memories, but MI false memories driven by familiarity. Therefore, the model predicts a higher LPC for DRM compared to MI false memories. The results were consistent with the prediction that there are no differences between DRM true and false memories. However, we did not find differences in the LPC between the two paradigms, suggesting there are no differences in recollection between DRM and MI false memories. Ayers and Reder argue that overlap in context between encoding sessions 1 and 2 may drive recollective process in false memories (1998). Specifically, if participants recall contextual details that are shared between the two encoding events in addition to the MI, it is possible MI false memories can result from recollection. Therefore, this theory could be interpreted to predict that MI false memories and DRM false memories may equally result from recollective processes. Our original interpretation of the SAC model of memory did not account for this. We assumed thematic nodes are only created in DRM paradigms, but it is possible that thematic nodes also connect the MI paradigm stories due to overlap in context. For example, when retrieving the yield sign, the car crash context could be recollected (which is thematic of both encoding sessions); this could lead to false recollection through SAC in the MI paradigm. Our results further support this interpretation of SAC.

N2 Discussion

Our N2 prediction was also not supported in our data. Specifically, we predicted more negative N2 for MI compared to DRM conditions. Our results showed no differences between the paradigms in N2. This suggests the conflict to participants during retrieval is equal whether false memories are other-generated or self-generated. A second interpretation is that participants did not notice the manipulation and therefore did not experience conflict during retrieval. This is supported through our debriefing form, where only 14 participants noted the misinformation effect (e.g. "different details were sometimes used for summaries compared to stories). Finally, the mismatch component may have been strongest during the second encoding session, rather than retrieval because the second encoding session actually contained the mismatch in the same context of the first session. To test this, future studies should scan or collect ERP during the second encoding session. Specifically, future research could examine if conflict present (through N2 amplitudes) during encoding session 2 predicts failure to produce false memories.

Review of Sensory Reactivation Results

Early visual activation (BA17, BA18) has previously dissociated between true and false memories, supporting the sensory reactivation theory of false memory. Our results did not support this difference in activation. One possibility for such divergence is the lack of localization in ERP compared to fMRI studies. For example, in the DRM paradigm, higher activation was seen in true memories compared to false memories for BA17 and BA18 (Slotnick and Schacter, 2006), while BA19 and BA37 showed no differences between true and false memories. However, since ERP recordings are less localized, the differences would be more difficult to discover. Another reason for such divergence may be the type of tasks typically used when differences in occipital activation are found. For example, Fabiani and colleagues found differences in occipital activation in the ERP when the stimuli were lateralized (2000). Specifically, they presented half the lists on the right side of the screen and half on the left side of the screen and noted that true retrieval was more lateralized than false retrieval in visual regions. Much of the literature remains uncertain about whether or not occipital differences are indicative of true versus false memories (found: Meek et al., 2013; not found: Kiat & Belli, 2015). Schacter suggests that occipital differences may be dependent specifically on the method (2002). To further examine the sensory reactivation theory's validity in predicting differences between true and false memories, a full meta-analysis should be done with a focus on methodological differences. Using those methods, the sensory reactivation theory could then be evaluated.

Alternative Interpretations of Results

Our results support that when false memory depends on recollection, the processes are similar to true memory. Although it cannot be assumed that both false memory familiarity and recollection are the result of similar memory processes as true memory in the DRM and MI paradigms, our results are the first to support this idea in recollection. FMRI studies should further examine this question, capitalizing on higher localization ability.

There is a possibility is that reconstructive processes drive false memories during the second encoding session. The theory of reactivation-induced reconsolidation postulates that memories can be changed when reactivated during retrieval processes (Hupbach, Gomez, Hardt, & Nadel, 2007). It has been argued that this reactivation of memory during the second encoding session in MI drives false memories (Hupbach, Gomez, & Nadel, 2009). Specifically, if memory of the first encoding session is reconstructed during the second encoding session and further details are attached to the episodic event (such as the MI), an inaccurate memory for the MI would be created during the second encoding session (the inaccuracy being that it was presented in the first encoding session). Importantly, this MI would have attached to the episodic memory node *prior* to retrieval. Furthermore, DRM false memories in our experiment would also be reconstructed during the second encoding session. Specifically, if the DRM critical lure is partially activated during the first encoding session and reactivated during the second encoding session, while simultaneously increasing accumulated activation (from the presentation of the new DRM words), a reconstructed memory representation of the critical lure is likely to be created. The critical lure would then be connected to the episode node of the first encoding session. In both MI and DRM, the first session would be reactivated during the second session due to the strong overlap in contextual details between the story and the summary. This is further supported by the fact that reconstructive processes of imagining events can lead to vivid false memories of those events (Schacter, 2012). When imagining an event, a previously encountered similar event may be recalled and the details from the new event could be added through reconsolidation, changing the original event. Therefore, one would predict no differences in true and false memories in either recollection or familiarity during retrieval. To test this theory, future studies should collect physiological data at encoding and testing sessions.

This project is the first to directly compare MI and DRM false memories. Because some types of false memories still remain controversial in nature, such as false confessions (Shaw & Porter, 2015; Kassin & Kiechel, 1996; Kassin, 2015) and false memory for sexual abuse (Loftus, Polonsky, & Fullilove, 1994; Loftus, 1994; Williams 1994), it is important to understand the mechanism behind false memories. Although MI and DRM false memories are less controversial, future studies should also compare these lab-created false memories to ecologically valid false memories. This project created more ecologically valid stimuli than previous studies in the DRM paradigm, which generally use list words. Therefore, we can infer that these false memories may be more closely related to naturally occurring false memories. The finding that neural differences between true and false memories are not pervasive has important legal and clinical perspectives. For example, many eyewitness testimonies may arise from false memories or “misidentification” (Pezdek, 2012). Understanding how the memory processes of false memories allow criminal procedures to be adjusted to minimize false memory creation. Furthermore, a better understanding of memory processes may allow us to better understand confabulations, such as alien abductions. Our finding of a positive correlation between the MI and DRM false memories fits with Clancy and colleagues' finding that those who confabulated on alien abductions were also more susceptible to DRM false memories.

Conclusion

The present project examined the cognitive mechanisms underlying MI and DRM false memories. A significant positive correlation was found between behavioral responses to the two types of false memories and no ERP differences were found between the paradigms. These results support the conclusion that there might not be mechanistic differences between types of false memories. We conclude that types of false memories cannot be distinguished through neural activity using ERP

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Table 1
Experimental Conditions.

Paradigm	Status in Paradigm	Encoding 1	Encoding 2	Participant Response	Condition
MI	Critical Item	Studied	Unstudied	Studied	MI True Memory
	Critical Item	Studied	Unstudied	Unstudied	MI Miss
	Misinformation	Unstudied	Studied	Studied	MI False Memory
	Misinformation	Unstudied	Studied	Unstudied	Rejection MI
DRM	DRM List Word	Studied	Unstudied	Studied	DRM True Memory
	DRM List Word	Studied	Unstudied	Unstudied	DRM Miss
	DRM List Word	Unstudied	Studied	Studied	MI-styled DRM False Memory
	DRM List Word	Unstudied	Studied	Unstudied	Rejection DRM List
	DRM Critical Lure	Unstudied	Unstudied	Studied	DRM False Memory
	DRM Critical Lure	Unstudied	Unstudied	Unstudied	Rejection Critical Lure
General Memory	Old	Studied	Unstudied or Studied	Studied	True Memory
	Old	Studied	Unstudied or Studied	Unstudied	Miss
	New	Unstudied	Unstudied	Studied	Unrelated False Alarm
	New	Unstudied	Unstudied	Unstudied	Correct Rejection

Table 2
Cognitive Theory Predictions

Theory	FN400	LPC
Fuzzy Trace Theory	MI = DRM	MI > DRM
Spreading Activation	MI < DRM	MI = DRM
MINERVA2	MI < DRM	N/A
SAC	MI = DRM	MI < DRM

Table 3
Behavioral Performance

Condition	**Mean % Old Responses (SD)**	**Mean # of ERP trials analyzed (range, SD)**	**Mean Confidence Rating (SD)**
MI True Memory	53.78% (12.51%)	43.67 (22-66, 11.89)	3.28 (1.99)
MI False Memory	42.98% (14.15%)	32.42 (10-75, 14.09)	3.89 (1.88)
DRM-Styled MI False Memory	40.82% (12.77%)	12.33 (2-24, 4.57)	3.92 (1.87)
DRM True Memory	60.72% (13.63%)	56.83 (17-81, 15.07)	2.97 (1.93)
DRM False Memory	64.64% (16.43%)	25.96 (13-43, 7.63)	2.94 (1.87)
MI-Styled DRM False Memory	49.47% (14.22%)	48.33 (14-79, 15.89)	3.58 (1.89)
True Memory	68.15% (10.38%)	41.92 (25-66, 10.72)	2.67 (1.86)
Unrelated False Alarm	22.26% (13.54%)	22.38 (5-46, 10.12)	4.73 (1.45)

Figure 1
Old/New Effects. All electrodes for old new effect. Y-Scale = -8 - 5

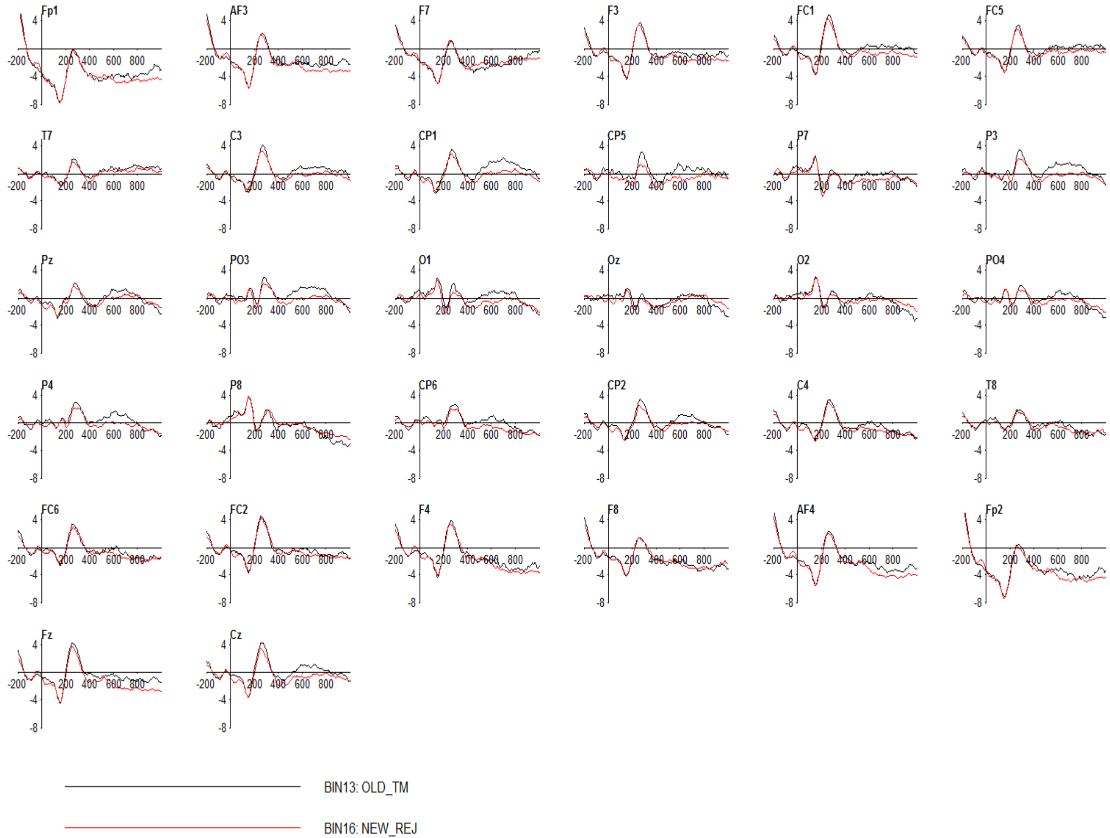
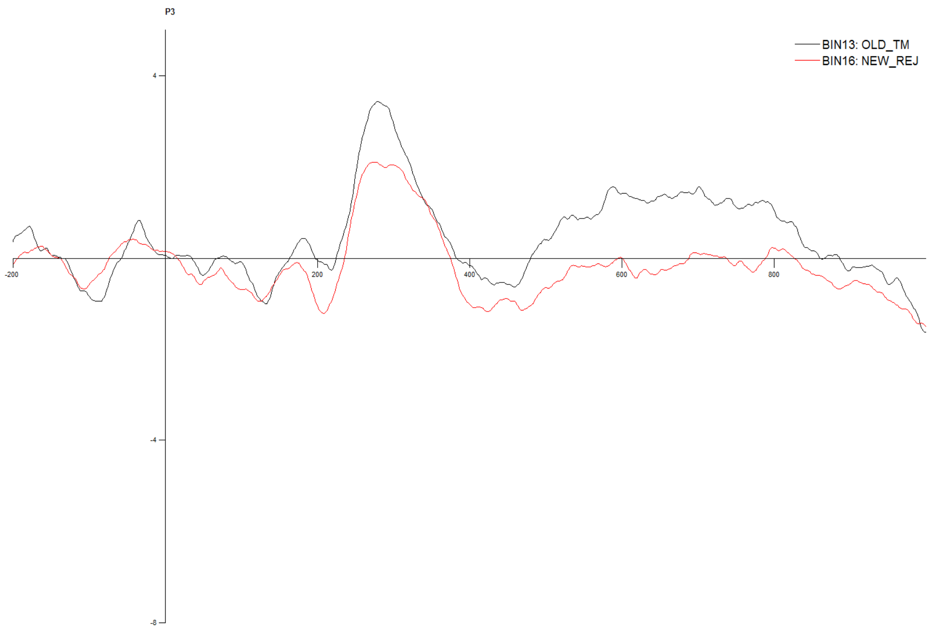


Figure 2

P3 and P4 old/new LPC effects.

2a) P3



2b) P4

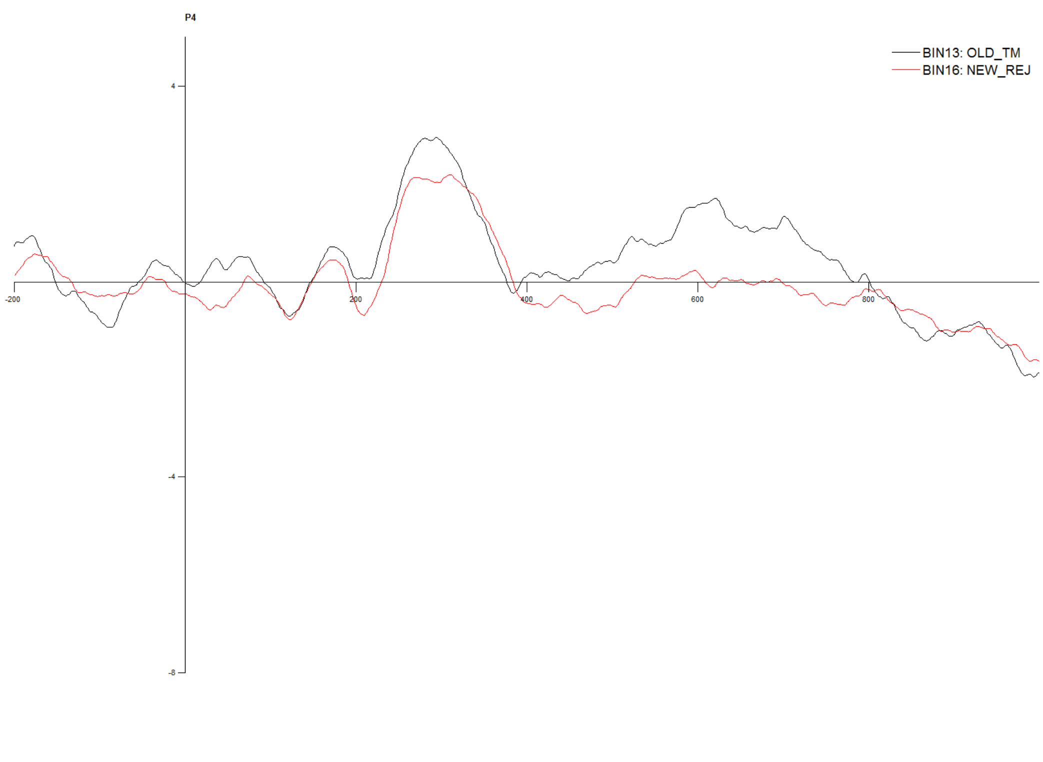


Figure 3

MI v DRM False Memories. All electrodes. Y-Scale = -10.9 - 4.4

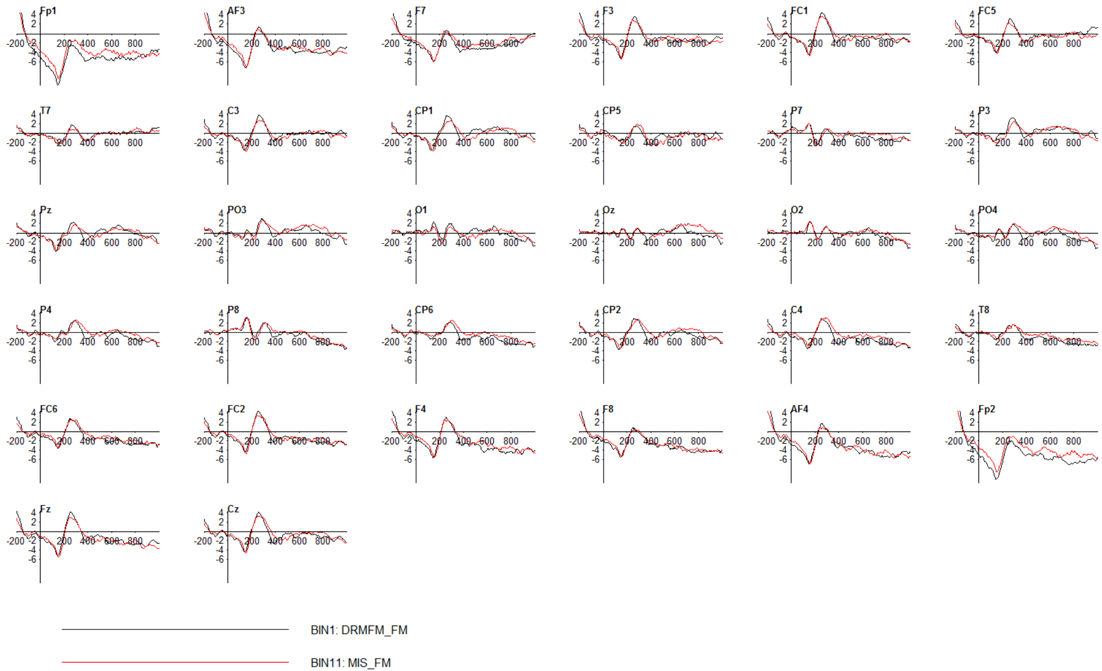
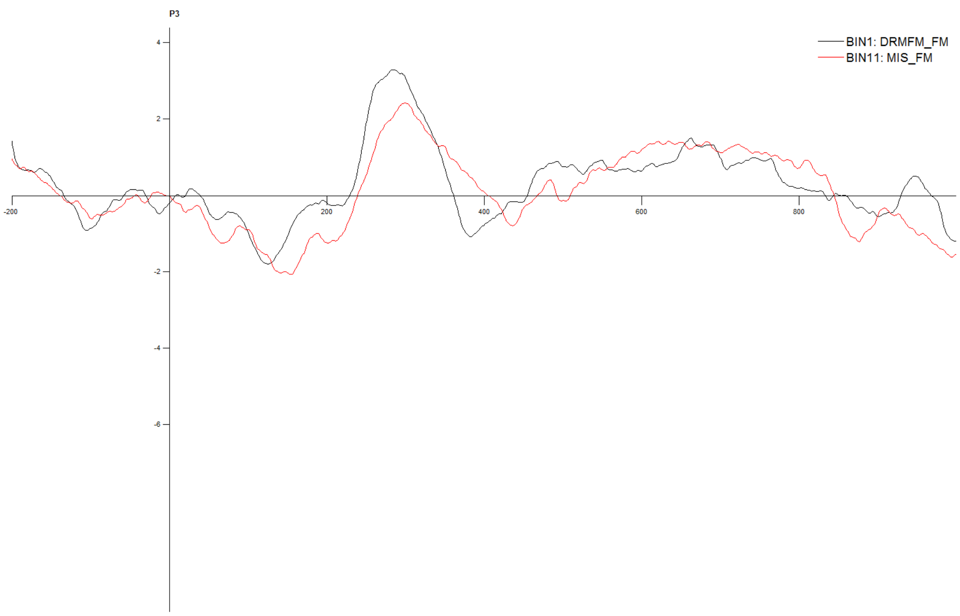


Figure 4

P3 and P4 MI v DRM False Memories.

4a) P3



4b) P4

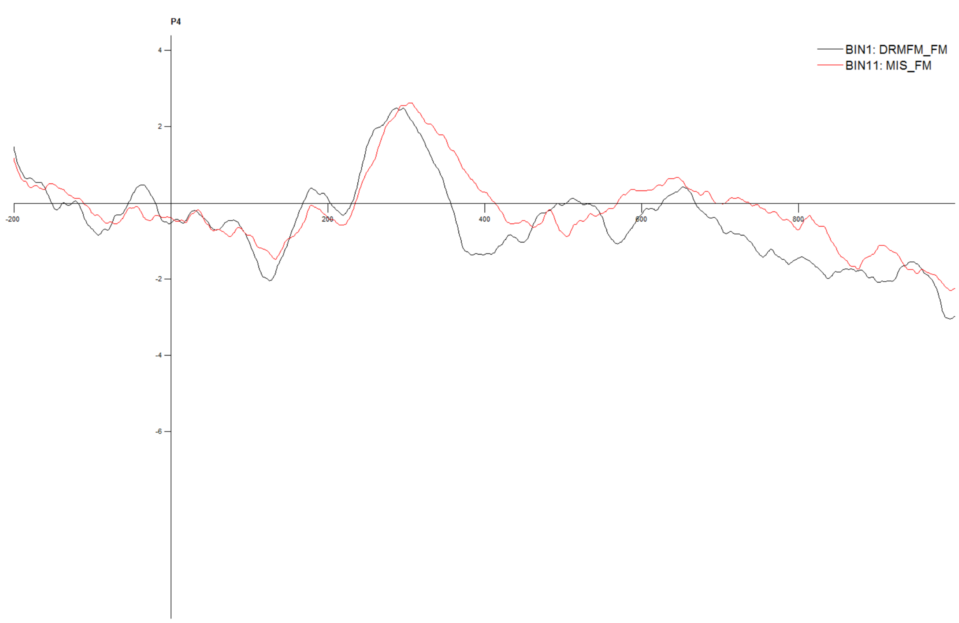


Figure 5
MI True vs. False Memories. All electrodes. Y-Scale = -9.6 – 3.8

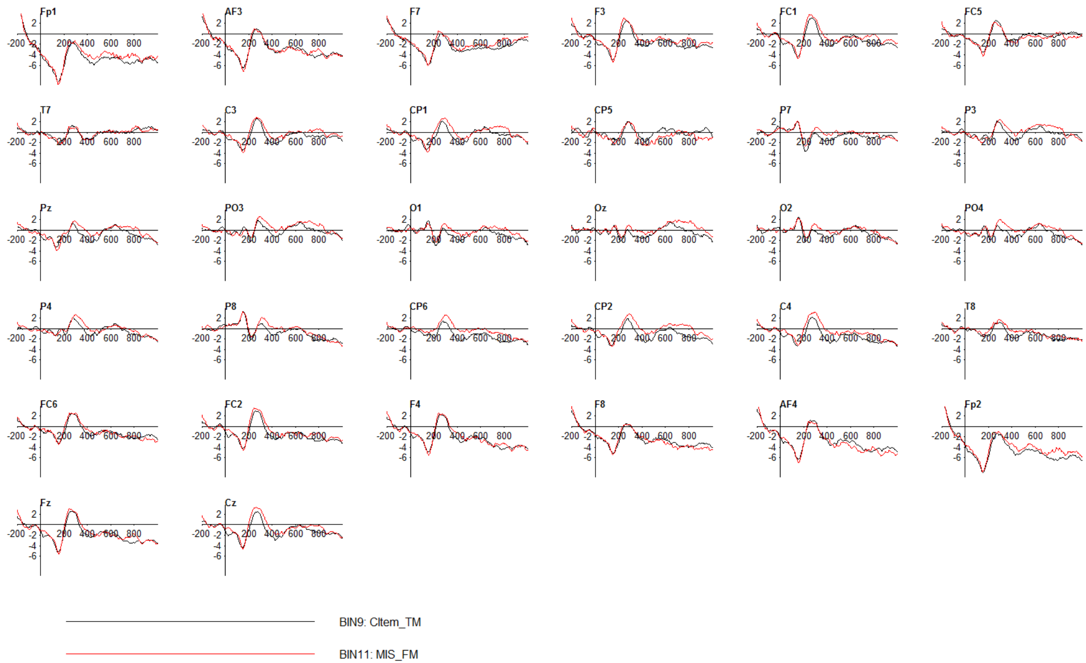
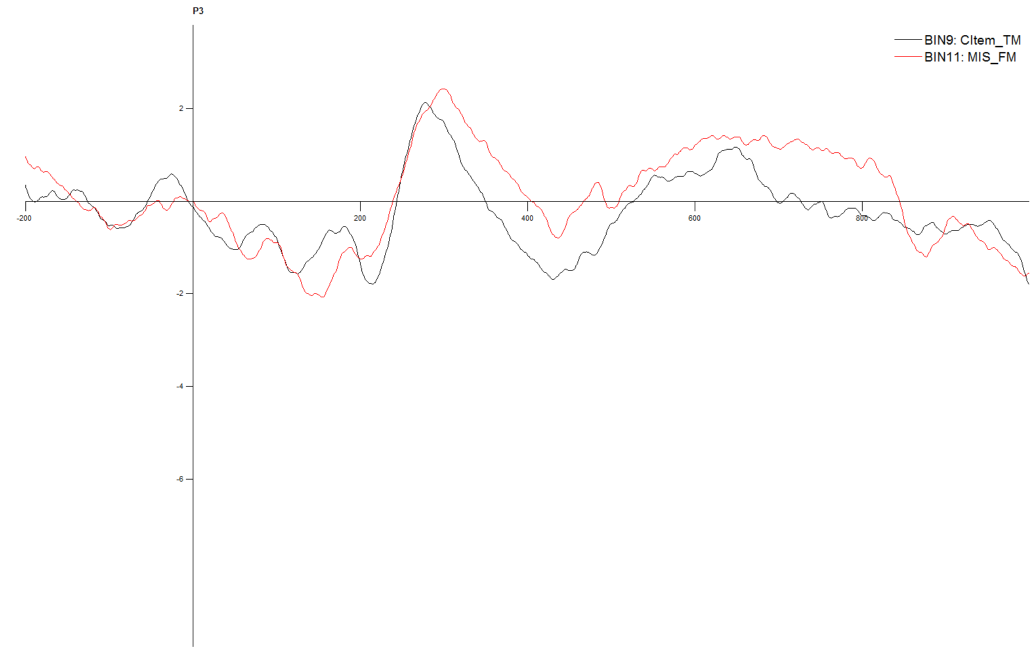


Figure 6

P3 and P4 MI True vs. False Memories.

6a)P3



6b)P4

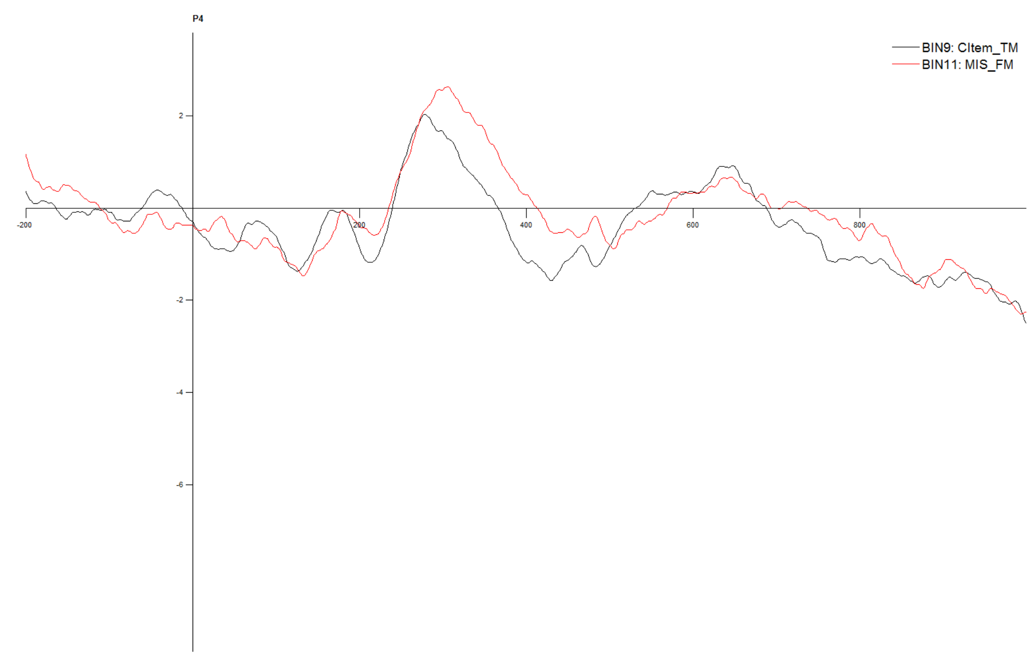


Figure 7

DRM True vs. False Memories. All electrodes. Y-Scale = -10.9 – 4.4

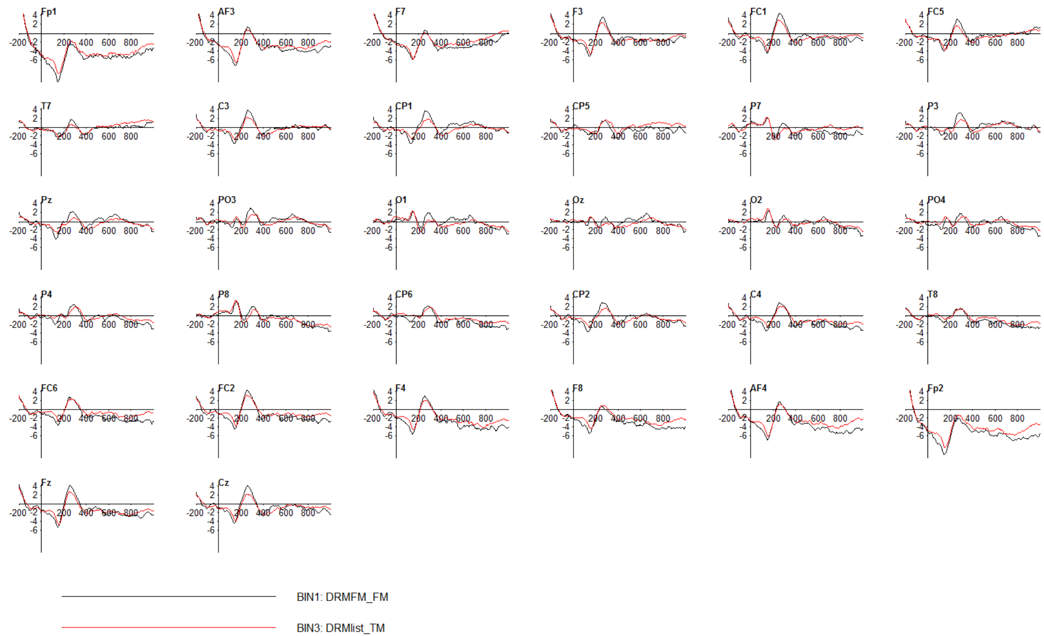
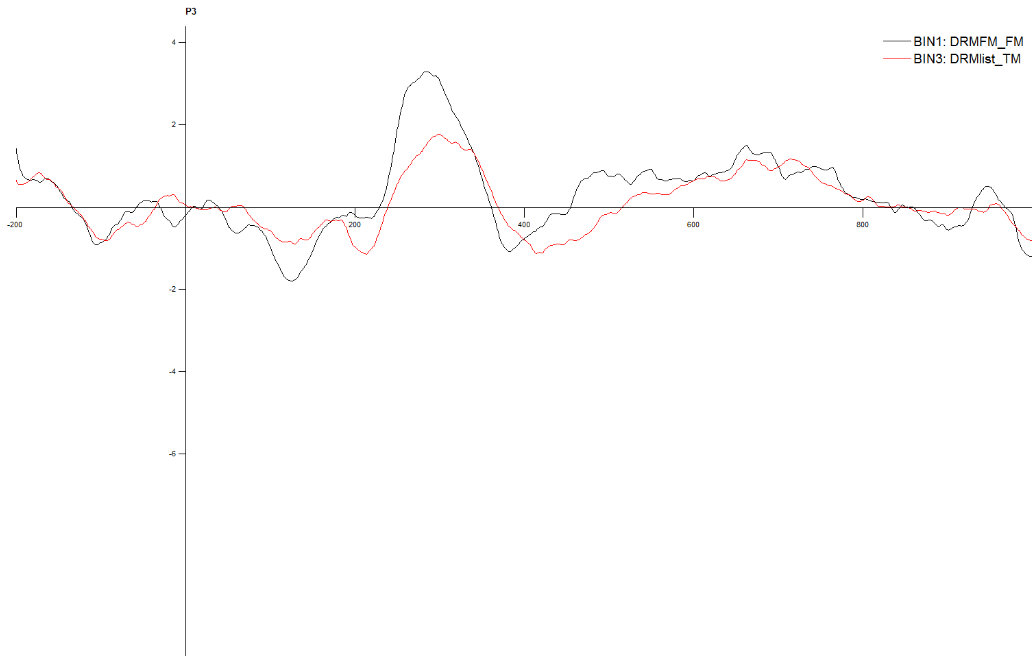


Figure 8

P3 and P4 DRM True vs. False Memories.

8a)P3



8b)P4

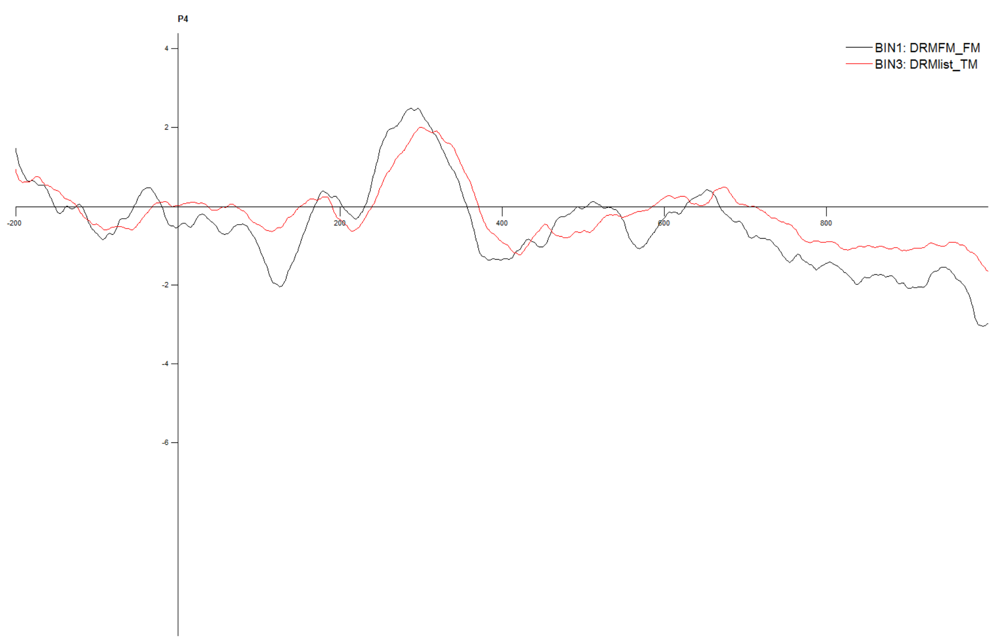
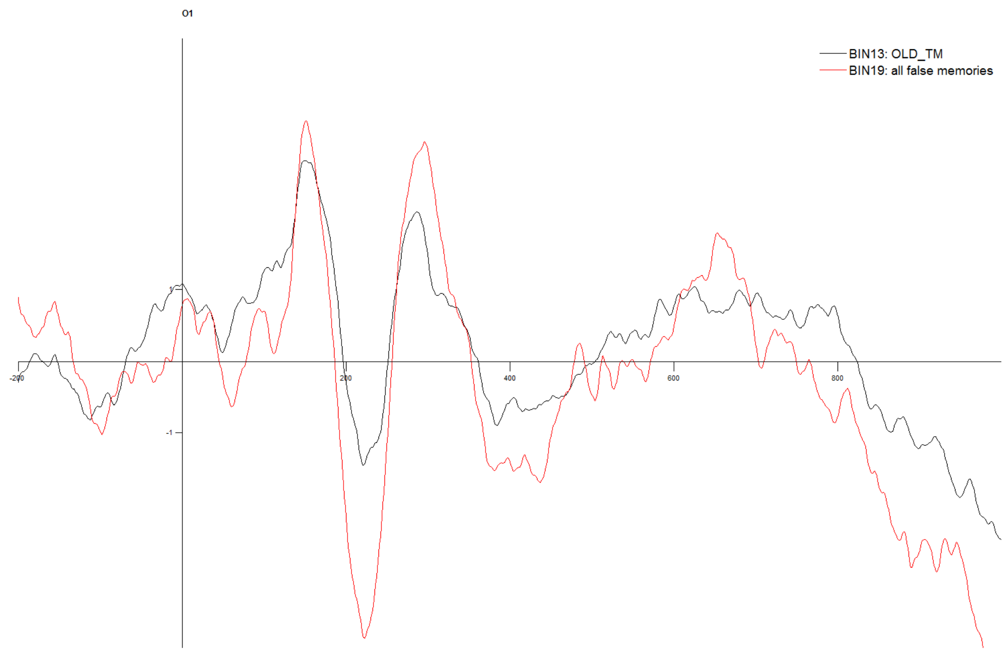


Figure 9

O1 and O2 True vs. False Memories. Y-Scale = -4.0 – 4.5

9a)O1



9b) O2

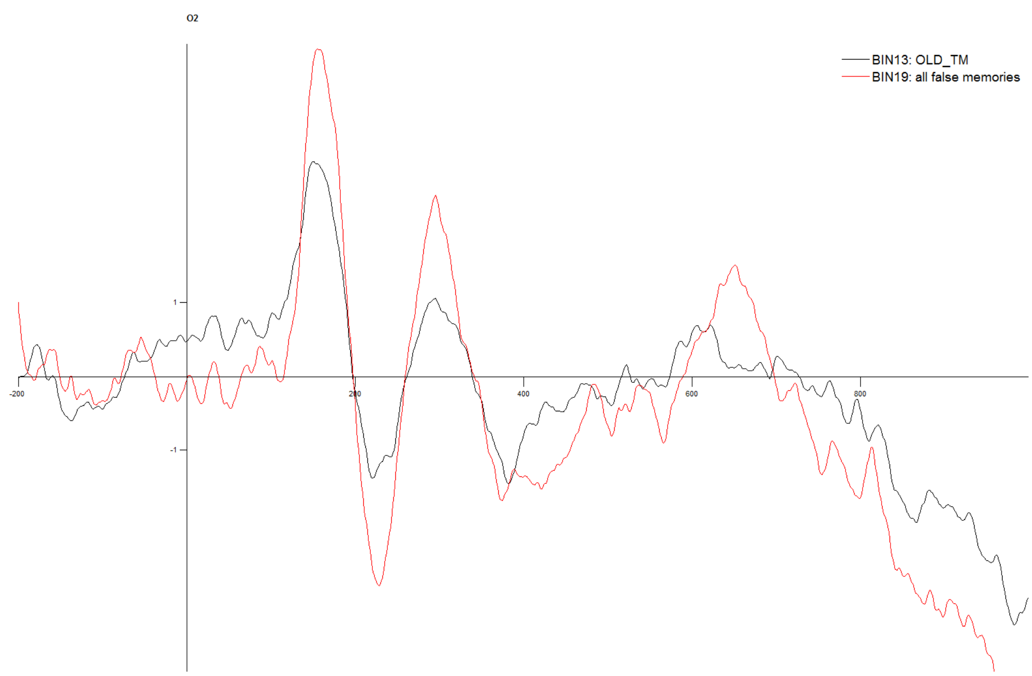


Figure 10

DRM and MI True vs. False Memories. All electrodes. Y-Scale = -10.9 – 4.4

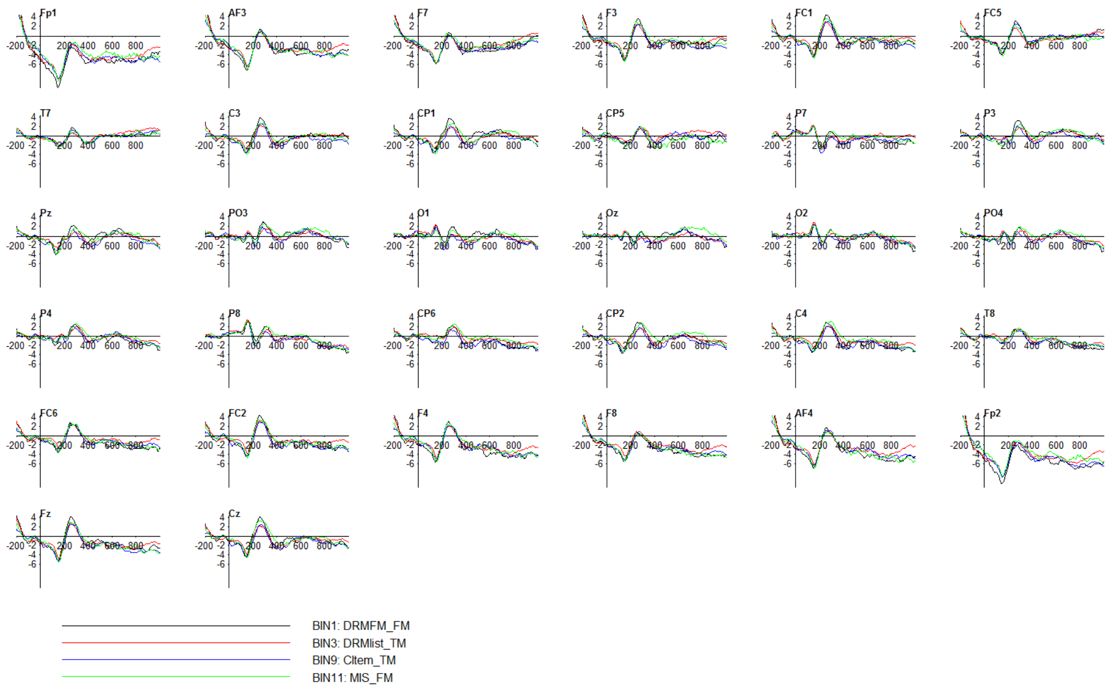
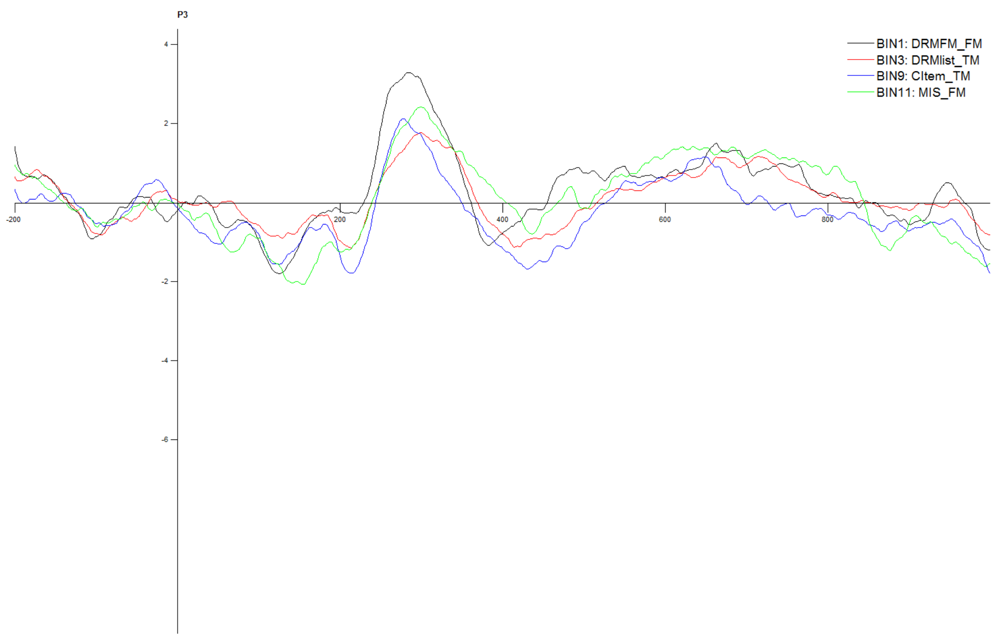


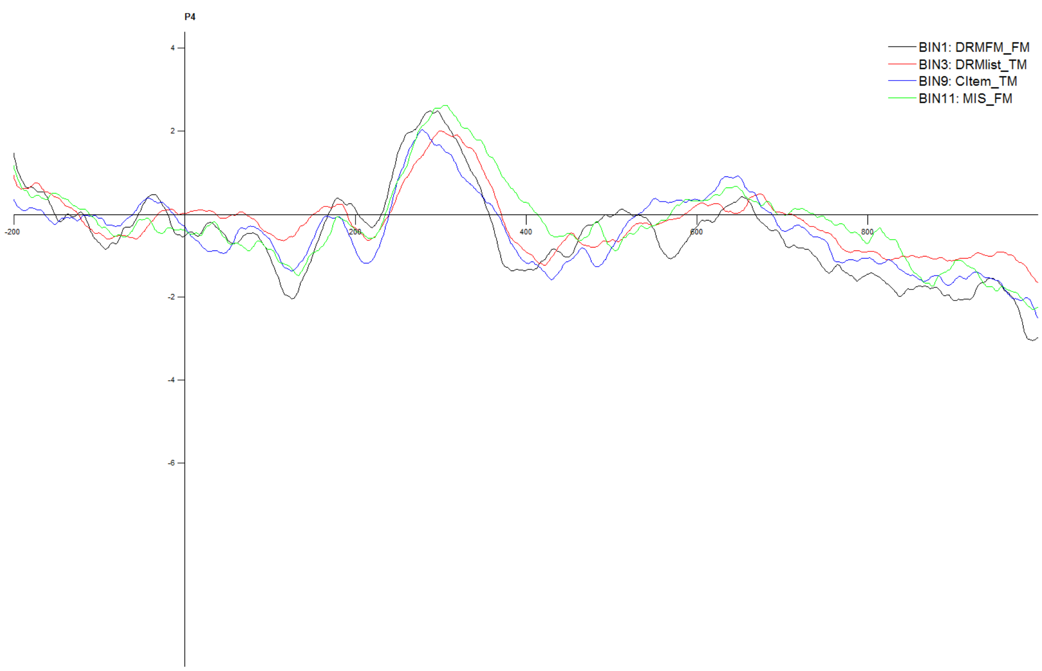
Figure 11

P3 and P4 DRM True vs. False Memories.

11a) P3



11b) P4



Appendix A

MI Story:

One Sunday, Martha Ann and Ryan decided to go to see a comedy about cats. First though, they wanted to grab some snacks at the concession stand. Martha Ann decided on nachos and Dots, while Ryan just bought a large soda. Once settled with snacks, they headed into the theater. The story revolved around a cat that got lost in New York and went on a big excursion. It faced many obstacles, such as dogs chasing it and losing its way. Eventually, the cats are able to find their way back home to their loving family. After, Martha Ann and Ryan decided the lives of the cats were more exciting than their lives! They wanted to create their own thrill. They wished they could go away, but their parents would not approve. They walked past their middle school and into the forest. There they decided to climb trees and imagined they were also lost. However, the night was advancing and they knew they should return to their residence. Once they made it back, their stepmother greeted them. Exhausted after their day, they ate dinner and discussed their day with their family. Their parents smiled at them and asked them more about the cats!

MI Summary:

On a Sunday, Ryan and Martha Ann decided to see a drama about cats. They walked to the concession stand, where Martha Ann got fries and Dots, while Ryan bought a large lemonade. The story revolved around a cat that got lost in New York and faced many obstacles. Ryan and Martha Ann decided to get lost as well, so went past their elementary school to the forest. They climbed trees until night came and they were exhausted. Their stepfather greeted them and they all had dinner together.

DRM-Styled MI Critical Lures: kitten, matinee

Appendix B

DRM Story

Theron had been up all night preparing for an exam he had in Physiological Psychology class. He had heard from previous students that the class was demanding and a lot of time needed to be put into the class to pass it. He worried he was not prepared enough. He was also extremely drowsy because he did not have a chance to rest at all. He let out a loud yawn. He knew he could not worry about that at that moment though because he had to run to catch the shuttle. He was able to catch the shuttle on time and he headed to campus. He got to the class really early and was sitting at his desk studying when he started to snore. The student who sat next to him arrived in class and nudged his shoulder. The movement caused Theron to gain consciousness. He became even more nervous that he was not ready for the exam. He decided he should have taken a nap before coming to this exam. His stress levels were at an all-time high. Theron suddenly rolled out of bed and hit the floor. It was actually 7:00 at night and he had not even left the house. The stress was really getting to him. He decided to take a break from studying.

DRM Summary

Theron was tired because he had been up the whole night before preparing for an exam in his Physiological Psychology class. He was worried he was not prepared enough and was not going to do well because he had not had a chance to snooze a little before leaving. He could not worry about that right now because he had to run and catch the shuttle to get to campus on time. He got to class early and was studying when he drifted into a slumber. The person next to him arrived in class and nudged his shoulder. He woke up in his bed. He had never left the house; he was in a dream. The stress had really gotten to him so he decided to take a break from studying.

DRM Critical Lures: sleep, doze

Appendix C

Sudoku #202 (Medium)

								2
	3	6				8		
	8			3		7	1	
9								
				4	1			3
		8				2		6
				9	6			5
1		2			5	3		
							7	

Appendix D

Debriefing Form

1) What do you think we were testing in this experiment?

2) Did you notice any systematic differences between the summaries and the stories?