Investigating the Influence of Top-Down Mechanisms on Hemispheric Asymmetries in Verbal Memory

by

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ABSTRACT

It is commonly known that the left hemisphere of the brain is more efficient in the processing of verbal information, compared to the right hemisphere. One proposal suggests that hemispheric asymmetries in verbal processing are due in part to the efficient use of top-down mechanisms by the left hemisphere. Most evidence for this comes from hemispheric semantic priming, though fewer studies have investigated verbal memory in the cerebral hemispheres. The goal of the current investigations is to examine how top-down mechanisms influence hemispheric asymmetries in verbal memory, and determine the specific nature of hypothesized top-down mechanisms. Five experiments were conducted to explore the influence of top-down mechanisms on hemispheric asymmetries in verbal memory. Experiments 1 and 2 used item-method directed forgetting to examine maintenance and inhibition mechanisms. In Experiment 1, participants were cued to remember or forget certain words, and cues were presented simultaneously or after the presentation of target words. In Experiment 2, participants were cued again to remember or forget words, but each word was repeated once or four times. Experiments 3 and 4 examined the influence of cognitive load on hemispheric asymmetries in true and false memory. In Experiment 3, cognitive load was imposed during memory encoding, while in Experiment 4, cognitive load was imposed during memory retrieval. Finally, Experiment 5 investigated the association between controlled processing in hemispheric semantic priming, and top-down mechanisms used for hemispheric verbal memory. Across all experiments, divided visual field presentation was used to probe verbal memory in the cerebral hemispheres. Results from all experiments revealed several important findings. First, top-down mechanisms used by the LH primarily used to

facilitate verbal processing, but also operate in a domain general manner in the face of increasing processing demands. Second, evidence indicates that the RH uses top-down mechanisms minimally, and processes verbal information in a more bottom-up manner. These data help clarify the nature of top-down mechanisms used in hemispheric memory and language processing, and build upon current theories that attempt to explain hemispheric asymmetries in language processing.

DEDICATION

To Mom and Dad ~ without your tireless work, and your constant support, I would not have been able to achieve as much as I have today.

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The brain's cerebral hemispheres have been traditionally thought to specialize in the processing different types of information. It is most commonly known that the left hemisphere (LH) is highly involved in language processing. In contrast, the right hemisphere (RH) is thought to handle the processing of non-verbal information. Evidence for material specific hemispheric processing originally comes from studies that have examined individuals with unilateral brain damage. For example, adults with unilateral brain damage in the LH often exhibit overt impairments to language production and comprehension (Benson & Ardila, 1996; Damasio, 1992; Geschwind, 1971). Unilateral brain damage to the RH has been shown to cause greater disruptions to the processing of more visuo-spatially oriented information (Harrington, 1987; Milner, 1971; Vilkki, 1987; Whitehouse, 1981). Studies with healthy adults have also found evidence for hemispheric specialization. Hemispheric asymmetries in processing can be studied behaviorally using divided visual field presentation. The arrangement of the human visual system is such that when stimuli are presented to the right visual field of the retina, information is projected to the LH. Stimuli presented to the left visual field are projected to the RH. Using this method, it has been demonstrated that the LH is more efficient in processing individual words, sentences, and overall language comprehension (for reviews, see Beeman & Chiarello, 1998; Hellige, 1993; Lindell, 2006). Conversely, RH advantages have been shown for visuo-spatial processing (for a review, see Hellige, 1995).

Despite the material specific distinction for the hemispheric processing of information, further evidence has shown that the LH and RH provide unique and cooperative contributions to language processing. Current frameworks for the lateralization of language processing suggests that the LH engages in more rapid, gist based processing, where only the most germane information is processed from any given language context. The RH is thought to process language information more broadly, maintaining information that is less relevant to a specific language context (Beeman & Chiarello, 1998; Federmeier, 2007). In this way, the LH can rapidly extract the most relevant information, while the RH maintains less relevant information, and only integrates that information when necessary.

Much of the evidence that supports hemispheric contributions to language processing comes from studies investigating hemispheric asymmetries in semantic priming. In their seminal study, Burgess and Simpson (1988) examined semantic priming differences in prime-target pairs that were biased for a dominant meaning (e.g., *bank-MONEY*) or a subordinate meaning (e.g., *bank-RIVER*). Target items (either *money* or *bank*) were presented to the left visual field / right hemisphere (LVF-RH), or the right visual field / left hemisphere (RVF-LH) to determine if the cerebral hemispheres differed in the degree of priming for either type of pair. In addition, they were interested in determining if the cerebral hemispheres differed in the time course of semantic processing. Stimulus onset asynchrony (SOA) was manipulated such that the target item (e.g., *money* or *bank*) was presented 35 or 750 milliseconds (ms) after the prime. At a short SOA (35 ms), priming was only observed for dominant meaning pairs in both hemispheres. At a long SOA (750 ms), priming was observed in the RH for both dominant and subordinate meaning pairs. In contrast, no priming was evident for subordinate meaning items in the LH. This was the first piece of evidence that suggested that the LH only rapidly accesses the most dominant, highly associated meanings for words, while the RH is able to access more weakly associated meanings for words. Similar patterns of semantic priming have been shown in other studies that have also used semantically ambiguous prime-target pairs (Atchley, Burgess, & Keeney, 1999; Atchley, Keeney, & Burgess, 1999; Chiarello, Maxfield, & Kahan, 1995), related pairs that vary in associative strength (Abernethy & Coney, 1993; Chiarello, Liu, Shears, Quan, & Kacinik, 2003), and categorically related pairs (Abernethy & Coney, 1996; Chiarello & Richards, 1992). Two particular processing frameworks have been proposed that attempt to explain these hemispheric processing differences. The *Fine Coarse Semantic Coding Theory* (FCT) proposes that hemispheric asymmetries in semantic processing are due to representational "coding" differences in the hemispheres (Beeman & Chiarello, 1998; Jung-Beeman, 2005). Alternatively, the *Production Affects Reception in the Left Only* framework (PARLO) proposes that the LH has more active use of top-down control mechanisms that are more able to facilitate language processing (Federmeier, 2007).

Theories for Hemispheric Asymmetries in Language Processing

Fine-Coarse Semantic Coding Theory (FCT)

According to FCT, semantic representations in the LH are stored in a relatively fine, narrow, and focal manner. In contrast, representations that exist within the RH are stored broadly and more coarsely. The fineness or coarseness of semantic representations is described in terms of "semantic fields". According to Jung-Beeman (2005), these semantic fields are thought to be analogous to other types of sensory receptive fields that exist within the brain. In FCT, language input causes strongly focused activation of semantic representations in the LH, and weak, diffuse activation in the RH. The organization of semantic representations in the LH and RH is suggested to be conducive to overall language comprehension. The narrow locus of activation in the LH is thought to be conducive for the access of highly frequent and context relevant semantic information. This allows the LH to focus on the processing of more relevant aspects of incoming language input. The broad locus of activation in the RH allows for the access of less frequent and less contextually relevant semantic information. This allows the RH to maintain more distantly related semantic information, which would help individuals' process alternative interpretations if the need arises. This interpretation aligns with semantic priming data which shows greater facilitation in the RH for pairs that are more distantly related.

Direct evidence for FCT comes from a study conducted by Beeman et al., (1994). In this study, a summation semantic priming paradigm was used. Participants saw a set of three weakly related primes followed by a target word (e.g., *foot-glass-pain:CUT*) or a single strongly associated prime followed by a target word (e.g., *scissors:CUT*). They predicted that if there is a fine-coarse coding distinction between the hemispheres, the magnitude of priming should differ in each hemisphere, based on the types of primes used. In the condition with three weakly related primes, the magnitude of priming was greater in the RH compared to the LH. In the condition with a single, strongly associated prime, more priming was observed only in the RH. When three weakly related primes are presented in succession, more diffuse semantic fields become activated. These broad semantic fields "overlap" the distant semantic representation of *cut*, increasing the magnitude of priming in the RH. Conversely, fine focal coding does not allow representations to overlap, explaining why priming does not occur in the LH. Following the idea that the RH can activate distantly related semantic information, other studies have indicated that the RH plays an active role in bridging inferences in larger discourse (Beeman, Bowden, & Gernsbacher, 2000) and is involved with the processing of jokes and metaphors (Coulson & Wu, 2005; Mashal, Faust, & Hendler, 2005).

Production Affects Reception in the Left Only Framework (PARLO)

The Fine Coarse Semantic Coding Theory posits that hemispheric differences in language processing are largely driven by the type of representational coding that exists within each hemisphere. In contrast to this idea, the Production Affects Reception in the Left Only (PARLO; Federmeier, 2007) suggests that hemispheric asymmetries in language processing are not only due to semantic coding, but also due to potential hemispheric differences in the use of top-down mechanisms during language processing. At its core, the PARLO framework posits processing that occurs in the LH is more interactive than in the RH. PARLO also suggests that lower levels of processing receive significantly more feedback from higher levels of processing in the LH. Conversely, RH processes language in a more feed-forward fashion. PARLO posits that the efficient use of top-down mechanisms in the LH is due to a close coupling between networks that control language comprehension and language production. Federmeier suggests that in the LH, there is stronger interconnectivity between the stored conceptual representations and associated output mechanisms. This enables the LH to receive stronger feedback during online language processing.

Greater use of top-down mechanisms also allows the LH to adopt a more predictive, expectancy-based processing strategy. This idea has been supported by several studies that have used divided visual field presentation in addition to measuring event-related potentials (ERPs). In Wlotko and Federmeier (2007), participants read sentences word by word, presented in the center of a computer screen. Sentence final words were presented to the LVF-RH or the RVF-LH. Critically, each sentence was strongly constrained for an expected, or unexpected final word (e.g., *He bought her a pearl necklace for her birthday / collection*), or were weakly biased for an expected or unexpected final word (e.g., *He look worried because he might have broken his arm / collection*). ERPs were measured for each sentence final word, specifically the N400 and P2 components. A hemispheric difference for the N400 component was found for strongly and weakly constrained sentences with expected endings, with the RVF-LH showing greater facilitation than the LVF-RH. Further, there was also a large hemispheric difference in the P2 component, with the RVF-LH showing greater facilitation for strongly constrained sentences with expected endings. Wlotko et al. suggested that hemispheric differences in the N400 reflect LH controlled processing ability. Hemispheric differences in the P2 component are thought to reflect preparatory attentional responses in sentences with highly constraining contexts. These ERP patterns have been observed in other studies examining the effect of contextual constraint on sentence processing in the hemispheres (Federmeier & Kutas, 2002; Federmeier, Mai, & Kutas, 2005). Additionally, similar ERP data has been found in a more recent study examining semantic priming (Kandhadai & Federmeier, 2010b). In Kandhahai and Federmeier (2010b) participants were presented with prime-target pairs that were strongly associated in a forward direction (e.g., *pillow-sleep*) or weakly associated in a backwards direction (e.g., *sleep-pillow*). Targets were presented to the LVF-RH or the RVF-LH. No hemispheric difference was observed for the N400 component. For the P2 component, greater facilitation was observed when forward prime-target pairs were processed by the RVF-LH, but not the LVF-RH. Another component, the Late Positive Complex (LPC) was also measured. This component is thought to reflect controlled semantic processing. Kandhahai and Federmeier found that in the LVF-RH, forward pairs elicited greater LPC activity than backwards pairs. In the RVF-LH, no such difference was found. Similar to conclusions from prior studies, these data were taken to support the idea that the LH uses a more predictive, expectancy-based processing strategy. Based on these studies, it is suggested that the LH is more able to engage in controlled semantic processing. The RH does not seem to engage controlled processing mechanisms, and seems to process information in a more passive manner.

Hemispheric Asymmetries in Verbal Memory

Investigations in hemispheric asymmetries in language processing have been largely confined to semantic priming and sentence processing studies. In comparison, there have been fewer studies that have examined hemispheric differences in verbal memory. Arguably, language comprehension relies on memorial processes. In order to understand printed text or spoken discourse, conceptual information must be retrieved from memory. Examining hemispheric asymmetries in verbal memory may provide more insight to hemispheric asymmetries in language processing.

Most memory studies investigating hemispheric verbal memory have examined hemispheric differences in false memory errors (Bellamy & Shillcock, 2007; Ben-Artzi, Faust, & Moeller, 2009; Faust, Ben-Artzi, & Harel, 2008; Giammattei & Arndt, 2012; Ito, 2001; Westerberg & Marsolek, 2003). These studies typically use variants of the well-known Deese-Roediger-McDermott (DRM) paradigm (Roediger & McDermott, 1995). In the traditional DRM paradigm, participants are asked to study lists of related words (e.g., *nurse, sick, medicine, hospital, dentist*). They are later tested on words they saw previously (e.g., *hospital*), an unrelated new words (e.g., *bank*) and critical lure words that they did not study before, but are strongly related to each word list (e.g., *doctor*). Three studies combined the traditional DRM method with divided visual field presentation (Bellamy & Shillcock, 2007; Ito, 2001; Westerberg & Marsolek, 2003). In these studies, memory probes were presented to the LVF-RH or the RVF-LH to examine hemispheric differences in false memories. False memory errors tend to be higher when critical lure words are presented to the LVF-RH (Bellamy & Shillcock, 2007; Westerberg & Marsolek, 2003), while hit rates to old words are higher when they are presented to the RVF-LH (Ito, 2001).

Recent studies have also examined hemispheric asymmetries in general recognition memory (Evans & Federmeier, 2007, 2009; Federmeier & Benjamin, 2005; see also Coney & Macdonald, 1988). Federmeier and Benjamin (2005) examined the time course of memory using a continuous recognition memory paradigm. In the continuous recognition memory paradigm, participants are tested on their memory multiple times during an experiment, and the interval between study and test phases is varied. The authors were interested in how the memory representations may differ in terms of storage over different time intervals. Some items were tested immediately after they were studied (no intervening items between study and test), some were tested after a short time lag (2 to 10 intervening items between study and test), other were tested at a medium (20 to 30 intervening items between study and test) or long time lag (50 intervening items between study and test). Study items were presented in either visual field, with memory probes presented centrally. Overall, accuracy favored items studied in the RVF-LH across all study-test lags. Response times were faster for items studied in the RVF-LH, but only for short and medium study-test lags. At long study-test lags, response times were faster for items presented in the LVF-RH. Evans and Federmeier (2007) found similar results when measuring ERP amplitudes. In their study, they found greater facilitation of the LPC component for items encoded in the RVF-LH, but only for short and medium lags. Greater facilitation in the LPC component was found for items encoded in the LVF-RH at long study-test lags. Evans and her colleagues suggested that verbal information stored in the RH is resistant to decay, and possibly more resistant to proactive interference. It was further suggested that verbal representations in the RH are stored more veridically. In contrast, the verbal information in the LH decays more rapidly, and may be more prone to interference effects. Evans and Federmeier (2009) examined if these ERP patterns were also observed when study items were presented centrally, and memory test probes were presented laterally. Interestingly, they were not able to replicate prior results, and found that ERP amplitudes were similar between the hemispheres when test probes were lateralized. The authors suggested that the central presentation of study items biases processing differently than when study items are lateralized. The central presentation of study items may cause the hemispheres to cooperate more strongly during processing. This leads to memory representations that are more distributed across hemispheres (rather separate representations stored within each hemisphere), which explains a lack of differences in ERP amplitudes. In sum, continuous recognition memory studies partially validate the idea that RH processes information in a more bottom-up manner, and maintains information until it is necessary to integrate it into a larger context.

The Relationship between Top-Down Mechanisms and Memory

Aside from representational differences, other cognitive mechanisms may influence the way memory representations are stored in the cerebral hemispheres. The PARLO framework alludes to this idea, and suggests that the hemispheres differ in the engagement of top-down mechanisms during the processing of information. Specifically, the PARLO framework suggests that the LH may use top-down mechanisms to engage controlled processes more efficiently, while the RH is less efficient in using top-down mechanisms. One drawback of the PARLO framework is that it does not directly specify the nature of these top-down mechanism, though there has been some suggestion that they may be related to working memory or other executive control processes (see Kandhahai & Federmeier, 2010b, p. 10).

Executive control / functioning is generally characterized as a set of cognitive processes used for goal maintenance, self-monitoring, decision making, and the resistance to internal and external distractions. Additionally, studies in the general memory literature have shown that executive control plays an important role in both memory encoding and retrieval (Unsworth & Engle, 2007). Evidence for this comes from studies measuring working memory capacity and its relationship to long term memory. It has been suggested that individuals with higher working capacity use executive control processes more efficiently for memory. Specifically, individuals with higher working memory capacity are better able to engage in the *active maintenance* of information in working memory, but are also better in the *inhibition / suppression* of distracting information that may displace information from working memory. Further, these individuals can use executive control more efficiently to search and retrieve information from memory (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Conway, Hambrick, & Engle, 2007). It has been demonstrated that individuals with higher working memory capacity are better able to resist proactive interference during memory encoding, compared to individuals with lower working memory capacity (Kane & Engle, 2000). Higher working memory capacity individuals have also been shown to be better able to suppress irrelevant information during memory encoding, are better able to focus on more task-relevant information (Delaney & Sahakyan, 2007). Individuals with higher working memory capacity also are more efficient in retrieving items from memory in verbal fluency tasks, free-recall tasks, and recognition memory tasks (Rosen & Engle, 1997; Rosen & Engle, 1998; Unsworth & Brewer, 2009; Unsworth & Engle, 2007).

In addition to studies examining healthy adults, individuals with executive *dysfunction* often exhibit memory deficits as well. Executive dysfunction typically occurs when frontal region of the brain, associated with executive control, are damaged due to head injury or stroke. For example, individuals with mild to moderate traumatic brain injuries (TBI) have been shown to perform poorly on neuropsychological assessments of memory (Vanderploeg, Crowell, & Curtiss, 2001; Wiegner & Donders, 1999). Individuals with a mild TBI are more susceptible to dual task manipulations during memory encoding, causing greater disruptions in memory retrieval relative to healthy controls (Mangels, Craik, Levine, Schwartz, & Stuss, 2002). Individuals with TBI are more susceptible to distracting information during memory encoding. They are more likely to false endorse this distracting information in a later memory test, in comparison to healthy controls (Ozen, Skinner, & Fernandes, 2010). It is thought that memory deficits observed in individuals with a TBI are associated with the inability to control attention efficiently. This prevents these individuals from efficiently maintaining information in working memory, and resisting interference that may displace with the contents of working memory. This results in weakly encoded long-term memories. Stroke patients with damage more localized to the frontal cortex of the brain also exhibit executive dysfunction and memory impairments (for a review, see Lim & Alexander, 2009).

It is clear the the ability use executive control mechanisms is important for memory. Relating these ideas back to the PARLO framework and hemispheric verbal memory, hemispheric differences should be observed in memory tasks that tap into top-down mechanisms during encoding or retrieval. PARLO predicts in these circumstances, that the LH should be more efficient in the use of top-down mechanisms for memory encoding and retrieval. Manipulations that influence top-down mechanisms should greatly influence LH memory. Conversely, if the RH does not use top-down mechanisms as efficiently, manipulations that influence top-down mechanisms should not greatly influence RH memory. While the PARLO framework suggests that the usage of top-down mechanisms should differ by hemisphere, there is no clear delineation of what these top-down mechanisms necessarily encompass. General human memory studies suggests executive control mechanisms, such as the active maintenance of information during encoding, and the controlled search of the contents of memory, are of particular importance. Most studies that can be potentially interpreted by the PARLO framework have primarily examined semantic priming and sentence processing differences in the cerebral hemispheres. Some of this evidence points to the idea that the LH may used “controlled processes” more efficiently. Evidence from priming studies suggest that the LH is able to suppress and inhibit irrelevant semantic information from becoming activated, while only maintaining context relevant information (Abernethy & Coney, 1993; Anaki, Faust, & Kravetz, 1998; Burgess & Simpson, 1988; Faust & Lavidor, 2003). Based on this, it is hypothesized that the LH should have advantages over the maintenance of information, and the inhibition / suppression of irrelevant information. The influence of these potential top-down mechanisms have not been closely examined in the hemispheric verbal memory literature. The goal of the current set of studies is to investigate how the hemispheres may differ in the usage of top-down mechanisms, to determine the specific nature of these mechanisms, and to provide converging evidence using different methodologies that are thought directly influence how top-down mechanisms and verbal memory interact. There are three sets of studies, organized by the different methods used to investigate the influence of top-down mechanism on hemispheric verbal memories. The first two studies utilize *item-method directed* *forgetting* to investigate how general maintenance and suppression mechanisms influence resulting memory representations in the cerebral hemispheres. The second set of studies investigates the influence of cognitive load manipulations on true and false memories in the cerebral hemispheres. The final study investigates the how expectancy-based processing during memory encoding influences resulting memory representations in the cerebral hemispheres.

Item-Method Directed Forgetting

A direct method to investigate the influence of maintenance and suppression on hemispheric verbal memories is through *item-method directed forgetting* (Basden, Basden, & Gargano, 1993; MacLeod, 1999). In item-method directed forgetting, participants shown a list of words to study, and are cued to actively "Remember" or "Forget" specific words. Later, they are given a memory test (either free recall or recognition memory). Typically, Remember words are recognized more accurately and more rapidly than Forget words. This advantage that Remember words have over Forget words is referred to as a *directed forgetting effect*.

There are several theories that attempt to explain item-method directed forgetting effects. Two prominent theories are the *Selective Rehearsal Theory* (Basden et al., 1993), and the *Attentional Inhibition Theory* (Zacks, Radvansky, & Hasher, 1996). The Selective Rehearsal Theory suggests that when participants receive a "remember" cue, they engage an active rehearsal process to facilitate the storage of that item into long-term memory. In contrast, when a "forget" cue is encountered, rehearsal immediately ceases, and the item is dropped or decays from working memory. Thus, "remember" words are generally maintained longer in working memory, and are more likely to be encoded into long-term memory. Conversely, “Forget” words are removed from working memory rapidly, and are weakly encoded into long-term memory.

The Attentional Inhibition Theory suggests that forgetting is effortful, and is as cognitively demanding as the process of remembering. A great deal of evidence from behavioral, electrophysiological and neuro-imaging studies have come to support this idea (Fawcett & Taylor, 2008, 2010; Nowicka, Marchewka, Jednoróg, Tacikowski, & Brechmann, 2011; Rizio & Dennis, 2013; Ullsperger, Mecklinger, & Muller, 2000; Wylie, Foxe, & Taylor, 2008; Zacks et al., 1996). Zacks et al. (1996) suggested that when participants receive a forget cue, attentional mechanisms are engaged to actively suppress an item from entering memory. Instead of allocating attention to maintain the item in working memory, attention is used to prevent the item from being rehearsed. In contrast to the Selective Rehearsal Theory, the Attentional Inhibition account posits that forgetting is an active and not a passive process. To provide evidence for Attentional Inhibition, Zacks et al. tested younger and older adults in an item-method directed forgetting tasks (Experiments 1A and 1B). They found that older adults were less able to suppress Forget words, and remembered the same amount of Remember and Forget words during the memory test. Zacks et al. suggested older adults were less able to allocate attention to suppress Forget words from entering memory.

One problem with the Zacks et al. (1996) study is that it only provided indirect evidence for Attentional Inhibition. Fawcett and Taylor (2008) conducted a study that directly probed for evidence that inhibition was actually occurring for Forget items. In their item-method directed forgetting study, participants were instructed to press the space bar 1400 ms, 1800 ms, and 2600 ms after receiving a remember or forget cue. Fawcett and Taylor hypothesized that if forgetting is as demanding as remembering, probe response times (recorded by space bar presses) should be higher after participants receive a forget cue. They found that in the 1400 ms and 1800 ms conditions, response times to forget cues were significantly slower than response times after remember cues. The authors suggested that when individuals receive a forget cue, items do not decay from working memory, rather they are actively suppressed from entering memory altogether. Fawcett and Taylor (2010) provided additional behavioral evidence for inhibition by embedding tasks that measured stop-signal inhibition and inhibition of return. In their first series experiments, after receiving remember or forget cues, participants were instructed to press the space bar when they saw a green circle (a Go trial), and to withhold response when they saw a red circle (No-Go trial). They found that response times on Go trials were slower after forget cues were presented. Additionally, error rates for No-Go trials were lower after forget cues were presented, suggesting that forget instructions facilitated response inhibition. Their second experiments adapted the general stop-signal paradigm to measure inhibition of return (IOR) and found that IORs were larger for No-Go trials relative to Go trials. These data are thought to indicate that inhibition is actively used when participants attempt to forget words.

Converging evidence for Attentional Inhibition also comes from ERP and neuro-imaging studies. Both Ullsperger et al. (2000) and Van Hoof et al. (2009) found topographical ERP differences for the old/new effect between Remember and Forget items. Remember items elicited an old/new effect on frontal and parietal electrode sites, while Forget items only elicited an old/new effect for frontal sites. The authors of these studies suggested that these effects reflected attentional inhibition operating on items that are cued to be forgotten. Neuro-imaging studies also provide insight to cortical areas involved with active maintenance and inhibition. These studies have found that there is greater activity in left prefrontal areas when participants are asked to remember items, while greater activity is found in right prefrontal areas when participants are asked to forget items (Rizio & Dennis, 2013; Wylie et al., 2008). Neuro-imaging data also support prior lesion studies that have suggested that inhibition is primarily localized to right prefrontal areas (specifically the right inferior frontal gyrus; Aron, Robbins, & Poldrack, 2004).

Experiment 1: Hemispheric Asymmetries in Item-Method Directed Forgetting

In conjunction with the divided visual field method, item-method directed forgetting allows for the examination of how active maintenance (through rehearsal processing for Remember words) and active inhibition (through inhibitory processes for Forget words) influences the processing of memory representations in the cerebral hemispheres. In the current experiment, participants were cued to actively remember or forget words presented centrally on a computer monitor. Later, they were given a recognition memory test on all the words that were presented during the study phase. To further examine the role of active maintenance, the timing of remember-forget cues was manipulated such that cues were presented at the same time as targets (*Simultaneous Cue condition*) or after a 500 ms delay (*Delayed Cue condition*). Divided visual field presentation was used to probe LH and RH verbal memory.

The PARLO framework suggests that the LH may be more influenced by manipulations of top-down control mechanisms through the different cue timing conditions. In the Simultaneous Cue condition, the presentation of a remember cue should engage a maintenance process to encode the item into long-term memory. Conversely, the presentation of a forget cue should engage an inhibitory process to suppress and remove target items from working memory. The influence of these two processes should be observed when each hemisphere is probed for memory. If the PARLO framework is correct in its assumptions, the difference between Remember and Forget word accuracy and response times should be greater when the RVF-LH is probed for memory. First, the LH should be better able to engage in both maintenance and inhibition processes. Remember words will be maintained better, and Forget words should be inhibited more effectively. Second, PARLO states that language comprehension and production mechanisms are tightly coupled in the LH, and afford the LH with greater feedback activation from higher levels of processing. This suggests that maintenance processes should inherently favor LH processing for verbal material. Thus, the directed forgetting effect (the difference between Remember and Forget words) should be significantly greater in the LH compared to the RH. In contrast, top-down control processes should exert less of an influence on encoded information in the RH. A directed forgetting effect should be evident in the RH as well, but should be smaller than what is predicted to be observed in the LH.

The Delayed Cue condition should yield a different pattern of results. The Delayed Cue condition should magnify the effects of effects of active maintenance, and partially negate inhibitory processes that may occur. A number of studies have shown that presenting cues after a target item decreases the overall magnitude of the directed forgetting effect, due to increases in accuracy for Forget words (Dulaney, Marks, & Link, 2004; Sego, Golding, & Gottlob, 2006; Wetzel & Hunt, 1977). When a cue is delayed, maintenance processes operate equivalently for target words (regardless if it is a Remember or Forget word). This should cause Forget words to be encoded more deeply relative to the Simultaneous Cue condition. The effects of extra maintenance should be more evident for LH verbal memory. In contrast to the Simultaneous Cue condition, the directed forgetting effect should be diminished in the LH, due to increased maintenance and rehearsal for Forget words. Predictions for the RH should be similar to the Simultaneous Cue condition. A directed forgetting effect should be observed in the RH, but it should be minimally influenced by the manipulation of Cue Timing. Therefore, the directed forgetting effect in the RH should not greatly differ between the Simultaneous and Delayed Cue conditions.

Method

Participants.

There were 65 undergraduates (54 female, 11 male) from Arizona State University who participated in this experiment. Participants were either enrolled in an introductory Psychology or Speech and Hearing Science course. Psychology students received course credit for their participation, Speech and Hearing Science students received extra credit for their participation. All participants were native English speakers, had no history of neurological impairment, and were right handed as assessed by through the Edinburgh Handedness Inventory (Oldfield, 1971). Mean laterality quotient of all participants was 0.82 (range: 0.52-1.00, where 1 indicates being strongly right handed, and -1 indicates being strongly left handed). All participants had normal or corrected to normal vision. Participants were randomly assigned to the Simultaneous Cue condition (N = 32) or the Delayed Cue condition (N = 33).

Stimuli and Design.

There were a total of 192 unrelated words chosen for this experiment (see Appendix A). All words were singular nouns that were 3-7 letters in length, and had a low printed word frequency (defined as 1-60 occurrences per million by (Kučera & Francis, 1967). All words were rated as highly concrete and highly imageable by the MRC Psycholinguistic Database (450-700 on a 100-700 scale; Coltheart, 1981). A total of 96 words were used during the study task (48 Remember words, 48 Forget words). A total of 192 words were used during the recognition memory test. Ninety-six study words were repeated, randomly intermixed with 96 new, unrelated words. Of the repeated study words, 48 were Remember words, and 48 were Forget words. Half of the words in the memory test were presented to the left visual field / right hemisphere (LVF-RH), and the other half were presented in the right visual field / left hemisphere (RVF-LH). All words were counterbalanced across Remember / Forget conditions during the study phase, and the left / right visual fields at test.

Procedure.

Participants were tested in pairs. They were seated approximately 50 cm in front of 15 inch CRT computer monitors. Presentation of the stimuli were controlled by E-prime 1.2, software that collected accuracy and response time data (Schneider, Eschman, & Zuccolotto, 2002). An illustration of the study phase procedure is in Figure 1.

In the study phase, participants were instructed to only study words they were cued to Remember (Remember words) and to forget all other words (Forget words). The timing of the cue presentation was a between-subjects manipulation. In the Simultaneous Cue condition, participants were instructed to only remember words presented in blue, and to ignore words presented in red. During each study trial, a fixation point appeared for 1000 ms, followed by a centrally presented blue / red word for 2000 ms. A 1000 ms inter-trial interval (ITI) occurred between target words. Stimulus presentation was similar in the Delayed Cue condition. Words were presented in black font, and were centrally presented for 2000 ms. After the presentation of a word, a screen with a row of asterisks (***) appeared for 500 ms. After this delay, a cue was displayed for 2000 ms, instructing the participants to remember the word ("RRR") or to forget the word ("FFF"). There was a 1000 ms ITI between the presentation of the cue, and the subsequent target word. After completing the study task, participants were given a distracter task, in which they evaluated a set of 20 math problems.

Prior to the recognition memory test, participants were informed that they were going to be tested on <u>all</u> the words they saw, regardless of the type of cue they received. See Figure 2 for an illustration of the memory test procedure. Participants were told to press a key labeled "YES" if they thought the word had been shown in the study phase (regardless of cue) and "NO" if they thought the word was new. They were told to respond as quickly and as accurately as possible. Participants were instructed to place

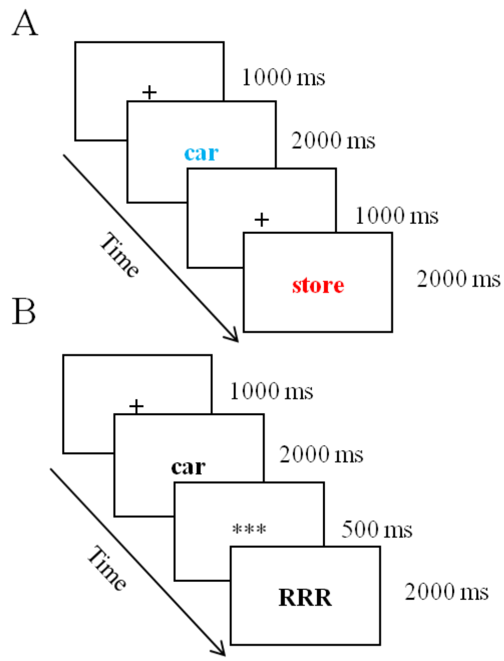

Figure 1. Experiment 1 study phase procedure for the Simultaneous Cue condition (A) and the Delayed Cue condition (B).

their head in a chinrest, and were told to focus their eyes on a fixation point throughout the memory test. At the start of each memory trial, a black fixation point appeared in the center of the screen for 1000 ms. This was followed by a colored fixation point (red, light blue, or yellow) for 250 ms, and another black fixation point for 100 ms. The flickering fixation point was used to orient the participants' eyes and attention towards the center of the screen. Immediately after, the target word appeared in the LVF-RH or the RVF-LH for 190 ms. The center of the target word subtended 3° of visual angle from the center of the screen (either in the LVF-RH or the RVF-LH). The innermost edge of the target word never subtended more than 1.1° of visual angle. Following the presentation of the target word, a red fixation point immediately appeared, prompting participants to make their YES or NO response. Participants had 5000 ms to respond. A 1000 ms ITI occurred

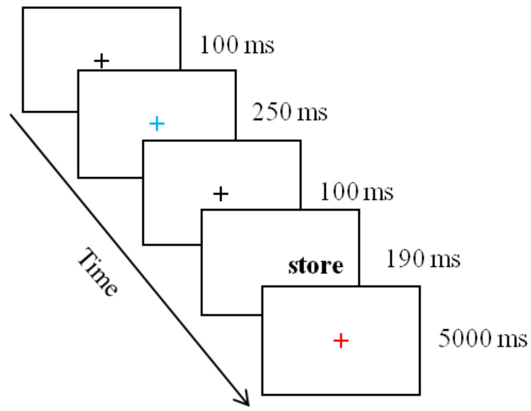

Figure 2. General procedure for the recognition memory test in Experiment 1, using divided visual field presentation.

before the next trial. Participants were instructed to only use their right hand to make responses. The hand used for responses was kept constant across all participants.

Results

Memory Accuracy.

Mean hit rates across Visual Field, Cue Type, and Cue Timing conditions are shown in Figure 3. A 2 (Visual Field: LVF-RH vs. RVF-LH) X 2 (Cue Type: Remember vs. Forget) X 2 (Cue Timing: Simultaneous vs. Delayed) mixed factor analysis of variance (ANOVA) was conducted on hit rates for study words. There was a main effect of Visual Field on hit rates, which suggested hit rates were higher in the RVF-LH (*M* =.57 , *SE* = .016) than in the LVF-RH (*M* =.62, *SE* =.016), [$F(1, 63) = 11.59$, $p = .001$, $\eta_\rho^2 = .155$]. There was a main effect of Cue Type, indicating hit rates for Remember words (*M* = .71, *SE* = .017) were higher than hit rates for Forget words (*M* =.48, *SE* =.017), [$F(1, 63) = 153.89$, $p < .001$, $\eta_\rho^2 = .71$]. There was a main effect of Cue Timing which revealed that hit rates were higher in the Delayed Cue condition (*M* = .64, *SE* = .02) compared to the Simultaneous Cue condition (*M* =.54, *SE* = .021), [$F(1, 63) =$

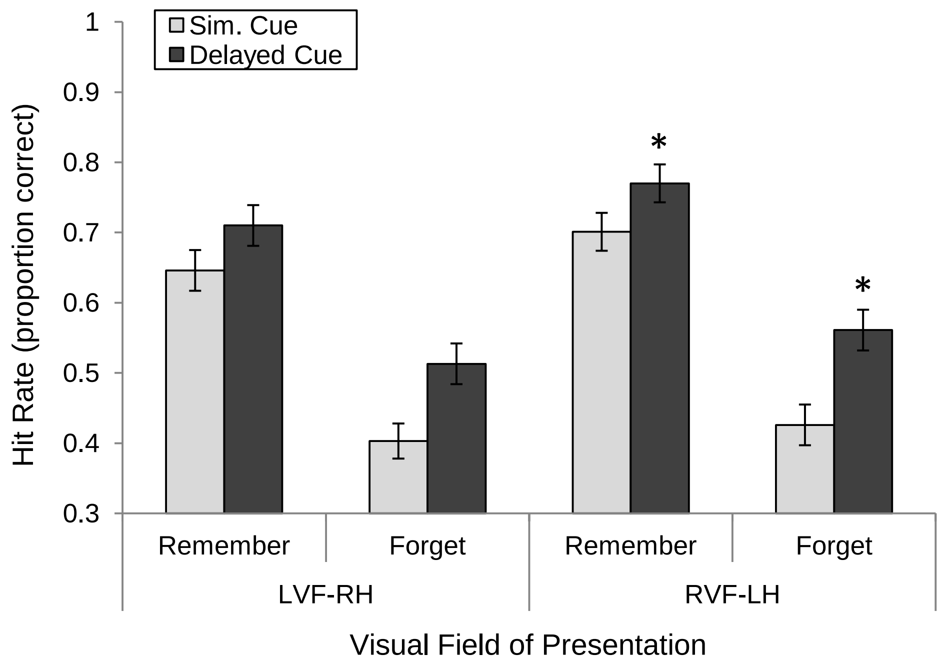

Figure 3. Mean Hit Rate for Remember and Forget words in Experiment 1, by Visual Field of Presentation. Error bars reflect standard errors. "Sim" Cue denotes Simultaneous Cue condition. * Denotes significantly different from Simultaneous Cue condition (both $p < .01$)

10.55, $p = .002$, $\eta_\rho^2 = .143$]. No significant interactions were observed between Visual Field, Cue Type, or Cue Timing.

A 2 (Visual Field) X 2 (Cue Timing) Mixed factor ANOVA was conducted on false recognition rates for new words. There was a main effect of Visual Field, whereby false recognition rate was higher for items presented in the RVF-LH ($M = .25$, $SE = .018$) compared to the LVF-RH ($M = .20$, $SE = .017$), [$F(1, 63) = 8.21$, $p = .006$, $\eta_\rho^2 = .115$]. To determine of memory discrimination was better in the RVF-LH or the LVF-RH, hit and false recognition rates were collapsed into sensitivity index vales (*d*'). This analysis compared the hit rate distribution, collapsed across Remember and Forget words, to the false alarm rate distribution for new words. Higher *d'* values represent a better ability to distinguish between old and new words, lower *d'* values represent poorer ability to distinguish between old and new words. A 2 (Visual Field) X 2 (Cue Timing) mixed factor ANOVA yielded no significant main effects of Visual Field (LVF-RH: *M* = 1.11, *SE* = .062; RVF-LH: *M* = 1.06, *SE* = .058), or Cue Timing (Simultaneous: *M* =1.03, *SE* = .075; Delayed: *M* = 1.15, *SE* = .074). No significant interaction was observed between Visual Field and Cue Timing for d' values.

Response bias (*C*) was also analyzed. Higher *C* values represent a more conservative response strategy (less likely to respond old), while lower values of C represent a more liberal response strategy (more likely to respond old). There was a main effect of Visual Field, suggesting that the RVF-LH lower *C* value (*M* = .214, *SE* = .046) than the LVF-RH (*M* = .385, *SE* = .054), [$F(1, 63) = 15.55$, $p < .001$, $\eta_\rho^2 = .198$]. There was also a main effect of Cue Timing, suggesting that the Simultaneous Cue condition had higher *C* values (*M* = .398, *SE* = .064), compared to the Delayed Cue condition (*M* = .201, *SE* = .063), [$F(1, 63) = 4.75$, $p = .033$, $\eta_\rho^2 = .07$]. No significant interaction was observed for *C* values.

Finally, Remember word hit rates were subtracted by Forget word hit rates to obtain a measure of the "directed forgetting effect." This index reflected the advantage Remember words had over Forget words in terms of hit rates. Directed forgetting effect values were entered into a 2 (Visual Field) X 2 (Cue Timing) mixed factor ANOVA. The analysis yielded no significant main effects or interactions, suggesting that the magnitude of the directed forgetting effect did not differ for the Visual Field and Cue Timing variables.

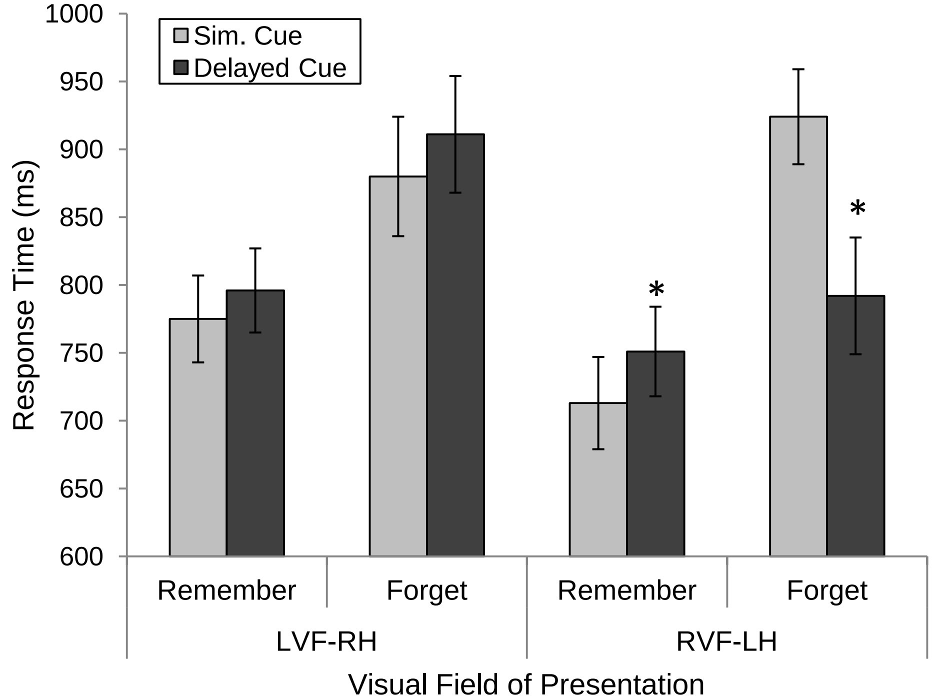

Figure 4. Response times for Remember and Forget word hit rates in Experiment 1, by Visual Field of presentation. Error bars reflect standard errors. “Sim. Cue” denotes Simultaneous Cue condition. * Denotes significantly different from LVF-RH (both p < .01).

Correct Response Times.

Mean response times (RTs) for each condition are shown in Figure 4. A 2 (Visual Field) X 2 (Cue Type) X 2 (Cue Timing) mixed factor ANOVA was conducted on mean response times for Remember and Forget word hit rates[1]. This analysis yielded a significant main effect of Visual Field, indicating response times were slower in the LVF-RH (M = 840, SE = 25), than in the RVF-LH (M = 795, SE = 28), [F(1, 63) = 8.05, p =

[1] ANOVAs were also conducted on response times for miss, correct rejections, and false recognitions. There were no significant effects for misses or corrected rejections (both F < 1, p > .1) A main effect of visual field was observed for false recognitions [F(1, 63) = 10.10, p = .002, $\eta_\rho^2 = .138$]. Response times for false recognitions were faster in the RVF-LH (M = 914), than in the LVF-RH (M = 1012). No significant interaction was observed for false recognition response times.

.004, η_ρ^2= .123]. A significant main effect of Cue Type was observed, which showed that response times were slower for Forget words (*M* = 877, *SE* = 31) compared to Remember words (*M* = 759, *SE* = 21), [$F(1, 63) = 41.01$, $p < .001$, η_ρ^2= .394]. The main effect of Cue Timing was not significant. There also were several interactions. A significant Visual Field X Cue Timing interaction was observed [$F(1, 63) = 5.77$, $p = .019$, η_ρ^2= .084]. Post-hoc pair-wise comparisons suggested that RTs in the RVF-LH (*M* = 771, *SE* = 39) were faster than the LVF-RH (*M* = 853, *SE* = 35), specifically in the Delayed Cue condition, $t(63) = 3.96$, $p < .001$. No difference was observed in the Simultaneous Cue condition. A significant Cue Type X Cue Timing interaction was observed, which suggested that the difference between Remember and Forget response times was larger in the Simultaneous Cue condition (Remember: *M* = 744, SE = 31; Forget: *M* = 902, *SE* = 45), compared to the Delayed Cue condition (Remember: *M* = 773, *SE* = 30; Forget: *M* = 851, *SE* = 44), [$F(1, 63) = 4.71$, $p = .034$, η_ρ^2=.07]. To examine the source of the interaction, directed forgetting effect magnitudes were calculated by subtracting Forget RTs by Remember RTs. An independent sample t-test suggested that the Simultaneous Cue condition did indeed have a larger directed forgetting effect, $t(63) = 2.201$, $p = .031$.

Finally, there was a significant three-way Visual Field X Cue Type X Cue Timing interaction [$F(1, 63) = 9.27$, $p = .003$, η_ρ^2= .128]. To determine the specific sources of this interaction, two separate 2 X 2 mixed factor ANOVAs were conducted for data within each Visual Field. In the LVF-RH, there was a main effect of Cue Type, suggesting that responses to Remember words (*M* = 785, *SE* = 22) were faster than responses to Forget words (*M* = 895, *SE* = 31), [$F(1, 63) = 27.79$, $p < .001$, η_ρ^2= .306]. No significant interaction was observed in the LVF-RH. In the RVF-LH, there was a main effect of Cue Type, where responses for Remember words (*M* = 732, *SE* = 24) were faster than responses for Forget words (*M* = 858, *SE* = 37), [$F(1, 63) = 23.48$, $p < .001$, $\eta_{\rho}^{2} = .272$]. Additionally, there was a significant Cue Type X Cue Timing interaction [$F(1, 63) = 10.63$, $p = .002$, $\eta_{\rho}^{2} = .144$]. An independent sample t-test comparing Forget word RTs across Cue Type conditions was marginally significant, suggesting that Forget word RTs in the Delayed Cue condition (*M* = 792, *SE* = 51) were faster than those in the Simultaneous Cue condition (*M* = 924, *SE* = 52), $t(63) = 1.78$, $p = .079$.

Another set of 2 X 2 repeated measure ANOVAs were conducted for data within each Cue Timing condition. In the Simultaneous Cue condition, there was a main effect of Cue Type, suggesting that Remember words (*M* = 744, *SE* = 30) were responded to more quickly than Forget words (*M* = 902, *SE* = 56), [$F(1,31) = 21.29$, $p < .001$, $\eta_{\rho}^{2} = .407$]. There was also a significant Visual Field X Cue Type interaction [$F(1, 31) = 7.86$, $p = .009$, $\eta_{\rho}^{2} = .202$]. Paired sample t-tests showed that Remember word RTs were faster in the RVF-LH (*M* = 713, *SE* = 31) than in the LVF- RH (*M* = 775, *SE* = 33), $t(31) = 2.67$, $p = .009$. In the Delayed Cue condition, there was a main effect of Visual Field, suggesting that response times were faster in the RVF-LH (*M* = 771, *SE* = 33) than in the LVF-RH (*M* = 853, *SE* = 28), [$F(1, 32) = 19.38$, $p < .001$, $\eta_{\rho}^{2} = .377$]. There was also a main effect Cue Type, suggesting that Remember words (*M* = 773, *SE* = 31) were responded to more quickly than Forget words (*M* = 851, *SE* = 29), [$F(1, 32) = 28.31$, $p < .001$, $\eta_{\rho}^{2} = .469$]. While no significant interaction was observed for data within the Delayed Cue condition, post-hoc paired sample t-tests revealed that Remember word RTs in the RVF-LH (*M* = 751, *SE* = 36) were marginally faster than Remember word RTs in the LVF-RH (*M* = 796, *SE* = 30), $t(32) = 1.77$, $p = .085$. Additionally, another post-hoc paired sample t-test revealed that Forget word RTs in the RVF-LH (*M* = 792, *SE* = 34) were significantly faster than Forget word RTs in the LVF-RH (*M* = 911, *SE* = 33), $t(32) = 3.64$, $p = .001$.

The three-way interaction between Visual Field, Cue Type, and Cue Timing seems to be primarily driven by the changes in Forget RTs, specifically in the RVF-LH. To confirm that this was actually the case, the directed forgetting effect was calculated for each condition. See Figure 5 for mean directed forgetting effect magnitudes. The calculated directed forgetting effect magnitudes were then entered into a 2 (Visual Field) X 2 (Cue Timing) mixed factor ANOVA. This analysis identically replicated the three-way interaction observed in the prior analysis on general RTs. Independent sample t-tests revealed that the directed forgetting effect did not differ across Cue Timing Conditions in the LVF-RH [$t< 1$, $p > .1$], but did differ across Cue Timing condition in the RVF-LH [$t(63) = 3.26$, $p = .002$]. In sum, in the RVF-LH, the magnitude of the directed forgetting effect was larger in the Simultaneous Cue condition relative to the Delayed Cue condition, but no such difference was observed in the LVF-RH.

Discussion

The overall goal for Experiment 1 was to investigate if top-down mechanisms were utilized differently by cerebral hemispheres to store, the subsequently retrieve information from verbal memory. Specifically, item-method directed forgetting was used to examine how active maintenance and inhibition mechanisms influenced resulting memory representations in the cerebral hemispheres. Participants were cued to remember and forget words, and these cues were presented at the same as study words, or after a

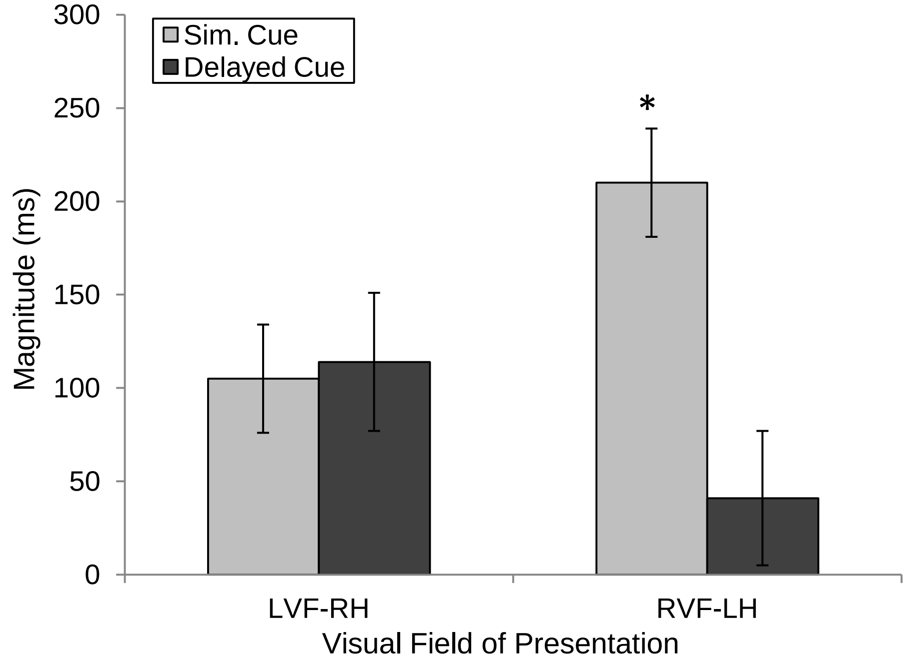

Figure 5. Magnitude of the directed forgetting effect for response times in Experiment 1, by Visual Field of Presentation and Cue Timing condition. Magnitude represents response times for Forget words subtracted by response times for Remember words. Error bars reflect standard errors. “Sim. Cue” denotes Simultaneous Cue condition.

short delay. Using divided visual field presentation, participants were tested on their memory for all the words they saw.

Predictions were made based on the PARLO framework. Recall that PARLO suggests that the LH can make more use of top-down mechanisms during processing. If this is the case, the overall directed forgetting effect should essentially change across Cue Timing conditions. In contrast, PARLO suggests that the RH is more of a “bottom-up” processor of information. Top-down mechanisms should not influence RH processing significantly. Based on this, the directed forgetting effect should not greatly differ based on Cue Timing manipulations. The hit rate data reveal a directed forgetting effect across visual fields. Hit rates were significantly higher for Remember words, in comparison to Forget words. Additionally, hit rates were even higher for Remember words in the Delayed Cue condition, relative to the Simultaneous Cue condition. This is likely due to the fact that Remember words receive extra rehearsal in the Delayed Cue condition, increasing their memory strength, which results in higher hit rates. Finally, there were was a slight hit rate advantage that favored the RVF-LH. This advantage replicated some prior recognition memory data (Coney & Macdonald, 1988; Federmeier & Benjamin, 2005). However, false recognitions to new words were higher in the LH. Therefore, accuracy advantages may be due to response bias. Sensitivity index values (*d’*) did not differ between hemispheres and response bias was more liberal for items presented in the RVF-LH. Participants likely see words more clearly in the RVF-LH, and attribute that clarity as a form of familiarity, increasing the probability of judging words presented in the RVF-LH as being “old” (Jacoby & Whitehouse, 1989).

Hit rates did not provide much insight regarding hemispheric differences in the use of top-down mechanisms. However, response times revealed an interesting pattern of results. Response times are thought to be an index of how accessible an encoded item is in memory. Lower response times indicate greater memory accessibility. Response times in Experiment 1 align more closely to initial predictions. In the Simultaneous Cue condition, a large directed forgetting effect was observed in the LH. In the Delayed Cue condition, the directed forgetting effect was significantly smaller in the LH. The difference in the directed forgetting effect seems to be due to faster response times for Forget words in the LH. This latter finding was surprising, and seems to suggest that Forget items in the Delayed Cue condition were encoded in a similar manner to

Remember words. In contrast, Cue Timing manipulations did not greatly influence directed forgetting effects in the RH.

Surprisingly, these data do not readily support the idea that inhibitory processes preferentially influence memory encoding or retrieval to one hemisphere or the other. If the LH has a better ability to use active inhibition, a different pattern of results would have been observed for hit rates and response times. In the Simultaneous Cue condition, hit rates for Forget words should have been lower in the LH relative to the RH. Similarly, response times to Forget words in the Simultaneous Cue condition should be higher in the LH relative to the RH. If inhibitory processes are exerting any influence during processing, they are doing so more generally and not in any hemispheric specific manner. On the surface, data from Experiment 1 seem to only support the idea that the LH is more able to control maintenance and rehearsal processes. In Experiment 2, the influence of rehearsal and maintenance processes are further explored. Instead of using Cue Timing as a means to manipulate rehearsal, some of the words in Experiment 2 were repeated once, or several times during the course of the experiment.

Experiment 2: Repetition Effects on Hemispheric Directed Forgetting

The goal of Experiment 2 is to provide additional evidence that maintenance and rehearsal mechanisms only influence the encoding of LH verbal memory representations, and not RH verbal memory representations. Data from Experiment 1 suggested that increasing the rehearsal time for a Forget word increases its accessibility in LH verbal memory, but not RH verbal memory. In Experiment 2, instead using Cue Timing as a way to manipulate rehearsal and maintenance processes, item repetition is used instead. It is hypothesized that item repetition should similarly mimic the Cue Timing manipulation from Experiment 1.

One clear finding in the human memory literature is that simple item repetition leads to improved memory performance in explicit memory tasks, such as recall and recognition. For example, Challis and Sidhu (1993) found that massed repetition of words greatly improves memory performance in explicit (but not implicit) memory tasks. Participants in their experiment studied words once, 4 times, or 16 times. In their study, participants either studied a list of words. Words in each study list were presented once, 4 times, or 16 times. Higher accuracy was observed for four repetitions vs. one, the highest accuracy was observed when items were repeated sixteen times. They suggested that the increased repetitions also increase conceptual processing, which directly influences explicit memory. Some models of memory suggest that for every repetition of an item, an additional memory trace is formed within long-term memory (e.g., Hintzman, 1988), or that the original memory trace is strengthened for every subsequent experience of the same item (McClelland & Chappell, 1998). Additional memory traces or the strengthening of the original memory trace is thought to increase the accessibility of that item in memory, allowing it to be better remembered.

In terms of directed forgetting, repetition of items is thought to reduce the degree of *retrieval inhibition* that may occur for words that are initially cued to be forgotten. When participants prevent words from entering memory, as with Forget words, active inhibitory processes may cause a decrease in the overall accessibility of that particular item, leading to poorer memory. Retrieval inhibition has been discussed more in studies using *list-method directed forgetting.* In the list method, participants study two lists of words in succession. After the first list is studied, participants are asked to forget that list, and to only remember the upcoming second list. When memory is tested on both lists, memory is significantly worse for words presented in the first list, but only when memory is tested with free recall. When a recognition memory test is used, the re-presentation of a study item is thought to release inhibition, improving memory (see Bjork, 1989). This effect has also been observed in item-method directed forgetting as well. In Geiselman and Bagheri (1985), participants were given an item-method directed forgetting task to complete, and were given a free recall memory test after the study phase. A general directed forgetting effect was observed in the initial free recall test. After the recall test, participants were given another study list, with some of the words repeated again. They were asked to study all the words, and were given another recall test. They still observed a directed forgetting effect after the second memory test, but performance for the original Forget words improved significantly. They suggested that the repetition of Forget words in the second study list released inhibition that may have blocked retrieval. Repetition of items should serve to improve memory, and should decrease the magnitude of overall directed forgetting effects.

Experiment 2 retains the same item-method directed forgetting design as the previous experiment, but manipulates repetition instead of cue timing. Participants saw some words only once (1x Repetition Condition), and saw other words presented four times (4x Repetition Condition). Repetition should increase the strength of encoded memories. Repetition is thought to increase the degree of rehearsal that occurs for both Remember and Forget words. If the PARLO framework is correct in its assumptions, this increase in maintenance and rehearsal should also significantly increase the accessibility of information stored within the LH, but have little influence for information stored in the RH.

Referring back to the overall PARLO framework and the results from Experiment 1, specific predictions can be made regarding how repetitions will influence overall memory performance in Experiment 2. The repetition manipulation in Experiment 2 should be similar to the Cue Timing manipulation in Experiment 1. It is thought then, that the 1x Repetition Condition should be similar to the Simultaneous Cue condition, while the 4x Repetition Condition should be similar to the Delayed Cue condition. It is predicted that memory accuracy and response times in the LH should mirror the overall results from Experiment 1. Repetition may actually serve to increase maintenance and rehearsal even further, decreasing the overall directed forgetting effect much more in the 4x Repetition Condition compared to the Delayed Cue condition in Experiment 1.

Repetition provides potentially more interesting test of RH verbal memory mechanisms. PARLO specifically states that the RH processes verbal information in a more bottom-up fashion, and stores information in a veridical, (and presumably) non-interfering manner. Repetitions are predicted to increase RH memory performance, but not to the same degree as the LH. Conversely, if the RH can actively utilize repetitions and mirror LH performance, this would rule out an interpretation that the RH operates as a “pure” exemplar-based processor of verbal information. Therefore, two specific hypotheses generated for what may occur in the RH. First, results in the RH may mirror Experiment 1. Repetitions will still influence the RH to some degree, but not to the same extent as the LH. A general directed forgetting effect should be observed for both Repetition Conditions, but they should not greatly differ from one another. Alternatively, repetitions may actually serve to significantly improve RH memory. It has been suggested that the RH stores information in an exemplar-based fashion (Federmeier, 2007; Marsolek, 2004). Evidence suggests that the RH is biased to retain physical aspects of verbal stimulus (e.g., modality of the verbal stimulus, indexical aspects such as printed word form or voice-specific auditory information). Changes in the any physical aspects of a verbal stimulus between study and test has been shown to detrimentally influence RH memory more so than LH memory (e.g., González & McLennan, 2007; Marsolek et al., 1992). In the current study, there is no change in perceptual form for words between study and test. If the RH stores information more episodically, repetitions will cause additional traces of the same word to be encoded into memory. This would increase the availability of items encoded in memory, presumably allowing the RH to access memory traces more easily. Exemplar-based models of memory suggest that this should occur when items are repeatedly encoded in memory (e.g., Hintzman, 1988). If this hypothesis is correct, accuracy and response times should be equivalent across both hemispheres.

Method

Participants.

Fifty undergraduate students from Arizona State University participated in this experiment (25 female, 25 male). Participants were students enrolled in an introductory psychology course, and were given course credit for their participation. All participants were native English speakers, had no history of neurological impairment, and were all right handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). Mean laterality quotient was .77 (range: 0.44-1.00). Participants had normal or corrected-to-normal vision.

Stimuli and Design.

The stimuli used in Experiment 2 were identical to Experiment 1. In Experiment 2, half of the words were repeated once (1x Repetition Condition), while the other half of words was repeated four times (4x Repetition Condition). A total of 96 words were used in the study task. There were 48 Remember words and 48 Forget words. From each of the 48 Remember and 48 Forget words, 24 words were in the 1x Repetition Condition, while the other 24 were in the 4x Repetition Condition.

In the recognition memory task, there were a total of 192 words. Ninety-six of the study words were repeated and were randomly intermixed with 96 new, unrelated words. Of the repeated study words, 48 were Remember words and 48 were Forget words. For each 48 Remember and Forget words, 24 were from the 1x Repetition Condition, and the other 24 were from the 4x Repetition Condition. Half of all words in the memory test were presented in the RVF-LH, and the other half presented to the LVF-RH. All words were counterbalanced across Remember / Forget conditions, 1x and 4x Repetition Conditions, and left / right visual fields at study and test.

Procedure.

The procedure in Experiment 2 was identical to the procedure in the Simultaneous Cue condition in Experiment 1. Participants were told to only remember the words presented in blue, and forget all the words presented in red. Words in the study phase were presented randomly. Participants were not informed of the repetition manipulation in the Experiment 2.

Results

Memory Accuracy.

Mean hit rates for Visual Field, Cue Type, and Repetition conditions are shown in Figure 6. There was a main effect of Cue Type, whereby hit rates for Remember words (M = .80, SE = .021) were higher than hit rates for Forget words (M = .49, SE = .023), [$F(1, 49) = 74.48$, $p < .001$, $\eta_\rho^2 = .60$]. A main effect of Repetition Condition was observed, which suggested that hit rates for words repeated four times (M = .69, SE = .017) was higher than hit rates for words repeated only once (M = .53, SE = .022), [$F(1, 49) = 72.41$, $p < .001$, $\eta_\rho^2 = .60$]. Additionally there was a significant Cue Type X Repetition Condition interaction [$F(1, 49) = 8.24$, $p = .006$, $\eta_\rho^2 = .144$). Pair-wise comparisons suggested that the difference between the 1x Repetition and 4x Repetition Condition was larger for Remember words (<u>1x Condition</u>: M = .629, SE = .028; <u>4x Condition</u>: M = .83, SE = .020; $t(49) = -8.88$, $p < .001$), than for Forget words (<u>1x Condition</u>: M = .44, SE = .026; <u>4x Condition</u>: M = .55, SE = .026; $t(49) = -4.11$, $p < .001$). No other significant main effects or interactions were observed.

A one-way repeated measure ANOVA was conducted on false recognition rates to new words by Visual Field. There was a significant main effect of Visual Field, suggesting that the RVF-LH had higher false recognition rates (M =.27, SE = .023) than the LVF-RH (M =.23, SE =.023), [$F(1, 49) = 11.28$, p =.002, $\eta_\rho^2 = .187$). An additional

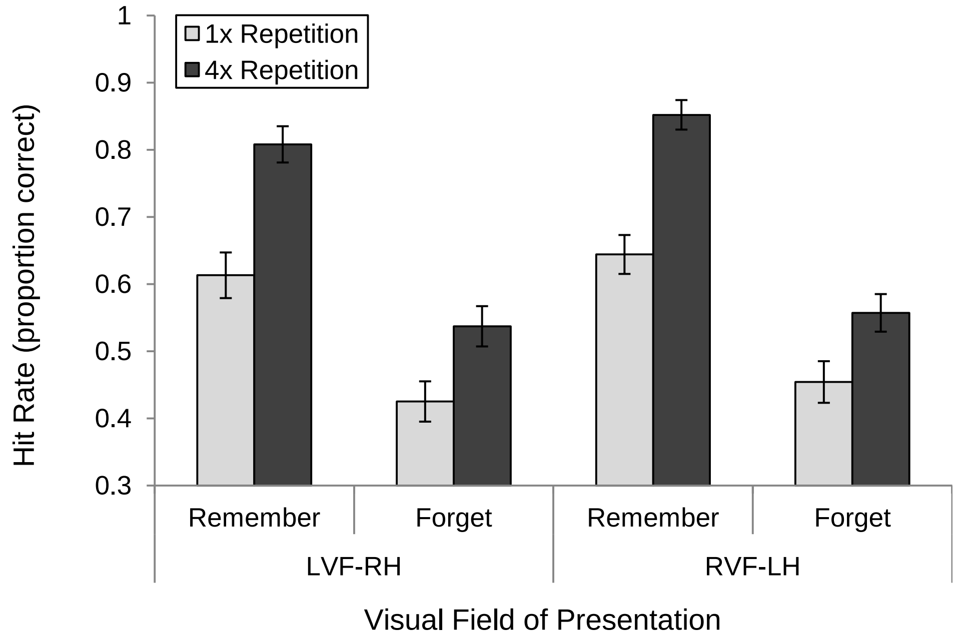

Figure 6. Hit rates for Remember and Forget words in the 1x or 4x Conditions in Experiment 2, by Visual Field of Presentation.

one-way repeated measure ANOVA was conducted on *d'* values by Visual Field. This analysis yielded no significant main effect of Visual Field, suggesting that there was no difference in discrimination for old and new items presented to the LVF-RH (*M* = 1.15, *SE* = .085) and the RVF-LH (*M* = 1.06, *SE* = .085). Finally, a one-way repeated measure ANOVA was conducted on response bias values (*C*) values by Visual Field. This yielded a significant main effect of Visual Field [$F(1, 49) = 7.49$, $p < .009$, $\eta_\rho^2 = .133$], indicating that participants adopted a more conservative response strategy for items presented to the LVF-RH (*M* = .306, *SE* = .062), and a more liberal response strategy for items presented to the RVF-LH (*M* = .185, *SE* = .051). Overall, signal detection analyses replicated what was observed in Experiment 1.

Finally, 2 (Visual Field) X 2 (Repetition Condition) repeated measures ANOVA was conducted on directed forgetting values. A main effect of Repetition was observed indicating that the 4x Repetition Condition (*M* = .28, *SE* = .031) had a larger directed forgetting effect than the 1x Repetition Condition (*M* = .19, *SE* = .033), [$F(1, 49) = 8.24$, $p = .006$, $\eta_\rho^2 = .144$]. No significant Visual Field X Repetition Condition interaction was observed, suggesting no hemispheric specific effects for directed forgetting magnitudes.

Correct Response Times.

Mean response times are shown in Figure 7. A 2 (Visual Field) X 2 (Cue Type) X 2 (Repetition Condition) repeated measure ANOVA was conducted on response times to hit rates. A significant main effect of Cue Type was observed, indicating that Remember words (*M* = 719, *SE* = 29) were responded to more quickly than Forget words (*M* = 853, *SE* = 46), [$F(1,49) = 26.69$, $p < .001$, $\eta_\rho^2 = .353$]. There was a significant main effect of Repetition Condition, suggesting that words repeated four times (*M* = 756, *SE* = 34) were responded to more quickly than words repeated only once (*M* = 816, *SE* = 41). No other significant main effects or interactions were observed.

While the three-way interaction was not observed in Experiment 2, separate 2 (Cue Type) X 2 (Repetition Condition) repeated measure ANOVAs were conducted for data within each Visual Field. This was done to probe for any possible statistical trend that might indicate hemispheric differences in the RT data for Experiment 2. In the LVF-RH, there were significant main effects for Cue Type [$F(1, 49) = 12.66$, $p = .001$, $\eta_\rho^2 = .205$], and Repetition Condition [$F(1, 49) = 10.53$, $p = .002$, $\eta_\rho^2 = .177$]. Pair-wise comparisons revealed that Remember words in the 4x Repetition Condition (*M* = 680, *SE*

= 33) were responded to more quickly than in the 1x Repetition Condition (*M* = 792, *SE* = 41). There was no significant difference between Forget words in the LVF-RH. In the RVF-LH, there was only a significant main effect of Cue Type [$F(1, 49) = 18.07$, $p < .001$, $\eta_\rho^2 = .270$]. While no other effects were reliable, there was a marginal trend towards a Cue Type X Repetition Condition interaction [$F(1, 49) = 2.71$, $p = .106$, $\eta_\rho^2 = .053$]. While the observed effect is small, it bears mentioning as it trends in the opposite direction compared to RVF-LH RTs in Experiment 1. Pair-wise comparisons show that responses for Remember words in the 4x Repetition Condition (*M* = 663, *SE* = 31) were quicker than responses in the 1x Repetition Condition (*M* = 739, *SE* = 39), $t(49) = 2.46$, $p = .018$. Conversely, responses for Forget words in the 1x Repetition Condition (*M* = 829, *SE* = 54) and the 4x Repetition Condition (*M* = 858, *SE* = 57) were not significantly different, $t < 1$, p > .1. Repetition influences remembering and forgetting in the hemispheres differently than the Cue Delay manipulation in Experiment 1. Finally, the same directed forgetting analyses from Experiment 1 were also conducted in Experiment 2 to verify the original RT data analyses. Directed forgetting RT magnitudes are shown in Figure 8. No significant main effects or interactions were observed. Pair-wise t-tests replicated the previously mentioned 2 (Cue Type) X 2 (Repetition Condition) analyses. Specifically, there was no significant difference between directed forgetting effects in the LVF-RH, but a marginal trend was observed in the RVF-LH, $t(49) = -1.64$, $p = .106$.

Discussion

In Experiment 2, participants were again cued to remember or forget certain words in a study list. Instead of manipulating Cue Timing, each item was only repeated

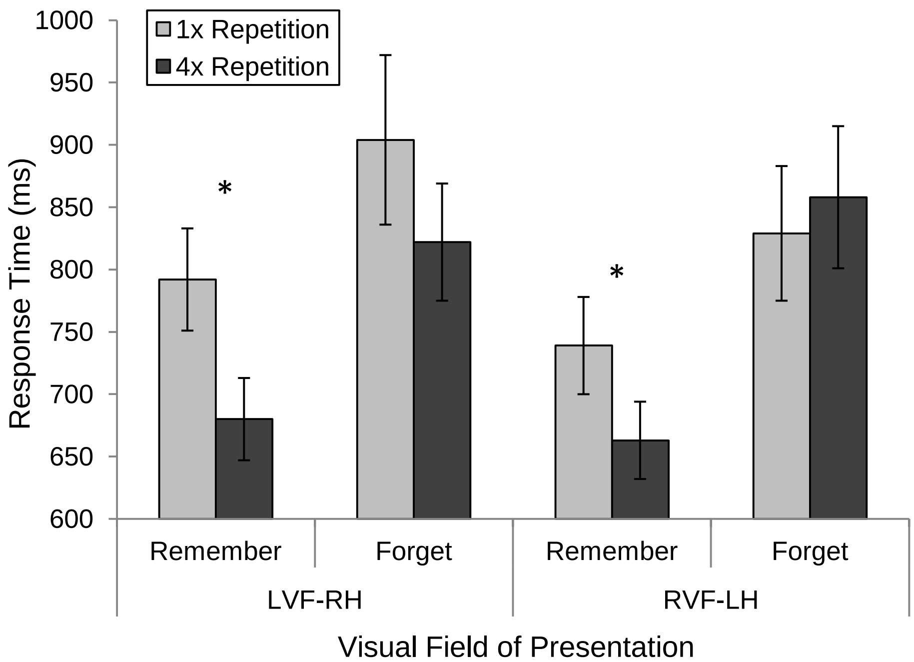

Figure 7. Response times for Remember and Forget word hit rates in Experiment 2, by Visual Field of presentation. Error bars reflect standard errors. * Denotes sig. difference between Repetition conditions

once (1x Repetition Condition) or four times (4x Repetition Condition). It was hypothesized that these two conditions should provide converging evidence that the LH is more able to use maintenance and rehearsal mechanisms. The manipulation of repetition should provide additional support for the data observed in Experiment 1.

In terms of hit rates, repetition was able to improve memory performance overall. Hit rates for words repeated four times was significantly higher than hit rates for words repeated once, regardless if it was a Remember or Forget word. Hit rates also revealed a second interesting result: Repetition seemed to greatly influence Remember words, but performance for Forget words did not approach the same level of improvement. Similar to Experiment 1, no hemispheric differences was observed for the directed forgetting

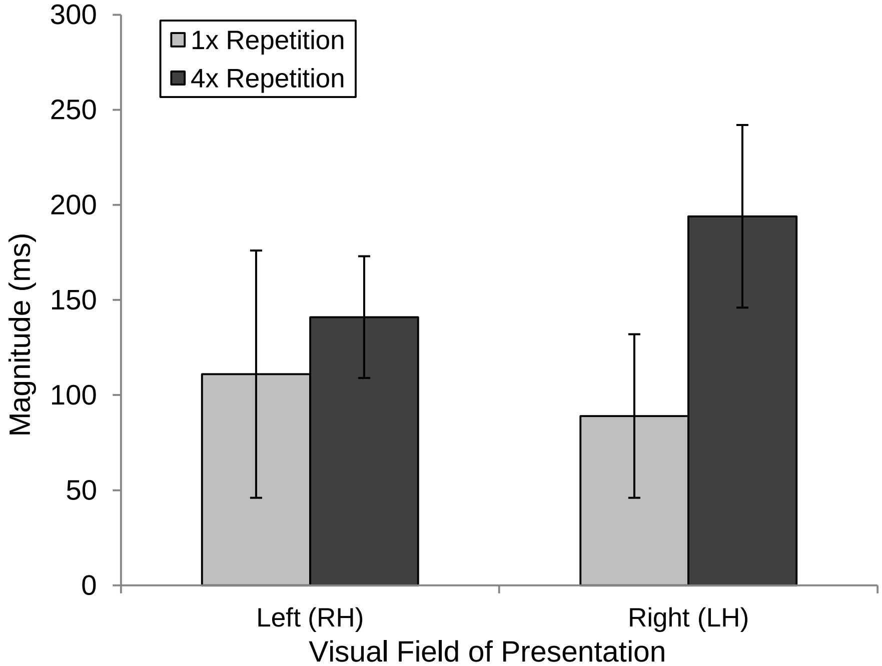

Figure 8. Magnitude of the directed forgetting effect for response times in Experiment 2, by Visual Field of Presentation and Repetition condition. Magnitude represents response times for Forget words subtracted by response times for Remember words. Error bars represent standard errors.

effect. Signal detection analyses also mirror results from Experiment 1, verifying that there is some level of consistency between Experiments 1 and 2. Like Experiment 1, hit rates in Experiment 2 do not help to confirm or reject any of the initial predictions. Hit rates do help clarify hypotheses regarding the RH. It was initially unclear if the RH could make use of repetitions of words. The results from Experiment 2 clearly show that the RH benefits from repetition of words, nearly to the same degree to as the LH.

Response times in Experiment 2 also did not reveal any significant hemispheric differences, but did provide interesting trends that were not observed in Experiment 1. With regards to repetition, Remember word response times mirror Remember word hit rates (faster RTs, higher hit rates). Remember words repeated once are retrieved more slowly than Remember words repeated four times. In contrast, Forget word response times are statistically equivalent across Repetition Conditions *and* across hemispheres. Even more surprising, Forget word response times do not replicate Experiment 1 response time data, and actually trend in the opposite direction. If the 4x Repetition Condition was similar to the Delayed Cue condition in Experiment 1, Forget words in the 4x Repetition Condition should be retrieved just as quickly as Remember word in the LH. Data from Experiment 2 clearly suggest that repetition does not engage maintenance and rehearsal mechanisms in the same way that Cue Timing did in Experiment 1.

General Discussion: Experiments 1 and 2

Experiments 1 and 2 examined hemispheric differences in item-method directed forgetting. In Experiment 1, participants were asked to remember or forget items as soon as a cue appeared on the computer screen, or after the presentation of the study item. In Experiment 2, participants were still cued to remember or forget words, but some words were only presented once, while other words were presented four times. Data from Experiment 1 suggested that the LH was able to use Cue Timing to influence how Forget words were encoded into memory. In contrast, Experiment 2 showed that Repetition does not influence maintenance and rehearsal in the same was as Cue Timing.

With regards to data in Experiment 1, a potential explanation for the improvement for Forget word RT is that the LH is better able to utilize active maintenance and rehearsal processes. This improvement in Forget word RT translated into large differences in the directed forgetting effect in the LH. Experiment 1 response time data potentially elucidate PARLO's assumptions regarding hemispheric differences in processing. These response times suggest that the LH can readily use top-down mechanisms, like maintenance and rehearsal, to strengthen encoded verbal information in the LH. As PARLO suggests, the LH received additional top-down feedback from higher processing levels due to more efficacious language production mechanisms. This idea is supported, as verbal rehearsal mechanisms influence LH encoding more than RH encoding. In general, Cue Timing did not influence the encoding of verbal information in the RH, and did little to increase (or decrease) the overall directed forgetting effect for RTs. This provides support for the idea that the RH processes information in a more bottom-up manner, and possibly suggests that memory representations in the RH are maintained in more of an exemplar-based manner (though not as a *pure* exemplar-based manner as data from Experiment 2 would suggest).

With regards to Experiment 2, Repetition did not influence response times in the same way that Cue Timing did in Experiment 1. As suggested before, repetition should decrease response times. If inhibition is occurring for Forget words, every repetition should decrease the amount of inhibition for that word, increasing its accessibility overall (Basden et al., 1993; Bjork, 1989). The findings in Experiment 2 are counter-intuitive to this idea: more repetitions for Forget words *increased* retrieval inhibition during the memory, specifically for Forget words in the LH. There appeared to be similarities between the Cue Timing variable in Experiment 1, and the Repetition variable in Experiment 2. On closer examination, the mechanisms that operate for each variable are slightly different. In the Delayed Cue condition of Experiment 1, participants rehearse words until they receive a cue, then rehearse it further (Remember cue) or attempt to suppress it (Forget cue). With repetition, participants solely engage in remembering or forgetting, regardless how many times a word is repeated. In the 4x Repetition condition, Remember words are rehearsed for a total of four times, while Forget words are suppressed or inhibited four times. In this way, the 4x Repetition Condition does not mimic the Delayed Cue condition, because participants are not verbally rehearsing words that are repeated (or just rehearsing them very minimally). What is likely occurring is that participants are devoting most of their attention to ignore Forget words. Inhibition is not released because participants do not attempt to actively rehearse Forget words with every presentation. This potentially explains why Forget word response times in the LH are statistically equivalent. Unlike in Experiment 1, accessibility for Forget words is not made any easier, although repetition does increase identification to a certain degree.

Response times from Experiment 2 also confirm a general conclusion made from Experiment 1: Inhibition does not preferentially influence one hemisphere over another. This helps clarify what is meant by “top-down mechanisms” within the PARLO framework. While maintenance and rehearsal are inherently verbal (in the context of these experiments), inhibition seems to be a more domain-general cognitive mechanism. While inhibition has been shown to be more right lateralized (Aron et al., 2004), there has been no indication to suggest that inhibitory mechanisms should solely influence information processing that occurs in the RH. Indeed, more complex tasks tapping into domain general executive processes tend to elicit more bilateral prefrontal activation, suggesting that these constructs operate over the cerebral hemispheres more generally (for a review, see Kane & Engle, 2002). Top-down mechanisms posited by PARLO are likely to be more verbal or language specific processes. Additional imaging evidence has demonstrated that verbal rehearsal engages left frontal regions of the cortex. This is most commonly seen in working memory tasks requiring the continuous rehearsal of items (Awh et al., 1996; Smith, Jonides, & Koeppe, 1996; see also Wager & Smith, 2003).

There a few potential limitations to these first initial experiments. These data do not necessarily speak to top-down mechanisms that operate specifically within each hemisphere. It has been suggested that centralizing the presentation of study items biases processing differently compared to when study items are lateralized (Evans & Federmeier, 2009). Recall the continuous recognition memory studies by Benjamin et al. (2005) and Evans et al. (2007). In these studies, study items were lateralized, and test items were presented centrally. Data from these studies reveal hemispheric specific effects for verbal memory. Conversely, Evans et al. (2010) centralized the presentation of study items, and lateralized memory test probes. In their behavioral data, memory accuracy and RTs favored the RVF-LH. However, ERPs revealed only a difference in the P2 component (favoring the LVF-RH), but not any other ERP components. The authors suggested that the P2 component reflected the ability for the RH to apprehend perceptual forms of words. Null effects for all other ERP components suggest that centralizing presentation of study items causes bilateral cooperation of memory encoding, also leading to representations that are more bilaterally distributed across hemispheres.

However, it is still unclear how these methodological factors influence what type of information is encoded in the cerebral hemispheres. Evans et al. (2009) noted that lateralizing study items inherently biases encoding for words presented to the RVF-LH. The beginnings of words are seen more clearly when presented to the RVF-LH. This is thought to facilitate lexical processing of words, compared to the LVF-RH, where only the ends of words are seen (Jordan, Patching, & Thomas, 2003). Evans et al. (2009) suggest that some of the results seen in prior continuous recognition memory studies (with lateralized study items) could be due to simple perceptual biases that influence the initial encoding of words. Experiments 1 and 2 (and all following studies) centralized presentation of study items as a methodological choice: if perceptual biases influence encoding, the results from a later memory test could be confounded by those biases. The exact differences between lateralizing study items and lateralizing test probes is still unclear. Several hemispheric verbal memory studies have centralized study items and lateralized test probes, and have observed hemispheric asymmetries in memory (Bellamy & Shillcock, 2007; Ben-Artzi et al., 2009; Faust et al., 2008; Giammattei & Arndt, 2012; Ito, 2001; Westerberg & Marsolek, 2003). Additional studies are necessary to examine potential differences in methodologies. Within Experiments 1 and 2, lateralizing Remember and Forget words during study may reveal a different pattern of results. For example, Remember words presented to the RVF-LH may be rehearsed and Forget words inhibited more effectively (as per PARLO assumptions). Conversely, imaging data suggests that inhibitory mechanisms are more right lateralized. Forget words may actually be inhibited more effectively by the LVF-RH. Additional studies lateralizing study items may further elucidate the nature of how top-down mechanisms operate within (and between) each cerebral hemisphere.

Other methods may provide more insight to top-down mechanisms and their influence on the cerebral hemispheres. Experiments 3 and 4 examine verbal memory in the cerebral hemispheres using the well-known Deese-Roediger-McDermott false memory paradigm (Roediger & McDermott, 1995). Most hemispheric false memory studies interpret their findings within the Fine Coarse Semantic Coding Theory. FCT poses more of a spreading activation based explanation for hemispheric asymmetries in false memories. However, general theoretical frameworks of false memory also suggest that the ability to *monitor* information plays a role in the susceptibility or resistance of false memory errors (Brainerd, Reyna, & Kneer, 1995; Roediger, Watson, McDermott, & Gallo, 2001). Experiments 3 and 4 further explore hemispheric asymmetries in false memory, and test whether there are potential hemispheric differences in the use of monitoring processes to mitigate false memories.

The Influence of Cognitive Load on Hemispheric True and False Memories

Hemispheric Asymmetries in False Memory

Verbal memory in the cerebral hemispheres has been predominately studied by using variations of the well-known Deese-Roediger-McDermott (DRM) false memory paradigm (Roediger & McDermott, 1995). Recall that in the DRM paradigm, participants study lists of related words (e.g., *nurse, sick, medicine, hospital*, *dentist*), then are tested on studied old words (e.g., *hospital*) and unstudied critical lure words (e.g., *doctor*). The majority of these studies have used the Fine Coarse Semantic Coding Theory (FCT) as a guiding framework for the interpretation of their results. More narrow, focal semantic fields in the LH are less likely to overlap with critical lure representations, and are less likely to activate it. Fine coding in the LH should lead to fewer false memory errors. Conversely, broader semantic fields in the RH are more likely to overlap with the critical lure representation, and are more likely to activate it. This would lead to greater false memories in the RH. Three particular studies used designs that closely mirror the original

Roediger and McDermott (1995) study. In a study by Ito (2001), participants studied Japanese word lists, and were tested on old words, new highly related critical lure words, and unrelated new words. Ito found that the LH was better able to discriminate between lure words and unrelated new words compared to the RH. One caveat was that these differences were attributed to higher hit rates in the LH, rather than false memory differences (though results were still interpreted using FCT). Another caveat was that only Japanese speakers were used. Westerberg and Marsolek (2003) conducted a hemispheric DRM study with English speakers. Their results found that false memory errors were indeed higher in the RH compared to the LH, as FCT would predict. Bellamy and Shillcock (2007) conducted a replication of these experiments, which mirrored Westerberg et al.'s results.

Other studies have used unique variations of the DRM paradigm to test specific aspects of FCT. Faust, Ben-Artzi, and Harel (2008) were interested in determining if the cerebral hemispheres differed in false memory errors when word lists were biased for a dominant meaning lure or a subordinate meaning lure. Results showed that memory errors were higher in the LH for word lists biased for dominant meaning lures, while memory errors were higher in the RH for word lists biased for subordinate meaning lures. These data supported the assertion of FCT that suggests that the LH only processes the most relevant conceptual information, while the RH processes less contextually relevant conceptual information. In a related study, Ben-Artzi, Faust, and Moeller (2009) examined if the hemispheres differed in false memory errors when words were presented as short passages versus traditional word lists. In their experiment, short passages were constructed such that they contained a set of related words. The authors were interested in the role of RH in discourse processing. Studies have suggested that the RH plays a critical role in discourse processing, specifically bridging gaps in discourse (e.g., Beeman, Bowden, Gernsbacher, 2000). They predicted that when related words were presented as a short passage, the RH would elicit more memory errors during the memory test. Results supported their prediction. The RH elicited more memory errors in conditions where words were studied as short passages *and* traditional word lists. Again, these results were thought to support FCT by suggesting that the locus of activation in the RH is much broader, which causes more memory errors to occur in the RH.

There have been a few discrepancies in this literature where FCT is unable to account for false memory effects. Specifically, a few studies have found that the LH actually has higher rates of false memory errors. In a split brain study, Metcalfe, Funnell, and Gazzaniga (1995) discovered that false memories were higher in the RH compared to the LH. In an ERP study by Fabiani, Stadler, and Wessels (2000), their behavioral data showed that false memory effects were more evident in than in the LH than in the RH. However, these studies used lateralized presentation of study items, while other studies presented items centrally, and tested memory using the lateral presentation of probes. As discussed previously, it is unclear how encoding or retrieval mechanisms differ when study or test probes are lateralized.

Activation-Monitoring Framework

A drawback of FCT is that it does not propose any active cognitive processes that may influence the susceptibility of false memory errors. FCT would suggest that hemispheric asymmetries in false memory errors occur due to differences in how activation is spread through semantic networks. However, it is known that other cognitive mechanisms play a role in the susceptibility of false memories. Outside of the hemispheric asymmetry literature, false memory studies have been interpreted using the *Activation-Monitoring* framework (Roediger et al., 2001). This theoretical framework proposes that two components during encoding and retrieval influence the probability of a false memory occurring. The first of these components is *activation*. This component is very similar to the concept of spreading activation proposed by other theories of semantic processing (Collins & Loftus, 1975; Meyer & Schvaneveldt, 1971; Morton, 1969). For example, when studying a list of related words (e.g., *nurse, sick, medicine, hospital, dentist*), activation spreads across all associations that may be strongly (or weakly) related. This activates a concept that an individual may have never encountered initially (e.g., *doctor*). Activation is thought to be both automatic and controlled, and there is some evidence that individuals may consciously generate associations when studying lists of related words (McDermott, 1997).

The second component, *monitoring*, refers to the ability to keep track of information that becomes activated during the course of processing. The idea of monitoring is heavily based on the source-monitoring framework proposed by Johnson, Hashtroudi, & Lindsay (1993). The source-monitoring framework suggests that stored memories can contain basic perceptual information (e.g., color, size), spatial information (e.g., location of something in a room), temporal details (e.g., day of the week), semantic information (e.g., category membership, item associations) and cognitive operations that occurred during the encoding of a specific memory. All this provides specific information to separate out events in encoded in memory, and is used to recall specific *source* of a memory (e.g., *I watched an episode of that TV show last Tuesday*). In terms of DRM studies, participants must be able to monitor the activation of items they actually studied (usually referred to as *veridical* memory) and activation of self-generated items they never actually experienced before (*false* memory). Monitoring of information has been implicated in encoding, but is primarily invoked during retrieval. For example, when participants are explicitly warned that they will be tested on words they never studied, false memory errors are reduced relative to when participants are not explicitly warned (e.g., Gallo, Roberts, & Seamon, 1997; Gallo, Roediger, & McDermott, 2001). Warnings are thought to engage monitoring processes more strongly during encoding, allowing individuals to better distinguish between true and false memories, leading to fewer false memory errors. In terms of memory retrieval, participants must be able to distinguish between true (*veridical*) and false memories. The ability to recall item-specific information aids individuals in the rejection of false memory lures. If they are unable to recall the context of the list items they studied (or if there is a great deal of semantic overlap between items), it becomes more difficult to distinguish between true and false memories. This monitoring process has been shown to be influenced by variables like item distinctiveness, item repetition, repeated study / test opportunities, and response deadlines. For example, if a critical lure is more distinctive than the list of items it is associated with, participants are more likely to reject the lure item (e.g., Gallo, McDermott, Percer, & Roediger, 2001). When pictures are used instead of words, false recognitions are significantly reduced, as pictures are more distinctive than words and are easier to recollect (Schacter, Israel, & Racine, 1999). Increased item repetition or study / test opportunities also serve to increase distinctiveness of encoded memories, reducing false memory errors (McDermott & Watson, 2001; McDermott, 1997; Toglia, Neuschatz, & Goodwin, 1999). Additionally, if participants are given more time to search memory prior to a memory response, they are more likely to reject a critical lure (e.g., Heit, Brockdorff, & Lamberts, 2004). Longer response deadlines allow more time for individuals to accurately reinstate source information.

In terms of hemispheric frameworks, FCT does not posit any type of active or controlled monitoring mechanisms during semantic processing. However, the Production Affects Reception in the Left Only framework (PARLO) arguably fits better within the general Activation-Monitoring framework. Recall that PARLO suggests the LH is more able to use top-down mechanisms during the course of semantic processing. If this is the case, studies that find reduced false memory errors in the LH could be accounted for by more efficient maintenance and monitoring employed by the LH. Greater false memory errors in the RH are simply due to the fact that the RH does not engage in either of these processes as actively. In addition to this, neuro-imaging studies support these assertions. Evidence suggests that left prefrontal cortex is more active when individuals engage in source monitoring (Dobbins, Simons, & Schacter, 2004). In contrast, the RH may rely on familiarity more when making memory decisions (Mitchell & Johnson, 2009).

Experiment 3: The Effect of Cognitive Load on Hemispheric True and False Memory during Encoding

One way to examine potential hemispheric asymmetries in activation and monitoring is by employing dual task or cognitive load manipulations. Cognitive loads are thought to disrupt ongoing controlled processes that influence memory encoding and retrieval. Cognitive load manipulations have been shown to decrease memory performance. For example, in Kane and Engle (2000), participants were asked to study a list a words without a secondary task, or were asked to do a complex finger tapping task while studying words. Participants (specifically individuals with higher working memory) showed decreases in memory performance when they were asked to study words while doing complex finger tapping. In Fernandes and Moscovitch (2000), participants studied an initial list of words. After, they listened to a second list of words; but were probed for their memory of the first list simultaneously. Not surprisingly, participants performed significantly worse on the subsequent memory test, as the cognitive load manipulation interfered with their ability to encode words. More recently, Knott and Dewhurst (2007a) found that Remember-Know memory judgments were disrupted when participants had to study words under cognitive load.

One study has specifically examined the influence of cognitive load on the susceptibility of false memories. Knott and Dewhurst (2007b) examined cognitive load and dual task manipulations during memory encoding and retrieval. During encoding or retrieval, participants were asked to generate a random number every 750 ms (denoted by a metronome within the experiment). Results showed that hit rates to old words and false recognition rates to critical lure words decreased when secondary tasks were given both at encoding and retrieval. The secondary task had a larger effect on encoding than retrieval. The authors suggested that a sufficiently difficult secondary task during memory encoding prevents participants from generating related associates, and reduces the spread of activation for old words and lure words. During memory retrieval, a secondary task selectively disrupts source monitoring processes, causing more difficulty distinguishing between studied items, and self-generated items (i.e., lure words).

The primary goal for Experiment 3 is to determine if cognitive load causes greater disruptions to LH verbal memory, or RH verbal memory. In Experiment 3, participants studied lists of related words and were tested on their memory for old words, critical lure words, and completely unrelated new words. Specifically, there were three study-test blocks. Each block consisted of a different secondary task a participant had to complete during memory encoding. Participants either completed a task that involved keeping track a set of digits on every trial (*Verbal Task* condition), keeping track of the orientation of a shape (*Visual Task* condition), or did not have to complete a secondary task at all (*Baseline Task* condition). If the cerebral hemispheres use top-down mechanisms differently, cognitive loads that disrupt these mechanisms should also influence memory performance differently across hemispheres.

Following the PARLO and Activation-Monitoring frameworks, cognitive load manipulations should have a greater influence on verbal memory in the LH compared to the RH. PARLO suggests that the LH able to process semantic information in a more controlled manner. Cognitive load manipulations should minimize the generation of related associates during encoding, which should impact LH verbal memory more than RH verbal memory. Similar to the results in Knott and Dewhurst (2007a), secondary tasks should reduce both hit rates for old words and false recognitions to new words in the LH. Cognitive load manipulations should disadvantage monitoring processes used by the LH as well. They will disrupt the encoding of item specific information, making it more difficult to reinstate it during memory retrieval. This would make it more difficult for the LH to monitor activations between old and critical lure words during the memory test. In contrast to the LH, PARLO suggests RH does not strongly engage in maintenance and monitoring processes, and relies more on the spread of activation to access semantic information. Secondary tasks used in Experiment 3 should only disrupt the spread of activation in the RH. Based on these ideas, memory performance in each secondary task condition, relative to performance in the Baseline Task condition, should differ by hemisphere. In the LH, hit and false recognition rates should be reduced more in the Verbal / Visual Task conditions, relative to the Baseline Task condition. In contrast, and the difference between Baseline and Verbal / Visual Task conditions should be smaller in the RH. A decline in hit rates and false recognition rates should be observed in the RH as well, but to a smaller degree compared to the LH.

The different cognitive load manipulations were included to test a secondary hypothesis. Some neuro-imaging evidence has shown that left and right prefrontal areas are biased to process material-specific information. Left prefrontal areas are shown to have greater activity when processing and encoding verbal materials, while right prefrontal have greater activity when processing visuo-spatial information (Kelley et al., 1998; Lee, Robbins, Pickard, & Owen, 2000; Wagner & Poldrack, 1998). In contrast, other imaging studies show that prefrontal areas do not specialize in a material specific processing. Rather, the left prefrontal cortex has been shown to be more active during memory encoding, and the right prefrontal cortex has been shown to be more active during memory retrieval (Habib, Nyberg, & Tulving, 2003; Nyberg, Cabeza, & Tulving, 1996). If there is material specific dissociation between hemispheres, the Verbal Task condition should cause greater disruptions to LH memory, while the Visual Task condition causes greater disruptions to RH memory. If there is not a material specific dissociation between hemispheres and the LH is more involved during memory encoding, both secondary tasks should disrupt the LH more than the RH.

Method

Participants.

Seventy-six undergraduates (41 male, 35 female) from Arizona State University participated in this experiment. Participants were students enrolled in an introductory psychology course, and were given course credit for their participation. All participants were native English speakers, had no history of neurological impairments, and were right handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). Mean laterality quotient was .83 (range: 0.55-1). All participants had normal or corrected-to-normal vision.

Stimuli and Design.

Study Phase.

A total of 36 related word lists were used in Experiment 3. All word lists were taken from previously established false memory norms (Roediger et al., 2001; Stadler, Roediger, & McDermott, 1999). Each individual word list consisted of 15 total items (e.g., *nurse, sick, lawyer, medicine, health*), and were all related to a critical lure word that was never studied (e.g., *doctor*). Items within each list were organized in terms of associative strength, the first item in each list had the strongest association with the critical lure word, and the last item had the weakest association. In this experiment, only the first 12 words were used in each list. In total, there were 432 used in the study phase of the experiment.

The 36 word lists used in the study phase were divided into three blocks of 12 lists each (or 144 words per block). See Appendix B for the word lists used in Experiment 3. Each block was associated with a different secondary task. There were 12 word lists in the *Baseline Task* block, 12 word lists in the *Verbal Task* block, and 12 word lists in the *Visual Task* block. The lists in each block were roughly equated in terms of average mean backwards associative strength (as defined by Roediger et al., 2001). Word lists were pseudo-randomly placed within each study block. Additionally, word lists were completely counter-balanced across blocks, such that each word list would appear in once in every block.

Recognition Memory Test.

There were a total of 144 target words used in the memory test phase. Memory test words were divided into three blocks (corresponding to which secondary task was completed in that block), with 48 words per block. From these 48 words, 12 were unstudied critical lure words corresponding to each related word list (e.g., *doctor*). Another 12 were studied old words, always sampled from position 3 in each word list (e.g., *lawyer*). The last 24 words were completely unrelated new words taken from un-used word lists (e.g., *net*).

Procedure.

Participants were tested in pairs. They were seated approximately 50 cm in front of 15 inch CRT computer monitors. Presentation of the stimuli were controlled by E-prime 1.2, software that collected accuracy and response time data (Schneider et al., 2002). An illustration of the study phase procedure is in Figure 9.

Participants were told that they would be studying lists of words, and that they should remember words as best as they can for a later memory test. Additionally, they were told while studying words, they would occasionally have to complete a simultaneous secondary task. They were encouraged to do their best to complete the secondary task, but were instructed that studying words for the later memory test was their primary goal. Prior to the actual experimental tasks, participants practiced each task to become more familiar with them.

Participants completed three study-test phase blocks. For each block, there was a different secondary task during the study phase. In the *Baseline Task* block, words were presented for 2000 ms each. Participants were told to press the Space Bar as they saw each word on the screen. After the presentation of the word, feedback was presented for 500 ms. A 1000 ms ISI occurred after the feedback was presented. There was no secondary task during the Baseline Task block, and participants were simply told to press the Space Bar for each word that appeared on the screen (in order to make sure they were attending to the task). The *Verbal Task* block was the similar to the Baseline Task block, however, individual numbers would appear below each word (always 1-9)[2]. There was

[2] Traditional short-term memory tasks, such as the Digit Span Task, use numbers to tap into verbal abilities. It is thought that in a Digit Span Task, participants verbally rehearse digits. This same logic was applied to the design of the Verbal Task in Experiment 3.

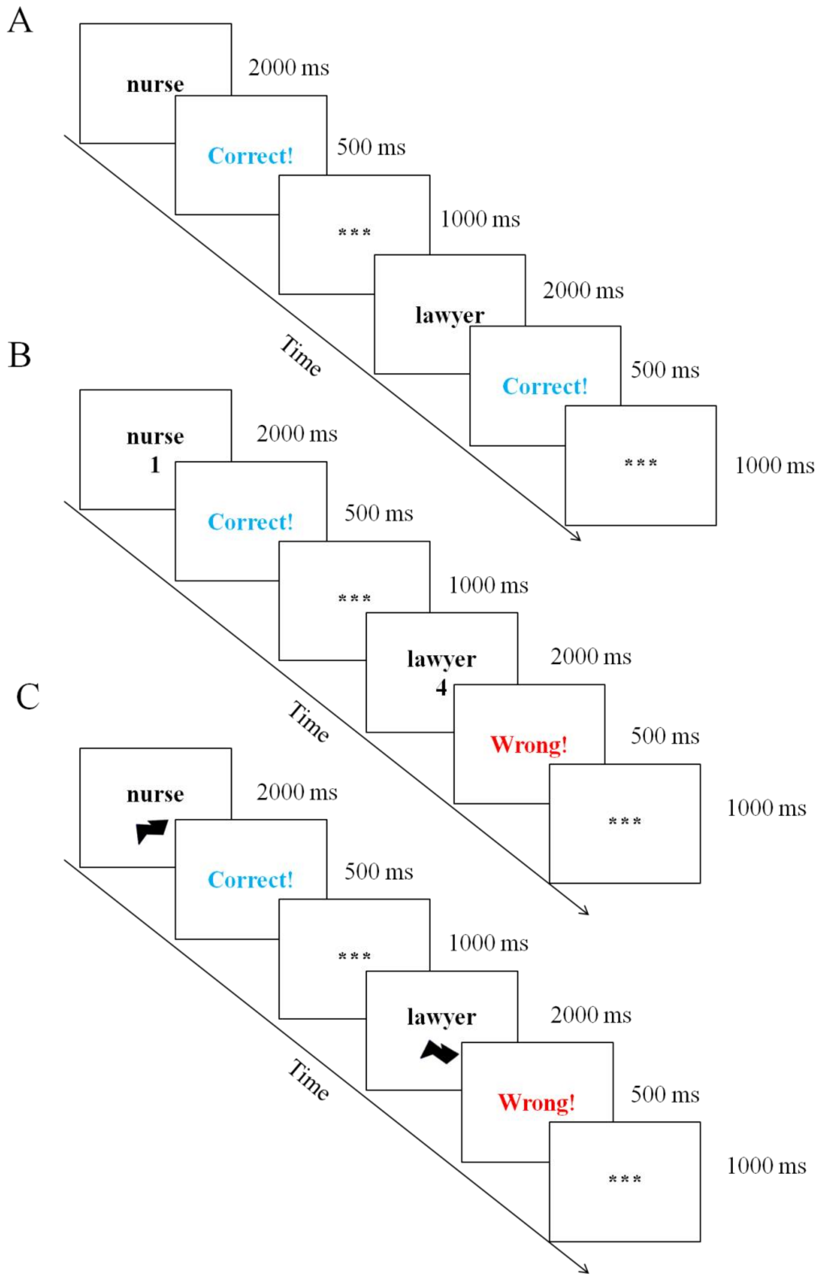

Figure 9. Experiment 3 general study phase procedure for the Baseline Task (A) and the Verbal Task (B) and the Visual Task (C).

always a different number on every trial. Participants were instructed that they had to decide if the number below each word was *higher* or *lower* than a number they saw on the previous study trial. If the number was higher, they were told to press a key labeled "Hi" on the keyboard. If the number was lower, they were told to press a key labeled "Lo". Participants only had 2000 ms to respond to each number, and were instructed to do their best to respond as quickly as possible. In the *Visual Task* block, instead of making decisions to numbers, participants made decisions to the orientation of an abstract shape[3]. Instead of seeing a number below each word, a shape would appear below each word. On each trial, the shape would always appear to be rotated in a different orientation. There were 8 different rotated orientations, with the shape rotated in 45° increments. Shapes never were rotated any more than 90° clockwise (right) or counter-clockwise (left) from trial to trial. Participants were asked to decide if the current shape on the screen was rotated to the left, or the right of the shape on the previous trial. Participants had 2000 ms to respond to each shape, and were instructed to do their best to respond as quickly as possible. Feedback for each trial was given after each decision was made, and was displayed for 500 ms. After receiving feedback, a 1000 ms ISI occurred, followed by the next study trial. Accuracy for all responses was recorded. The presentation of word lists in each study phase organized in a pseudo-randomized fashion. Words within each list were organized in order of associative strength to the critical lure word (strongest to weakest). Following each study phase, participants were given distracter task which consisted of a set of 20 math problems. They were asked to determine if the equation on the screen was correct or incorrect by pressing keys labeled "YES" or "NO".

[3] The Visual Task was modeled after Rotation Span Task from Shah and Miyake (1996), and is thought to tap into more visuo-spatial working memory abilities.

Following the distracter task, participants were tested on their memory for words, using divided visual field presentation. During the memory test, participants were asked to place their heads on a chinrest that was placed in front of them. They were instructed to keep their eyes focused on a central fixation point that appeared throughout the memory test. Timing and presentation of the fixation point and presentation of the probe words was identical to Experiments 1 and 2. Probe items in the memory test were randomly ordered. Finally, study-test blocks were also randomly ordered for each participant.

Results

Secondary Task Performance.

A one-way repeated measures ANOVA was conducted on overall accuracy for each Task Type (Baseline, Verbal, and Visual). There was a significant main effect of Task Type, which suggested that the highest accuracy was observed in the Baseline Task (M =.95, SE = .007), followed by the Verbal Task (M = .89, SE = .009), and lowest the Visual Task (M = .74, SE = .015), [$F(2, 150) = 149.07$, $p < .001$, $\eta_{\rho}^2 = .665$]. All pair-wise comparisons between tasks were significantly different (all ps < .001).

Omnibus Memory Accuracy.

Hit rate and false recognition data were analyzed for Experiment 3. Primary analyses of interest focused on the proportion of “old” responses for Old words, Critical Lures, and Unrelated New words. Old responses to Old words are considered a correct response, while old responses to Critical Lure and Unrelated New words are considered "false recognitions". See Figure 10 for proportion of old responses by Visual Field, Task Type and Item Type. An omnibus 2 (Visual Field: Left, Right) X 3 (Task Type: Baseline, Verbal, Visual) X 3 (Item Type: Old, Critical Lure, New) repeated measures ANOVA was conducted on the proportion of old responses for Old words, Critical Lure words, and Unrelated New words. This yielded a significant main effect of Visual Field, where the proportion of old responses was higher in the RVF-LH (*M* =.51, *SE* = .015) compared to the LVF-RH (*M* = .46, *SE* = .015). There was also a main effect of Item Type, indicating that the proportion of old responses to Old words (*M* = .59, *SE* = .015) was higher than the proportion of responses to Critical Lures (*M* = .55, *SE* = .019) and Unrelated New words (*M* =.31, *SE* = .019). Pair-wise comparisons[4] between Item Types supported this assertion (Old vs. Critical Lure: $t(75) = 2.81$, $p = .006$; Old vs. New: $t(75) = 13.72$, $p < .001$; Critical Lure vs. New: $t(75) = 13.64$, $p < .001$). No other main effects were statistically significant. A significant Task Type X Item Type interaction was observed [$F(4, 300) = 14.37$, $p < .001$, $\eta_\rho^2 = .161$]. All pair-wise comparisons between Old, Critical Lure, and New words were significantly different in the Baseline Task condition (*p*s < .001). In Verbal and Visual Task conditions, only comparisons between Old / New words, and Critical Lure / New words were significantly different (*p*s < .001).

There was also a significant Visual Field X Task Type X Item Type interaction [$F(4, 300) = 3.34$, $p = .011$, $\eta_\rho^2 = .043$]. To investigate the nature of this interaction, individual 2 (Visual Field) X 3 (Task Type) repeated measure ANOVAs were conducted on the proportion of old responses to Old words, Critical Lures, and Unrelated New

[4] All pair-wise comparisons used a Bonferroni corrected alpha (*p* = .016)

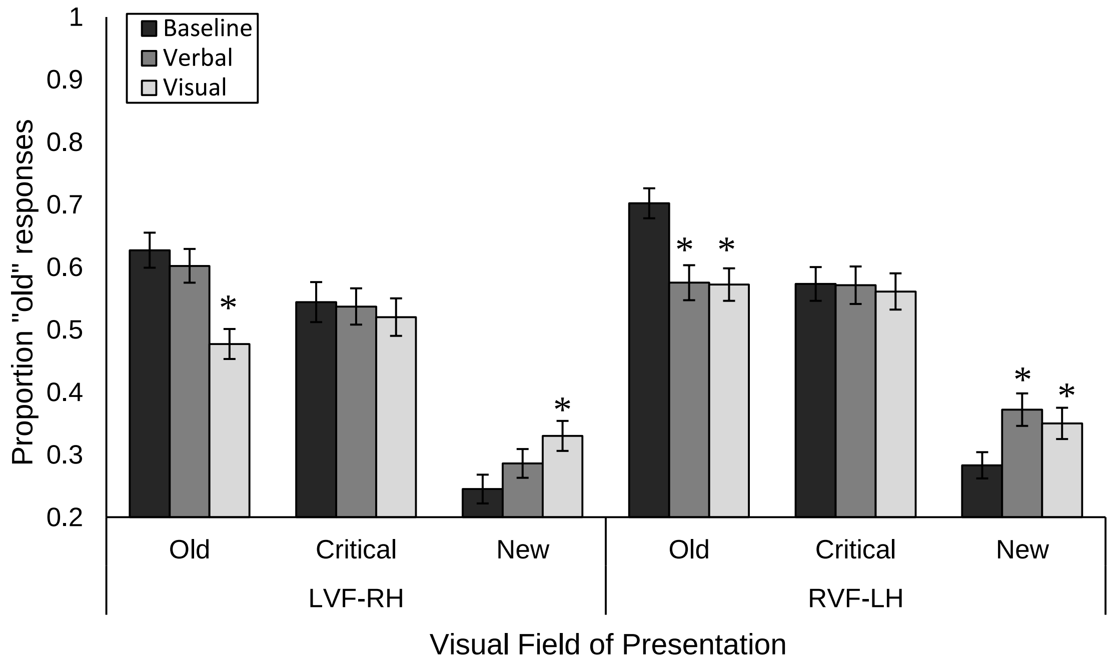

Figure 10. Proportion of old responses in Experiment 3, by Visual Field, Block Type, and Item Type. Error bars represent standard errors. * Denotes significantly different from Baseline (p < .016)

words. Of particular interest was if there were significant Visual Field X Task Type interactions for each individual Item Type. A Visual Field X Task Type interaction would suggest secondary tasks had different influences on memory for each hemisphere. For each ANOVA, additional pair-wise comparisons were conducted comparing responses within each hemisphere (i.e., comparing Baseline Task responses to Verbal Task and Visual Task responses), and between hemispheres (e.g., comparing LVF-RH Baseline response to RVF-LH Baseline response). These particular analyses would help elucidate the nature of hemispheric differences in memory, and if secondary tasks had a large impact over one hemisphere or another.

Old Word Analysis.

For Old words[5], a significant Visual Field X Task Type interaction was observed [$F(2, 150) = 4.43$, $p = .014$, $\eta_\rho^2 = .056$]. First, pair-wise comparisons were conducted to compare Baseline Task responses to Verbal and Visual Task responses. In the LVF-RH, the proportion of old responses was higher in the Baseline Task condition ($M = .62$, $SE = .027$) compared to the Visual Task condition ($M = .48$, $SE = .023$), $t(75) = 4.77$, $p < .001$. A higher proportion of old responses was also observed in the Verbal Task condition ($M = .60$, $SE = .027$) compared to the Visual Task, $t(75) = 3.99$, $p < .001$. No significant difference was observed between Baseline and Verbal Tasks in the LVF-RH. In the RVF-LH, a higher proportion of old responses was observed in the Baseline Task ($M = .70$, $SE = .022$) compared to the Verbal Task condition ($M = .57$, $SE = .028$), $t(75) = 3.90$, $p < .001$. The proportion of old responses was also higher in the Baseline Task condition compared to the Visual Task condition ($M = .57$, $SE = .025$), $t(75) = 4.19$, $p < .001$. No significant difference was observed between the Verbal and Visual Tasks in the RVF-LH. Pair-wise comparisons by Visual Field revealed that the RVF-LH a higher proportion of old responses in the Baseline Task (RVF-LH: $M = .70$, $SE = .022$; LVF-RH $= .63$, $SE = .027$; $t(75) = 2.60$, $p = .011$), and in the Visual Task (RVF-LH: $M = .57$, $SE = .025$; LVF-RH $= .48$, $SE = .023$; $t(75) = 2.96$, $p = .004$). No difference was observed for the Verbal Task.

[5] Main effects were omitted for the sake of brevity, and are reported in footnotes. For Old words, there were also main effects of Visual Field [$F(1, 75) = 6.18$, $p = .015$, $\eta_\rho^2 = .076$] and Task Type [$F(2,150) = 17.78$, $p < .001$, $\eta_\rho^2 = .192$]. Proportion of old responses was higher in the RVF-LH compared to the LVF-RH (.62 vs. .57). Pair-wise comparisons showed that the proportion of old responses was higher in the Baseline Task ($M = .67$) compared to the Verbal Task ($M = .59$), and the Visual Task ($M = .52$).

Critical Lure and New Word Analyses.

For Critical Lure words[6] there was no significant Visual Field X Task Type interaction [$F(1, 75) = .033$, $p = .986$, $\eta_\rho^2 = .000$] This suggested that the cerebral hemispheres *did not* differ in the false recognitions to critical lure words across the different Task Types. All pair-wise comparisons (both within and across Visual Fields) yielded no significant results (all *p*s > .1)

Finally, for Unrelated New words[7], a Visual Field X Task Type interaction approached significance [$F(2, 150) = 3.011$, $p = .052$, $\eta_\rho^2 = .039$]. In the LVF-RH, the proportion of old responses was only marginally lower for the Baseline Task condition ($M = .25$, $SE = .023$) compared to the Verbal Task condition ($M = .28$, $SE = .023$; $t(75) = -1.83$, $p = .071$), and was significantly lower compared to the Visual Task ($M = .33$, $SE = .023$). The proportion of old responses in the Verbal Task condition was only marginally lower compared to the Visual Task condition, $t(75) = -1.97$, $p = .052$. In the RVF-LH, the proportion of old responses was significantly lower in the Baseline Task ($M = .28$, $SE = .020$) compared to both the Verbal Task ($M = .37$, $SE = .023$; $t(75) = -4.03$, $p < .001$) and

[6] For Critical Lure words, there was also a main effect of Visual Field [$F(1, 75 = 4.82$, $p = .031$, $\eta_\rho^2 =.060$]. This indicated that false recognitions were higher in the RVF-LH ($M = .57$) than the LVF-RH ($M = .53$).

[7] For Unrelated New words, there was a main effect of Visual Field [$F(1, 75) = 14.82$, $p < .001$, $\eta_\rho^2 = .165$] indicating that false recognitions were higher in the RVF-LH ($M = .34$) than the LVF-RH ($M = .29$). There was also a main effect of Task Type [$F(2, 150) = 10.49$, $p < .001$, $\eta_\rho^2 =.122$]. Pair-wise comparisons indicated that false recognitions were the lowest in the Baseline Task ($M =.264$), but equivalent in the Verbal ($M = .33$) and Visual Tasks ($M = .34$)

Table 1

False Memory d', C and associated Standard Error values for Experiment 3

	Visual Field			
	LVF-RH		**RVF-LH**	
Task	*d'*	*C*	*d'*	*C*
Baseline	.257 (.10)	-.276 (.08)	.409 (.09)	-.451 (.07)
Verbal	.214 (.10)	-.215 (.07)	.041 (.09)	-.229 (.07)
Visual	-.128 (.09)	.011 (.07)	.034 (.09)	-.189 (.06)

the Visual Task (*M* = .35, *SE* = .025; $t(75) = -3.02$, $p < .001$). No significant difference was observed between the Verbal and Visual Task conditions in the RVF-LH. Pair-wise comparisons across hemispheres showed that the proportion of old responses to Unrelated New words was higher in RVF-LH in both the Baseline Task condition (RVF-LH: *M* = .28, *SE* = .020; LVF-RH: *M* = .25, *SE* = .023; $t(75) = 2.00$, $p = .048$) and the Verbal Task condition (RVF-LH: *M* = .37, *SE* = .025; LVF-RH = .29, *SE* = .023; $t(75) = 3.81$, $p < .001$). No significant difference was observed for the Visual Task condition.

Signal Detection Analyses.

One surprising result from the prior analyses was that hemispheric memory primarily differed for old and new words, but not for lure words. Signal detection analyses were conducted to provide additional evidence, and to verify the previous analysis[8]. In this analysis, *d'* was calculated in two ways, in order to examine both false

[8] Several participants recorded hit rates of hit rates of 1 and false recognition rates of 0. To correct for this, the correction method outlined by Macmillan and Kaplan (1985) was used. False recognition rates = 0 were

Table 2

Veridical Memory d', C and associated Standard Error values for Experiment 3

	Visual Field			
	LVF-RH		**RVF-LH**	
Task	*d'*	*C*	*d'*	*C*
Baseline	1.29 (.11)	.244 (.07)	1.34 (.11)	.015 (.05)
Verbal	.997 (.10)	.176 (.06)	.652 (.09)	.076 (.06)
Visual	.46 (.09)	.30 6(.05)	.693 (.09)	.141 (.06)

memory and veridical (true) memory. The first method (referred to as *False Memory d'*) calculated *d'* by taking the inverse z-transformed distribution for hit rates to old words and subtracting them inverse z-transformed distribution for false recognitions to critical lure words. This would provide an index of false memory differences between hemispheres. The second method (referred to as *Veridical Memory d'*) calculated *d'* by taking the inverse z-transformed distribution for hit rates to old words and subtracting them by the inverse z-transformed distribution for false recognitions to unrelated new words. This would provide an index of more general memory abilities. Associated *d'* and *C* values are shown in Tables 1 and 2.

A 2 (Visual Field) X 3 (Task Type) repeated measure ANOVA was conducted on False Memory *d'* values. This analysis yielded a main effect of Task Type [$F(2, 150) = 8.55$, $p < .001$, $\eta_\rho^2 = .102$]. Pair-wise comparisons suggest that the Baseline Task condition ($M = .33$, $SE = .075$), had marginally higher False Memory *d'* value than the

replaced with values equal to 1/(2N), where N is the total number of possible false recognitions. Hit rates = 1 were replaced with 1-1/(2N), where N is the total number of possible hits.

Verbal Task condition (*M* = .127, *SE* = .069; *t*(75) = 1.78, *p* = .079), or the Visual Task (*M* = -.051, *SE* = .072; *t*(75) = 4.43, *p* < .001). Additionally, the Verbal Task condition was marginally higher than the Visual Task condition, *t*(75) = 2.26, *p* = .027. No significant interaction was observed[9]. These results support previous accuracy analyses which suggested that false memories did not seem to differ across hemispheres. Another 2 (Visual Field) X 3 (Task Type) repeated measure ANOVA was also conducted on response bias (*C*) values. There was a main effect of Visual Field, suggesting that decisions made to words in the RVF-LH (*M* = -.289, *SE* = .056) were more liberal than those presented to the LVF-RH (*M* = -.160, *SE* = .054), [$F(1, 75) = 7.65$, $p = .007$, η_ρ^2 =.093]. There was also a main effect of Task Type [$F(2, 150) = 9.74$, $p < .001$, η_ρ^2 =.115]. Pair-wise comparisons indicated that the Baseline Task condition had a marginally more liberal response bias (*M* = -.363, *SE* =.063) than the Verbal Task condition (*M* = -.222, *SE* = .064; *t*(75) = -2.17, *p* = .033), and a significantly more liberal response bias than the Visual Task condition(*M* = -.089, *SE* = .056; *t*(75) = -4.77, *p* < .001). There was only a marginal difference between response bias values for the Verbal Task and the Visual Task conditions, *t*(75) = -1.88, *p* = .064.

Veridical memory *d'* values were also entered into a 2 (Visual Field) X 3 (Task Type) repeated measure ANOVA. A main effect of Task Type suggested that the Baseline Task condition (*M* = 1.32, *SE* = .095) had a higher *d'* than both the Verbal Task condition (*M* = .825, *SE* = .082; *t*(75) = 5.22, *p* < .001) and Visual Task (*M* = .578, *SE* = .078; *t*(75) = 7.96, *p* < .001). The Verbal Task condition also had a higher *d'* than the

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[9] While *d'* values indicated a trend for an interaction, all pair-wise comparisons that probed for possible hemispheric differences were not significant (all *p*s > .1)

Visual Task condition, $t(75) = 2.74$, $p = .008$. There was a significant Visual Field X Task Type interaction [$F(2, 150) = 6.25$, $p = .002$, $\eta_p^2 = .077$]. Pair-wise comparisons within the LVF-RH showed the Baseline Task condition had a marginally higher *d'* value than the Verbal Task condition [$t(75) = 2.45$, $p = .017$] and a significantly higher *d'* value than the Visual Task condition [$t(75) = 7.16$, $p < .001$]. The Verbal Task condition also had a higher *d'* value than the Visual Task condition [$t(75) = 4.62$, $p < .001$]. Within the RVF-LH, the Baseline Task condition had a higher *d'* value than the Visual Task [$t(75) = 5.39$, $p < .001$] and the Verbal Task conditions [$t(75) = 5.29$, $p < .001$]. No significant difference was observed for *d'* values between the Verbal and Visual Tasks.

Pair-wise comparisons revealed that there was no Visual Field difference in the Baseline Task ($p > .1$). For the Verbal Task condition, the LVF-RH had a significantly higher *d'* value than the RVF-LH, $t(75) = 2.69$, $p = .009$. For the Visual Task condition, the LVF-RH had a marginally lower *d'* value than the RVF-LH, $t(75) = -2.06$, $p = .043$. Pair-wise analyses suggested that discrimination between old and unrelated new words was similar between hemispheres for the Baseline Task condition. In the Verbal Task condition, *d'* values favored the LVF-RH, while in the Visual Task, *d'* values favored the RVF-LH. Finally, a 2 (Visual Field) X 3 (Task Type) repeated measure ANOVA was conducted on Veridical Memory response bias (*C*) values. Only a main effect of Visual Field was observed, suggesting that the LVF-RH had a significantly more liberal response bias ($M = .242$, $SE = .078$) than the RVF-LH ($M = .078$, $SE = .048$), [$F(1,75) = .18.87$, $p < .001$, $\eta_p^2 = .201$].

Response Time Analysis.

Several participants recorded hit rates and false recognition rates equal to zero. This led to potential missing data for response times (RTs) in each condition. To handle missing data, a linear mixed model was used to analyze response times (West, Welch, & Galecki, 2006). The interpretation of linear mixed model results is similar to a standard repeated measure ANOVA analysis. One advantage to using a linear mixed model is that it uses a maximum likelihood algorithm to estimate missing data. This allows for a full analysis of the data, unlike standard ANOVAs that drop missing cases from the analysis. Similar to a standard repeated measure ANOVA, a linear mixed model report *F*-tests for each factor entered into the model (e.g., Visual Field, Task Type, and Item Type). The interpretation of this is similar to main effects and interactions observed in a standard ANOVA.

In the linear mixed model analysis for old response RTs, there was a significant main effect of Visual Field [$F(1, 1193) = 7.77$, $p = .005$], indicating that response times in the RVF-LH ($M = 1029$, $SE = 33$) were faster than response times in the LVF-RH ($M = 1096$, $SE = 34$). There was also a significant main effect of Item Type [$F(2, 1195) = 4.31$, $p = .014$]. Pair-wise comparisons only yielded a significant difference between Old words ($M = 1035$, $SE = 35$) and Unrelated New words ($M = 1109$, $SE = 36$), $p = .036$.

Discussion

In Experiment 3, participants studied lists of related words while completing a Verbal or Visual secondary tasks. Participants were tested on their memory for old words, critical lure words, and unrelated new words. According to PARLO, greater disruptions to memory should be observed in the LH compared to the RH. Additionally, if the hemispheres do engage in material-specific processing, the Verbal Task should have caused greater interference in the LH, while the Visual Task should have caused greater interference in the RH.

The first important, yet surprising, result observed in Experiment 3 was that the proportion of false memory errors to critical lure words did not differ by hemisphere or by Task Type. These results are inconsistent with findings that suggested that the RH is more susceptible to false memory errors. If the RH is indeed more susceptible to false memory errors, this effect should have been observed in the Baseline Task condition, where participants did not have to complete a secondary task. Secondary tasks did not influence susceptibility to false memory errors either. It was suggested by Knott and Dewhurst (2007b) that secondary tasks may limit the degree of spreading activation. The current data speaks against this idea: there were no reductions in false memory errors for either the Verbal Task or the Visual Task conditions. Secondary tasks prevented participants from generating related associates while studying words, but did not disrupt the overall spread of activation. Additionally, instructions did not encourage the active generation of associates. It is likely that participants did not engage in more effortful elaboration strategies to encode items. This would explain why the proportion of memory errors in the Baseline Task condition did not differ from Visual and Verbal Task conditions.

The second important finding observed in Experiment 3 was that veridical memory (memory for studied words), were significantly impacted by secondary tasks (evidenced by differences in *d'* values). In the LH, both secondary tasks caused equal declines in veridical memory, as hit rates to old words or *d'* values did not significantly differ between Verbal and Visual Task conditions. In contrast, RH veridical memory was not influenced much by the Verbal Task condition, and only decreased in the Visual Task condition. These results, at least on the surface, provide some evidence to suggest that the hemispheres engage in material specific processing. In the Verbal Task condition, veridical memory was affected more in the LH compared to the RH. Top-down mechanisms that are used for the encoding and retrieval of LH memory are disrupted more in the Verbal Task condition, indicating that these mechanisms (specifically rehearsal and monitoring processes) may be verbally oriented in nature. Conversely, the opposite can be said about RH memory. Top-down mechanisms that are used for the encoding of RH memory are disrupted more in the Visual Task condition, indicating that these mechanisms operating on the RH may be more visuo-spatially oriented in nature.

One specific finding refutes the idea that the top-down mechanisms engage solely in material specific processing: LH memory also decreased in the Visual Task condition. If top-down mechanisms affecting LH encoding were purely verbally oriented, the Visual Task should have had minimal influence on LH memory. What this suggests is top-down mechanisms that affect LH memory encoding are not solely verbal in nature; rather they may also operate in a more domain general fashion. Another important observation is that the Visual Task influenced veridical memory in both the LH and RH. It may be the case that in the Visual Task condition, top-down mechanisms were recruited more bilaterally, affecting memory in both hemispheres. The Visual Task was more difficult than the Verbal Task (as shown by accuracy in both conditions). Under more difficult processing conditions, top-down mechanisms may be invoked more bilaterally (e.g., Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999).

Results for veridical memory, at least on the surface, support ideas suggested by PARLO. Cognitive loads disrupted maintenance and rehearsal processes, which in turn, detrimentally influenced LH memory more so than RH memory. Additionally, cognitive loads caused monitoring processes used by the LH to be disadvantaged at retrieval: Source information for old words could not be recalled as accurately, leading to declines in veridical memory. In contrast, RH memory only decreased in the Visual Task condition. This suggested that top-down mechanisms that potentially influence RH memory are only impaired when tasks are more cognitively demanding. Overall, verbal memory in the LH was disrupted by cognitive loads more than verbal memory in the RH. Consistent with PARLO, disruptions to top-down mechanisms consequently cause greater impairments to LH verbal memory, indicating that the LH heavily relies on these mechanisms to facilitate verbal processing.

Experiment 4: The Effect of Cognitive Load on Hemispheric True and False Memory during Retrieval

In order to provide converging evidence for the assumption that cognitive loads disrupt the LH more than the RH, Experiment 4 imposes similar cognitive loads during memory retrieval, rather than during memory encoding. In Experiment 4, the Baseline, Verbal and Visual Tasks were administered during retrieval instead of encoding. It has been suggested that monitoring processes play a larger role during memory retrieval rather than memory encoding (Johnson, Hashtroudi, & Lindsay, 1993; Roediger, Watson, McDermott, & Gallo, 2001). To successfully reject false memories, individuals must be able to recall context-specific information from studied old items. If they are unable to recall this information, they are more likely to endorse critical lure words during memory retrieval. Secondary tasks used during memory retrieval may disrupt overall monitoring processes. For example, Knott and Dewhurst (2007b) showed that imposing a cognitive load on memory retrieval caused an increase in false memory errors. Similar to what was hypothesized in Experiment 3, cognitive loads during retrieval should influence verbal memory in the LH more than verbal memory in the RH. If the LH is able to use top-down mechanisms for memory retrieval (i.e., monitoring), cognitive loads should cause greater disruptions to LH verbal memory. It is predicted that cognitive load manipulations during retrieval should result in a greater amount of false memory errors in the LH compared to the RH. If the RH simply operates on the automatic spread of activation, cognitive loads may minimally influence the degree of memory errors in the RH. Therefore, the magnitude of difference in false memory errors between Baseline and Verbal / Visual Task conditions should be larger in the LH, and smaller in the RH. Further, if cognitive loads disrupt source monitoring, hit rates to old words should be diminished as well. The magnitude of difference in hit rate to old words between Baseline and Verbal and Visual Task conditions should also be larger in the LH. Finally, Experiment 4 was conducted to test the hypothesis that the RH is more involved with memory retrieval than the LH. Some imaging studies show that the RH is more active during memory retrieval (Habib et al., 2003; Nyberg et al., 1996). If the RH is more active during memory retrieval, disruptions caused by cognitive load manipulations should detrimentally influence the RH more than the LH.

Method

Participants.

Ninety-nine undergraduates (45 male, 54 female) from Arizona State University participated in this experiment. Participants were students enrolled in an introductory psychology course, and were given course credit for their participation. All participants were native English speakers, had no history of neurological impairments, and were right handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). Mean laterality quotient was .88 (range: 0.44-1). All participants had normal or corrected-to-normal vision.

Stimuli and Design.

All word lists used in Experiment 4 were the same as they were in Experiment 3. There was one minor change for the number of stimuli in each memory test. Thirty-six total words were used in each memory test (108 total). There were 12 Old words, 12 Critical lure words, and 12 Unrelated New words (versus 24 unrelated new words in Experiment 3).

Procedure.

Study Phase.

Each study phase in Experiment 4 was mostly identical to the Baseline Task in Experiment 3. There was one minor difference between the Baseline Task in Experiment

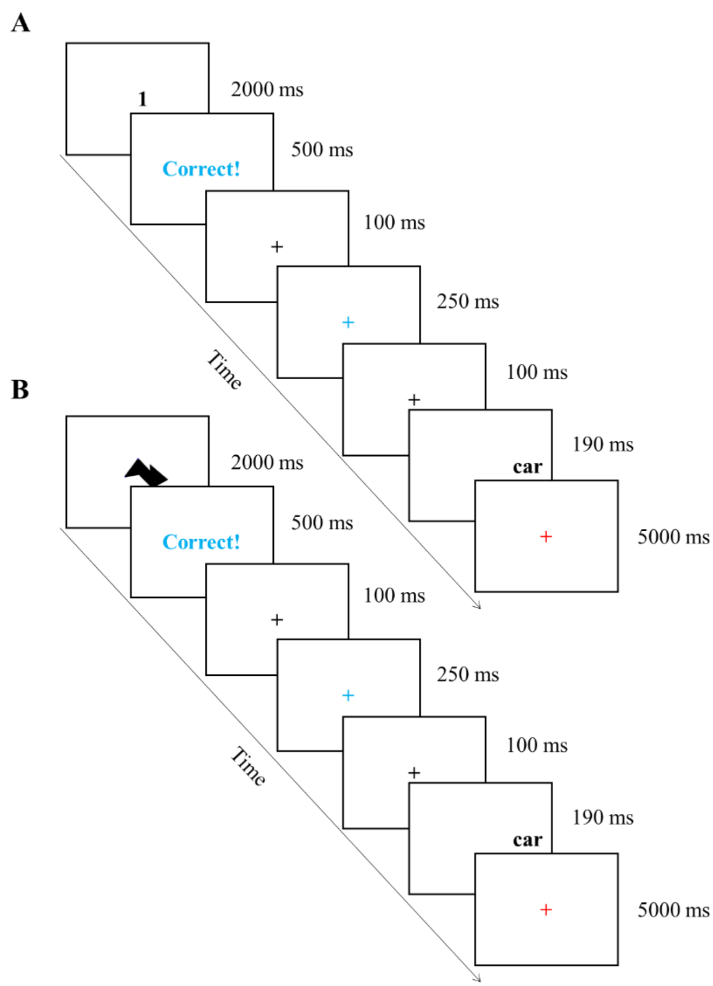

Figure 11. Experiment 4 general memory test procedure for the Verbal Task (A) and the Visual Task (B).

3, and each study phase in Experiment 4. After each word list was presented, there was a short pause for 5000 ms before the next list was presented (indicated by a row of red ***).

Recognition Memory Test.

Like Experiments 1-3, the memory tests in each block used divided visual field presentation. In addition to responding to probe items in the memory test, participants were occasionally required to complete a secondary task (see Figure 11 for an illustration of each task). In the *Baseline Task* block, participants simply responded to memory probes without completing a secondary task. In the *Verbal Task* block, participants were presented with a number (1-9) for 2000 ms at the beginning of the trial. They did not respond to the very first number. After the presentation of the number, the trial proceeded identically to previous experiments, and participants were asked to make their memory decisions as quickly but as accurately as possible. Immediately after responding to the memory probe, another appeared, different from the previous one. Participants had to decide of that number was higher or lower than the previous number they saw (by pressing keys labeled "Hi" or "Lo"). They were given 2000 ms to make their decisions. A screen displaying feedback was then presented for 500 ms. After the feedback screen, the rest of the trial proceeded as normal. The next trial would begin with another number, and participants would have to do the same comparison. The *Visual Task* block was similar, except participants had to make judgments on the orientation of an abstract shape. Like Experiment 3, the shape was rotated in one of eight different positions (45° increments) on each memory test trial. The shape was never rotated more than 90° clockwise or counter-clock wise. In the Visual Task block, participants were instructed to decide of the shape was rotated to the left or the right of the previous shape they saw on the last trial (by pressing keys labeled "L" or "R"). They were given 2000 ms to make their decision, and were given feedback after every decision. Like Experiment 3, all blocks were randomly ordered for every participant.

Results

Omnibus Memory Accuracy.

First, accuracy in the Verbal and Visual Task conditions was evaluated by a one-way repeated measure ANOVA. This yielded a main effect of Task Type, indicating that the accuracy was higher in the Verbal Task condition (*M* = .79, *SE* = .013) than in the Visual Task condition (*M* = .60, *SE* = .013), [$F(1, 98) = 164.65$, $p < .001$, $\eta_\rho^2 = .627$]. Analyses were conducted on the proportion of old responses to Old words, Critical Lures, and Unrelated New words. See Figure 12 for the proportion of old responses by Visual Field, Task Type, and Item Type. A 2 (Visual Field: Left, Right) X 3 (Task Type: Baseline, Verbal, Visual) X 3 (Item Type: Old, Critical Lure, New) repeated measure ANOVA was conducted on the proportion of old responses. There was a main effect of Visual Field suggesting that the proportion of old responses was higher in the RVF-LH (*M* = .55, *SE* = .015) than the LVF-RH (*M* = .49, *SE* = .014), [$F(1, 98) = 21.73$, $p < .001$, $\eta_\rho^2 = .181$]. There was also a main effect of Item Type [$F(2, 196) = 290.95$, $p < .001$, $\eta_\rho^2 = .748$]. Pair-wise comparisons showed that Old words (*M* = .66, *SE* = .015) had a higher proportion of old responses compared to Lure words (*M* = .62, *SE* = .018; $t(98) = 2.50$, $p = .014$) and Unrelated New words (*M* = .27, *SE* = .016; $t(98) = 21.64$, $p <. 001$). Critical Lure words also had a higher rate of old responses compared to Unrelated new words, $t(98) = 18.42$, $p < .001$. A main effect of Task Type approached significance [$F(2, 196) = 2.96$, $p = .054$, $\eta_\rho^2 = .054$], but pair-wise comparisons showed no significant differences. No significant interactions were observed.

Old, Critical Lure, and New Word Analyses.

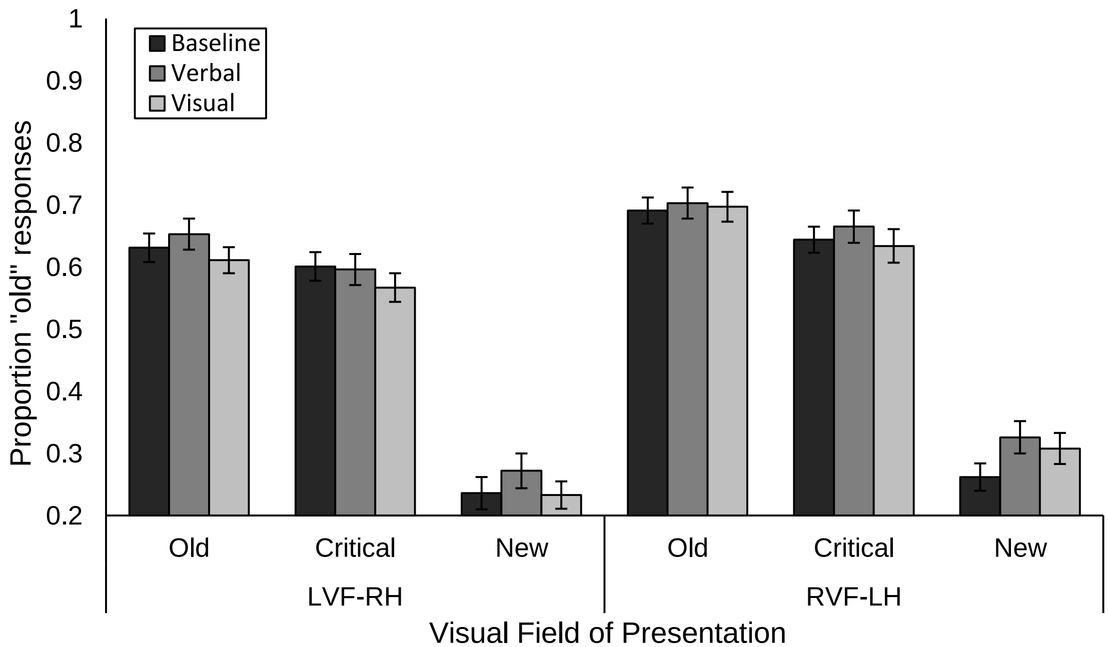

Figure 12. Proportion of old responses in Experiment 4, by Visual Field, Block Type, and Item Type. Error bas represent Standard Errors

Similar to Experiment 3, individual 2 (Visual Field) X 3 (Task Type) repeated measure ANOVAs were conducted for Old words, Critical Lures, and New words. This was done to probe for interactions that may indicate possible hemispheric asymmetries in memory. For Old words, no significant interaction was observed. There was only a main effect of Visual Field, indicating that the RVF-LH (M = .70, SE = .016) had a higher proportion of old responses than the LVF-RH (M =.63, SE = .016), [F(1, 98) = 17.44, p < .001, η_ρ^2 = .151].

Analyses for Critical Lure words did not reveal a significant Visual Field X Task Type interaction. Similar to Old words, only a main effect of Visual Field was observed, indicating that the RVF-LH (M = .65, SE = .020) had a higher proportion of old responses

Table 3

False Memory d', C and associated Standard Error values for Experiment 4

	Visual Field			
	LVF-RH		**RVF-LH**	
Task	*d'*	*C*	*d'*	*C*
Baseline	.078 (.10)	-.337 (.07)	.159 (.10)	-.581 (.07)
Verbal	.181 (.10)	-.418 (.07)	.067 (.09)	-.648 (.08)
Visual	.189 (.09)	-.303 (.08)	.190 (.10)	-.573 (.07)

than the LVF-RH (*M* = .59, *SE* = .021), [*F*(1, 98) = 11.22, *p* = .001, η_ρ^2 =.013]. There was no significant Visual Field X Task Type interaction for New words. For New Words, there was a main effect of Visual Field, indicating the RVF-LH (*M* = .30, *SE* = .20) had a higher proportion of old responses than the LVF-RH (*M* = .25, *SE* = .020), [*F*(1, 98) = 7.63, *p* = .007, η_ρ^2 = .072]. There was a main effect of Task Type [*F*(2, 196) = 3.26, *p* = .046, η_ρ^2 = .031]. However, no significant differences were observed for pair-wise comparisons.

Signal Detection Analyses.

Signal Detection Analyses were conducted for both false memory and veridical memory, where *d'* and response bias (*C*) values were entered into separate 2 (Visual Field) X 3 (Task Type) repeated measure ANOVAs. These values are shown in Tables 3 and 4. No significant main effects or interactions were observed for False Memory *d'* values. For *C* values, there was a main effect of Visual Field, which showed that the RVF-LH (*M* = -.601, *SE*= .057) had more liberal response bias than the LVF-RH (*M* = -

Table 4

Veridical Memory d', C and associated Standard Error values for Experiment 4

	Visual Field			
	LVF-RH		RVF-LH	
Task	*d'*	*C*	*d'*	*C*
Baseline	1.39 (.11)	.279 (.07)	1.51 (.10)	.094 (.07)
Verbal	1.31 (.11)	.148 (.06)	1.33 (.11)	-.013 (.07)
Visual	1.35 (.11)	.278 (.07)	1.36 (.11)	.011 (.07)

.366, *SE* = -.058), [$F(1, 98) = 23.17$, $p < .001$, $\eta_\rho^2 = .191$]. No significant interaction was observed for False Memory *C* values. Analysis of Veridical Memory *d'* values also did not yield a significant main effect or interaction. For Veridical Memory *C* values, there was a significant main effect of Visual Field, suggesting that the RVF-LH (*M* =.031, *SE* = .057) had a more liberal response bias than the LVF-RH (*M* = .236, *SE* = .051), [$F(1, 98) = 15.70$, $p < .001$, $\eta_\rho^2 = .138$]. No significant interaction was observed for Veridical Memory *C* values.

Response Time Analysis.

Similar to Experiment 3, several participants recorded hit rates and false recognition rates equal to zero. This led to missing data for response times to falsely recognized lure words, and hit rates to old words. Like Experiment 3, a linear mixed model was used estimate missing data, and to analyze RT data. A main effect of Visual RH (*M* = 967, *SE* = 21). There was a significant main effect of Task Type [*F*(1, 1502) =

Field was observed [$F(1, 1502) = 5.33$, $p = .021$]. However, pair-wise comparisons showed no significant difference between the RVF-LH ($M = 943$, $SE = 21$) or the LVF-27.01, $p < .001$]. This indicated that the Baseline Task had faster responses ($M = 884$, $SE = 23$) than both the Verbal Task ($M = 985$, $SE = 22$) and Visual Task ($M = 1002$, $SE = 23$), (both *p*s < .01). No difference was observed between Verbal and Visual Tasks. There was a significant main effect of Item Type [$F(1, 1504) = 19.34$, $p < .001$]. Old words ($M = 913$, $SE = 22$) were responded to more quickly than unrelated new words ($M = 1023$, $SE = 24$), $p = .001$. Finally, there was a Task Type X Item Type interaction [$F(1, 1501) = 2.43$, $p = .045$]. No other significant effects were observed for RTs. Pair-wise comparisons showed that the source of this interaction was that RTs for old and lure words significantly differed between Baseline and Verbal Task conditions (both *p*s < .001), but not the Visual Task condition. Further, RTs for unrelated new words did not significantly differ as a function of any Task Type condition (*p*s > .05).

Discussion

In Experiment 4, participants completed secondary tasks during memory retrieval instead of encoding. Results revealed that cognitive load manipulations did not affect overall memory performance. False and Veridical memory did not differ as a function of secondary task type. In fact, false memory errors were slightly higher in the LH overall (although false memory *d'* values did not differ between hemispheres). These results were surprising, given that cognitive load manipulations influenced veridical memory in Experiment 3. A few potential reasons may explain why cognitive load manipulations at retrieval did not influence memory performance. First, evidence has shown that cognitive load and divided attention manipulations have minimal effects during memory retrieval

(Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Fernandes & Moscovitch, 2000; Kane & Engle, 2000). Craik, Govoni, Naveh-Benjamin and Anderson (1996) suggested that memory retrieval (in a recognition memory task) is an automatic process that is relatively impervious to cognitive load / dual task manipulations. Other evidence has shown that cognitive load manipulations can influence retrieval, but only if the material used in the secondary task is the same as the material used during a memory test (Fernandes & Moscovitch, 2002). Additionally, if secondary tasks are sufficiently difficult, they can deplete attentional resources and detrimentally influence memory retrieval (e.g., Knott & Dewhurst, 2007a, 2007b). Secondary tasks in Experiment 4 did not influence memory retrieval. It is likely these tasks were not difficult enough, and did not interfere with individuals' performance on the primary memory retrieval task.

Another interesting result from Experiment was that there was a greater amount of false memory errors in the LH compared to the RH. This result is inconsistent with other hemispheric false memory studies that have observed the opposite pattern (Bellamy & Shillcock, 2007; Westerberg & Marsolek, 2003). Other studies have shown that the LH can elicit greater false memory errors under specific conditions. When lateralizing the presentation of word lists, the LH has been shown to elicit greater false memory errors compared to the RH (Fabiani et al., 2000; Metcalfe et al., 1995). Ben-Artzi, Faust, and Harel (2009) showed that the LH elicits greater memory errors when word lists are biased for dominant meaning critical lures, compared to word lists biased for subordinate meaning critical lures. Giammatei and Ardnt (2012) found that the LH also elicited more false memory errors when longer response deadlines were used during the memory test. The latter study is interesting, as it suggests that with additional time to monitor, more false memory errors can be elicited by LH. It seems that the degree of false memory errors in the LH or RH is driven by several different factors, and cannot simply be solely explained on the type of representational coding that is thought to exist in either hemisphere.

Finally, there was no evidence to indicate that memory retrieval specifically favored one hemisphere or the other, inconsistent with neuro-imaging data that has shown that the RH is more active during memory retrieval (e.g., Habib, Nyberg, & Tulving, 2003; Nyberg, Cabeza, & Tulving, 1996). A potential explanation is that RH-lateralized activation in memory retrieval have only been observed in more traditional episodic memory tasks, rather than memory tasks that require retrieval from semantic memory. Other imaging studies have shown that retrieval of more semantic (rather than episodic) information engages left prefrontal areas, in addition to right prefrontal areas (Buckner, 1996; Gabrieli et al., 1996; Wagner, Paré-Blagoev, Clark, & Poldrack, 2001). This also extends to memory retrieval in tasks using variations of the Deese-Roediger-McDermott false memory paradigm (Gallo, 2010). In sum, the results from Experiment 4 alone do not seem to fully inform how the cerebral hemispheres differ in the use of activation and monitoring processes during memory retrieval. Despite the lack of positive results, data from Experiment 4 complement results from Experiment 3. Results from all task conditions in Experiment 4 seem to replicate the data from the Baseline Task condition in Experiment 3. The implications of this will be discussed in further detail in the general discussion of Experiments 3 and 4.

General Discussion: Experiments 3 and 4

False memory data from Experiments 3 and 4 are generally inconsistent with much of the evidence that suggests the hemispheres differ in susceptibility of false memories (evidenced by False Memory *d'* values[10]). This is not necessarily surprising, however, given the nature of the results reported in this literature. In studies that closely replicated the methodology of the original Roediger et al. (1995) investigation, false memory differences between the LH and RH may be considered small. For example, Westerberg and Marsolek (2003) showed that the proportion of false memory errors between hemispheres in their two experiments ranged from 2.5-4% difference (with greater false memory errors in the RH). Bellamy and Shillcock (2007) found a slightly larger difference between hemispheres, around a 6% difference (again, with greater false memory errors in the RH). Ito (2001) did not find any difference between hemispheres at all, only finding that hit rates favored the LH. In fact, data from Experiments 3 and 4 replicate Ito (2001), also showing that the LH had higher hit rates. More inconsistent findings have also been reported, indicating several different variables can influence the proportion of false memory errors elicited by the LH or the RH (Fabiani et al., 2000; Faust et al., 2008; Giammattei & Arndt, 2012; Metcalfe et al., 1995). This makes it difficult to reach clear conclusions regarding mechanisms that underlie hemispheric asymmetries in false memory.

Theoretical frameworks also make contrasting predictions regarding hemispheric asymmetries in false memory. The Fine Coarse Semantic Coding Theory suggests that

[10] Low discriminability between old words and critical lure words have been observed in prior hemispheric false memory studies, but also the original Roediger and McDermott (1995) study. In these studies, hit rates to old words *and* false recognition rates to lure words tended to be relatively high.

the RH should always be more susceptible to false memories, due to the larger locus of activation that may occur in the RH. Conversely, PARLO predicts that the LH should be more susceptible to false memories because its ability to conduct more gist-based processing. Federmeier (2007) suggested that greater feedback from top-down levels allows the LH to engage in more efficient verbal processing. However, Federmeier states that this comes at a cost: top-down feedback causes the loss of item-specific information during processing. In PARLO, top-down feedback may cause the formation of more gist-based information, obscuring more item-specific information. If this gist-based information is strongly active during memory retrieval, individuals may be more likely to endorse critical lure words when they are presented to the RVF-LH. The observed data in Experiment 4 show that the LH is more susceptible to false memories. However, a simpler explanation can explain that pattern of data. Response bias values to words presented in the RVF-LH were more liberal than words presented to the LVF-LH. Participants were more likely to respond "old" for words presented to the RVF-LH. This could account for the higher proportion of old responses for both old and lure words in the RVF-LH. Participants may have simply been able to see words presented in the RVF-LH more clearly, and attributed that clarity as a form of familiarity. If the word seemed more familiar, they would be more likely to judge the word as being old.

The most interesting results come from veridical memory data in Experiments 3 and 4. Veridical memory across all secondary task conditions in Experiment 4 replicated results from the Baseline Task condition in Experiment 3. This suggests that under full encoding conditions, participants stored item-specific information into memory, rather than encoding old items weakly, then falsely remembering them. Secondary tasks completed during encoding also impacted LH veridical memory more than RH veridical memory. In Experiment 3, an equal decrease in memory performance was observed in the LH for the Verbal and Visual Task conditions. In the RH, the memory performance only decreased slightly in the Verbal Task condition, while a much larger decrease was observed in the Visual Task condition. On the surface, these data seem to support the idea that the hemispheres engage in more material specific processing. However, since the LH veridical memory was also disrupted in the Visual Task condition, a material specific processing explanation cannot explain this pattern of data. As alluded to previously, one possible explanation for this is that overall task difficulty influenced veridical memory in either hemisphere. Participants had a harder time completing the Visual Task, as indicated by accuracy data in Experiments 3 and 4. Participants may recruit more central resources to complete the Visual Task, eliciting more bilateral activity between hemispheres. It has been shown that task difficulty can modulate bilateral activations in the left and right prefrontal cortices. The more difficult the task, the stronger the bilateral activation (e.g., Crane, Maillet, Floden, Valiquette, & Rajah, 2011; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). Visuo-spatially oriented tasks are thought to engage cognitive control processes more strongly, perhaps because they are inherently more difficult than verbal tasks (e.g., Kane et al., 2004). While some level of material specific processing occurs in Experiment 3, task difficulty provides a better explanation for the pattern of results. Materials in the Verbal Task condition interfered with the ability to accurately encode verbal information, influencing veridical memory in the LH more than the RH. The Visual Task condition required additional recruitment of central processing resources from both hemispheres. This led to a decrease in veridical memory for the LH and the RH.

The pattern of data observed in Experiment 3 has also been observed in false memory studies with individuals that have source monitoring impairments, such as patients with Alzheimer's disease. In addition to episodic memory impairments, individuals with Alzheimer's disease also can exhibit impairments to more general cognitive control abilities (Belleville, Chertkow, & Gauthier, 2007; Perry & Hodges, 1999). Interpreting their memory and cognitive control deficits within the Activation-Monitoring framework may provide additional information regarding cognitive mechanisms that are selectively impaired. For example, Balota et al., 1999 examined false memory in young adults, healthy older adults, and older adults with Alzheimer's disease. They found that false recall and recognition remained stable across all groups (with slight increases with healthy older adults and older adults with Alzheimer's). In contrast, there was a steep decline in veridical memory for older adults and adults with Alzheimer's disease. It was suggested that in older adults and adults with Alzheimer's disease, monitoring is impaired but activation pathways between related information remains intact. Individuals with Alzheimer's disease are unable to recall item specific information to help them discriminate old words from lure and new words. This explains why veridical memory is impaired in individuals with Alzheimer's disease, but false memory remains relatively the same across all groups. Balota et al.'s results show a clear distinction between activation and monitoring processes, and their contributions to veridical and false memory. Within the current study, cognitive load manipulations essentially simulate individuals that have deficits in source monitoring.

This interpretation has implications regarding hemispheric specific mechanisms involved with verbal memory encoding. Maintenance and monitoring processes that operate on LH encoding and retrieval are more sensitive to the effects of interference in general. This suggests that these top-down mechanisms are used more heavily for the processing of verbal information in the LH, and play less of a role in the RH. Imaging evidence supports this assertion, and has shown that the left prefrontal areas are more active in tasks that involve more controlled semantic processing (Badre, Poldrack, Paré-Blagoev, Insler, & Wagner, 2005; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Wagner, Paré-Blagoev, Clark, & Poldrack, 2001). Another general conclusion that can be made is that the LH is also involved with cognitive control processes that are domain-general in nature. In the current experiments, the LH was revealed to be more sensitive to interference, regardless type of interference. While it is clear that the LH excels in the processing of most linguistic information, left frontal areas are also used for other types of general cognitive control processes involved with memory (see Badre & Wagner, 2007). This all indicates that the domain generality of top-down mechanisms used by the LH is driven by task demands. The more difficult the task, the more likely general cognitive control functions are used. In contrast to the LH, the control mechanisms seem to exert a lesser influence on RH verbal processing. Only the Visual Task disrupts top-down mechanisms that influence the RH, and this was most likely due to bilateral recruitment of both hemispheres due to more difficult task conditions. More interestingly, the RH is somewhat less susceptible to the effects of verbal interference, and seems to be able to retain item-specific information for words in the Verbal Task condition. This particular finding supports a growing body of evidence that shows the RH retains specific episodic details of verbal information (e.g., Evans & Federmeier, 2009; González & McLennan, 2007; Laeng, Øvervoll, & Ole Steinsvik, 2007; Marsolek, 2004).

In conclusion, data from Experiments 3 and 4 align more with the PARLO interpretation of hemispheric processing. These data indicate that top-down mechanisms used by the LH are biased for the processing of verbal information, but also employed for more domain general cognitive control processes. These results also provide converging evidence that the RH does process information in a more bottom-up fashion, and encodes information more veridically. Little evidence was found to support coding distinctions proposed by the Fine Coarse Semantic Coding Theory. This does not mean coding distinctions do not exist; it is possible that the stimuli or the methods used in the current experiment were not able to take advantage of LH and RH coding differences. Experiment 3 and 4 provide evidence that suggest that top-down mechanisms do a play a role in hemispheric verbal memory, specifically for veridical memory.

Experiment 5: The Relationship Between Controlled Semantic Processing and Hemispheric Verbal Memory

Top-down mechanisms used in hemispheric verbal memory may to reflect more controlled processes, and are possibly part of a more general cognitive construct used for other types of processing (e.g., executive control). Outside of the current investigations, hemispheric asymmetries in controlled processing have not been widely examined in terms of memory encoding and retrieval. Controlled processing in the cerebral hemispheres has been typically examined through semantic priming. In general, semantic priming studies (and sentence processing studies to some degree) have presented evidence that LH uses both automatic and controlled semantic processing mechanisms, while the RH only uses automatic semantic processing mechanisms (see Koivisto & Laine, 2000). It is not clear how controlled processes in hemispheric semantic priming may translate into mechanisms that are involved with the hemispheric encoding and retrieval of verbal memory. Experiment 5 was designed to explore the potential link between controlled processes in semantic priming, and mechanisms involved with verbal memory encoding and retrieval in the cerebral hemispheres.

The idea of automatic and controlled semantic processing mechanisms come from general semantic priming theories (Neely, 1991). In a typical semantic priming experiment, participants are presented with related or unrelated prime-target pairs (e.g., *dog-cat*). They are asked to make some type of decision to the target word in each pair (e.g., naming, lexical decision, or relatedness decision). Responses to target words (e.g., *cat*) are generally faster if it is related in some way to the initial prime word (e.g., *dog*). This facilitation is thought to be caused by two variables: the initial automatic spread of activation and controlled semantic processing mechanisms. Upon the presentation of a prime word, activation automatically spreads to other related concepts within a semantic network (Meyer & Schvaneveldt, 1971). Controlled semantic processes are engaged later during processing, usually when prime-target pair stimulus onset asynchronies (SOAs) are larger than 250-300 ms. Controlled semantic processes are more strongly invoked when there is a greater amount of related prime-target pairs than there are unrelated prime-target pairs (referred to as *Relatedness Proportion*, or *RP*). High RP and long SOAs bias participants to engage in an expectancy-based processing strategy. High RP biases participants to engage in strategic processing, while long SOAs allow more time for participants to generate possible associates based on a given prime. If a participant generates a semantic associate that matches the target item, the magnitude of priming becomes even larger. The combination of spreading activation and expectancy-based processing strategy creates larger priming magnitudes beyond conditions where automatic processing only occurs (e.g., prime-target SOA < 300, low RP).

Recent evidence has suggested that controlled processing mechanisms are also associated with executive functioning mechanisms, such as attentional control. Hutchison (2007) investigated the relationship between attentional control and controlled processing in semantic priming. Individuals with greater attentional control may also be able to engage in more efficient controlled semantic processing, which would lead to larger magnitudes of priming. Participants in this study were first given a battery of tasks used to measure working memory and attentional control (Operation Span, Antisaccade, and Stroop Tasks). Based on scores from these tasks, participants were split into a High Attention Control group, a Moderate Attention Control group, and a Low Attention Control group. After completing the test battery, participants completed the semantic priming task. Two variables were manipulated in the semantic priming task. RP was either small (22%) or large (77%), and SOA was either short (267 ms) or long (1240 ms). It was predicted in conditions that facilitated controlled semantic processing (large RP, long SOA) there would be larger priming effects for the High Attention Control group compared to the Moderate and Low groups. Results matched the initial predictions; the High Attention Control group had larger magnitudes of priming with high RP and a long SOA, compared to Moderate and Low groups. Individuals in the High Attention Control group were more able to search semantic memory and generate plausible semantic associates that matched target items. This would explain why these individuals exhibited larger semantic priming magnitudes in the high RP, long SOA condition. This result was not entirely surprising, other studies have shown that individuals with better attention control also perform better in other tasks requiring the generation of semantic associates, such as verbal fluency tasks (Rosen & Engle, 1997).

Studies examining hemispheric asymmetries in semantic priming have typically manipulated SOA (not RP). This is done to investigate hemispheric differences in the time-course of semantic processing. It has been found that the LH is able to engage in controlled semantic processing at longer SOAs, while the RH only operates on the automatic spread of activation. For example, in the original Burgess and Simpson (1988) study, priming in the LH was found for pairs biased for dominant and subordinate meaning at short SOAs, but at long SOAs, there was only priming for pairs biased for dominant meanings. This indicated that the LH uses controlled semantic processes to selectively maintain frequent, context relevant information while suppressing less frequent information. Conversely, no priming was observed in the RH for short SOAs, but priming for both types of pairs was evident at long SOAs. The RH only operates on the spread of activation, and this spread of activation may be slower than the LH. Other hemispheric priming studies have found similar patterns of results when SOA has been manipulated (Atchley, Burgess, et al., 1999; Atchley, Keeney, et al., 1999; Chiarello, Burgess, Richards, & Pollock, 1990; Chiarello et al., 1995).

Only one study has directly assessed automatic and controlled processes in the cerebral hemispheres. Collins (1999) examined hemispheric semantic priming for categorically related pairs, and wanted to also determine if the hemispheres differed under conditions that facilitated automatic processing, or controlled processing. There were two experiments. In Experiment 1, prime-target pairs were separated by a 250 ms SOA, and RP was only 25%. In Experiment 2, prime-target pairs were separated by a 750 ms SOA, and RP was increased to 50%. Conditions in Experiment 1 were thought to only facilitate automatic processing, while conditions in Experiment 2 were thought to facilitate more controlled, expectancy-based processing. Results from Experiment 1 showed that priming did not differ between hemispheres. This suggested that automatic processing did not differ greatly between hemispheres. Results from Experiment 2 showed that only priming occurred in the LH, which indicated that the LH is more able engage in controlled processing, while the RH only operates on the automatic spread of activation. In a similar vein, imaging studies have demonstrated similar findings, showing that the left prefrontal cortex is strongly activated in priming tasks with long SOAs and high RP (Mummery, Shallice, & Price, 1999; Rossell, Bullmore, Williams, & David, 2001; Rossell, Price, & Nobre, 2003).

The question remains as to how controlled semantic processes with mechanisms involved with hemispheric verbal memory. Logically, controlled processing used in semantic priming, and top-down mechanisms used in memory encoding and retrieval should share the same underlying cognitive construct. The primary goal for Experiment 5 was to provide complementary evidence that the controlled processes used in semantic priming are similar (if not the same) as mechanisms used in hemispheric memory encoding and retrieval. To this end, Experiment 5 was designed to examine controlled semantic processing and its potential influence on hemispheric verbal memory.

Experiment 5 consisted of two parts, a study phase, and a surprise memory test. In the study phase of Experiment 5, participants were shown related and unrelated prime-target pairs, and were asked to judge the relatedness of these pairs. Related word pairs were split into two different types: Synonym pairs (e.g., *wet-moist*) and Antonym pairs (e.g., *easy-difficult*). While overall relatedness proportion was not manipulated, the proportion of Synonym and Antonym word pairs were manipulated (for a similar method see Davie et al., 2004). The manipulation of pair-type proportion was done to bias participants to engage in expectancy-based processing for a single pair type. In one condition Synonym and Antonym pairs were evenly split among the total number of related word pairs (50% Synonym Proportion condition). In another condition there was a greater proportion of Synonym pairs than Antonym pairs (70% Synonym Proportion condition). Participants were not told ahead of time about the memory test, in order to prevent the overt rehearsal of information. In the memory test, participants were tested on their memory for old pairs, and unstudied, semantically related foil pairs (e.g., *wet-dry*) using divided visual field presentation. Critically, target foil pairs consisted of a prime word that stayed consisted throughout the experiment (e.g., *wet*) and a target that was from the opposite pair type (the Antonym *dry* instead of the Synonym *moist*).

Predictions for Experiment 5 followed the PARLO framework and general conclusions made from hemispheric semantic priming investigations. It was hypothesized that the LH should engage in controlled semantic processing during the study phase. When participants are generating related associates for primes in the study phase, this controlled processing should strongly activate representations in the LH more so than in the RH. This would lead to the strengthening of memories for studied word pairs, but also other unstudied words that participants may have generated. In contrast, if the RH operates only on the automatic spread of activation, and uses controlled processes minimally, encoded representations should be weaker overall.

The PARLO framework would predict that memory for old word pairs *and* false memory for foil pairs should be higher in the LH than in the RH. If the LH is can take advantage of controlled processing, the generation of related associates should result in more semantic competitors strongly activated in memory. This would lead to a greater amount of false memory errors in the LH. Therefore, different predictions can derived for the 50% Synonym Proportion condition and the 70% Synonym Proportion condition. It is predicted that in the 50% Synonym Proportion condition, expectancy-based processing is more weakly engaged (but not completely absent). Hit rates to old word pairs and false alarm rates to related foil pairs should be equivalent between hemispheres, or may slightly be higher in the LH relative to the RH. In the 70% Synonym Proportion condition, expectancy-based processing should be more strongly engaged. Specifically, participants should be biased to generate Synonym pairs. If the LH uses controlled semantic processing more efficiently, then it is predicted that hit rates to old Synonym pairs, and false recognition rates to semantically related foil pairs should be higher compared to the RH. Thus, hit rates and false recognition rates should be higher in the LH for the 70% Synonym Proportion condition, compared to the 50% Synonym Proportion condition. The RH should be relatively insensitive to these manipulations. Hit rates and false recognition rates in the RH are predicted not to greatly differ between the different Synonym Proportion conditions.

Method

Participants.

Ninety-five undergraduate students from Arizona State University participated in this experiment (55 female, 40 male). Participants were students enrolled in an introductory psychology course, and were given course credit for their participation. All participants were native English speakers, had no history of neurological impairment, and were all right handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971). Mean laterality quotient was .86 (range: 0.53-1.00). Participants had normal or corrected-to-normal vision. Participants were randomly assigned to one of two conditions, the 50% Synonym Proportion condition (N = 46) and the 70% Synonym Proportion condition (N = 49).

Stimuli and Design.

Study Phase.

Study phase stimuli were split into target word pairs, filler word pairs, and unrelated word pairs. There were a total of 60 target word pairs. All target pairs were highly associated words, chosen from the University of South Florida word association norms (Nelson, McEvoy, & Schreiber, 2004). Thirty of these target word pairs were *Antonym pairs*, and another 30 target word pairs were *Synonym pairs*. Antonym pairs are defined as two words that are strongly associated with each other, but share an opposite meaning (e.g., *easy-difficult*) or are part of opposite categories (e.g., *girl-boy*). Synonym pairs are defined as two words that strongly associated and overlap in overall meaning (e.g., *wet-moist*) or a part of the same category (e.g., *dad-father*). An additional 40 filler word pairs were included in the study phase. The composition of the 40 filler pairs differed by Proportion Condition. In the 50% Synonym Proportion condition, 20 fillers were Antonym pairs, and 20 fillers were Synonym pairs. This evenly divided the number of Antonym and Synonym pairs that were used in the study phase (50 total Antonym pairs, 50 total Synonym pairs total). In the 70% Synonym Proportion condition, all fillers were Synonym word pairs. In this condition, the total number of Synonym pairs was greater than Antonym (30 total Antonym pairs, 70 total Synonym pairs total). Finally, there were a total of 100 unrelated word pairs. Unrelated word pairs were words that shared no association with one another (e.g., *grape-lantern*). All word pairs are listed in Appendix C.

Memory Test.

In the memory test, there were a total of 60 word pairs (corresponding to the 60 target pairs in the Study Phase). These 60 word pairs were divided into 30 Antonym pairs, and 30 Synonym pairs. Additionally, Antonyms and Synonyms were divided evenly among 3 types of foil pairs. Ten of the word pairs were *Old* pairs repeated from the study phase (e.g., *easy-difficult*). Another ten word pairs were *Opposite* foil pairs. In Opposite foil pairs, the first word in each pair was one repeated from the study phase, but the second word was always a word of the opposite type from the study phase. For example, the Antonym pair *easy-difficult* would appear as *easy-simple* in the memory test. Similarly, the Synonym pair *wet-moist* would appear as *wet-dry* in the memory test. Finally, there were at set of 10 *New* foil word pairs. New foil word pairs consisted of a repeated first word, and a more weakly associated second word (e.g., *easy-basic*). Half of all words were presented to the LVF-RH and the other half to the RVF-LH. All items were counterbalanced by foil type and visual field of presentation across experimental lists.

Procedure

Study Phase.

Participants were tested in pairs. They were seated approximately 50 cm in front of 15 inch CRT computer monitors. Presentation of the stimuli were controlled by E-prime 1.2, software that collected accuracy and response time data (Schneider et al., 2002). Participants were randomly assigned to the 50% Synonym Proportion condition or the 70% Synonym Proportion condition. An illustration of the study phase procedure is in Figure 13.

In the study phase, participants were instructed that would see two words in succession of one another. Participants were not informed that they would be tested on their memory for word pairs. They were instructed to decide if the second word was related in some way to the first word, and to make this decision as quickly but as accurately as possible. Each trial started with a blank screen that appeared on the screen for 750 ms. Then, the first word in a pair would be presented for 1000 ms. Another blank screen appeared for 300 ms. After, the second word appeared for a total of 5000 ms or until the participant responded (this resulted in an SOA of 1300 ms). Participants pressed a key labeled “YES” if the second word was related to the first and “NO” if they thought it was not related. Participants were given feedback for each of their responses, which appeared on the screen for a total of 750 ms. After receiving feedback, the next study

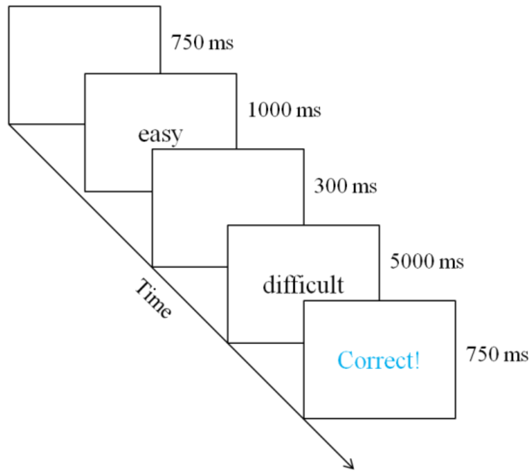

Figure 13. The study phase procedure in Experiment 5.

phase trial would begin. Accuracy and response times were recorded for each of their decisions. After the study phase, participants were given a set of 15 math problems to evaluate. For each math problem presented on the screen, they were asked to press "YES" if the math problem was correct and "NO" if it was incorrect.

Memory Test.

Similar to all other experiments, the memory test used divided visual field presentation. See Figure 14 for an illustration of the memory test procedure. After the distracter task, participants were informed that they would be tested on their memory for the word pairs they saw in the initial part of the experiment. Participants were told that they would initially see a word presented in the center of the screen, then later in the trial, another word presented very briefly to the left or right side of the screen. They were instructed to decide if they remember seeing those two words together before, or if they thought it was a completely new word pair. Finally, participants were told that they would see a fixation point (+) throughout the trial, and to always keep their eyes focused on it throughout the memory test. At the beginning of each trial, the first word in each

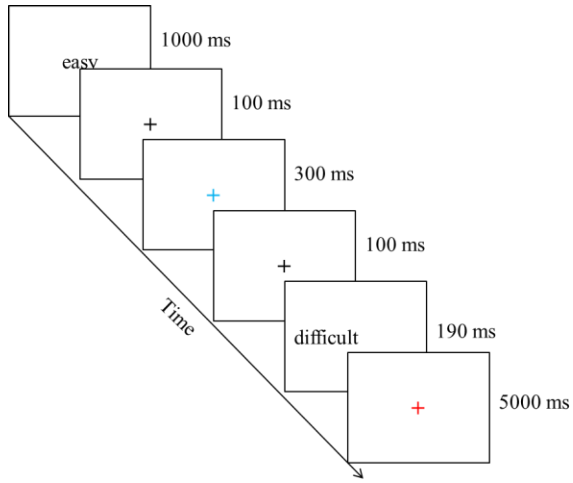

*Figure 14.*The memory test procedure in Experiment 5.

pair was presented in the center of the screen for 1000 ms. After this first word appeared, the trial proceeded identically to all prior experiments. Participants would see a word flashed briefly to the LVF-RH or the RVF-LH (for 190 ms). A red fixation point cued participants to respond by pressing a "YES" if they thought they saw those two words together before, or "NO" if they thought it was a completely new word pair. Participants were asked to respond as quickly and as accurately as they could. Participants always used their right hand to respond. After their response, the next memory test trial would begin. Accuracy and response times were recorded for each of their memory decisions.

Results

Relatedness Decision Analyses.

Accuracy and correct responses times (RTs) were analyzed for relatedness decisions to Antonym, Synonym, and Unrelated word pairs in the study phase. See Figure 15 correct response times for each Pair Type by Proportion Condition. Accuracy data was entered into a 3 (Pair Type: Antonym, Synonym, Unrelated) X 2 (Proportion Condition: 50%, 70%) mixed factor ANOVA. There was a main effect of Pair Type [F(2, 186) =

12.98, $p < .001$, $\eta_\rho^2 = .181$]. Pair-wise comparisons[11] showed that accuracy for Unrelated word pairs ($M = .97$, $SE = .002$) was higher than both Antonym pairs ($M = .95$, $SE = .01$; $t(94) = 3.73$, $p < .001$) and Synonym pairs ($M = .94$, $SE = .01$; $t(94) = 5.19$, $p < .001$). There was no significant difference in accuracy between Antonym and Synonym pairs ($t < 1$, $p > .1$). No other significant main effects or interactions were observed for accuracy. For correct response times, there was a main effect of Pair Type [$F(2, 186) = 60.59$, $p < .001$, $\eta_\rho^2 = .394$]. Pair-wise comparisons showed that RTs for Unrelated pairs ($M = 880$, $SE = 17$) were slower than RTs for both Antonym pairs ($M = 797$, $SE = 16$; $t(94) = 9.77$, $p < .001$) and Synonym Pairs ($M = 799$, $SE = 14$; $t(94) = 8.50$, $p < .001$). RTs for Antonym and Synonym pairs were not significantly different ($t < 1$, $p > .1$). There was also a main effect for Proportion Condition, suggesting that the 50% Synonym Proportion condition ($M = 862$, $SE = 22$) had slower RTs than the 70% Synonym Proportion condition ($M = 791$, $SE = 21$), [$F(1, 93) = 5.13$, $p = .026$, $\eta_\rho^2 = .052$].

Post-hoc independent sample t-tests were conducted to examine if correct RTs differed by Proportion Condition, for each Pair Type. Unrelated pairs were only marginally faster in the 70% Synonym Proportion condition compared to the 50% Synonym Proportion condition , $t(93) = -1.93$, $p = .056$. Similarly, Antonym pairs were only marginally faster in the 70% Synonym Proportion condition compared to the 50% Synonym Proportion condition, $t(93) = -1.80$, $p = .075$. Synonym pairs were

[11] Pair-wise comparisons used to compare Pair Types in the Study Phase and Foil Types in the Test Phase used a Bonferroni corrected alpha ($p = .016$).

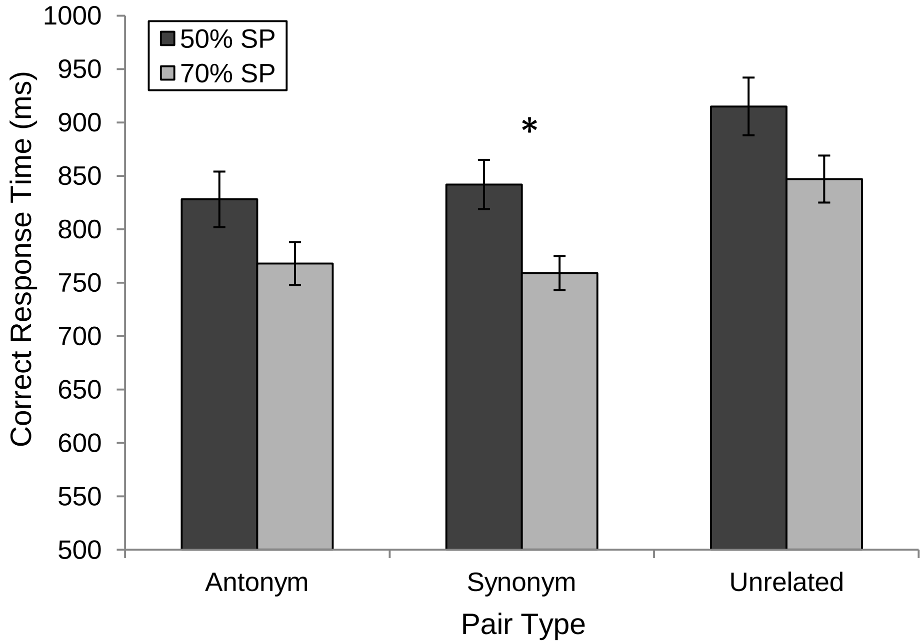

Figure 15. Correct Response Times in Experiment 5, by Pair Type and Proportion condition. Error bars are standard errors. Note: SP denotes "Synonym Proportion". * Denotes significantly different between Proportion Conditions, $p < .016$.

significantly faster in the 70% Synonym Proportion condition compared to the 50% Synonym Proportion condition, $t(93) = -2.87$, $p = .005$. This latter analysis indicated that a higher proportion of Synonym pairs seemed also to improve overall response times for Synonym pairs.

The degree of semantic priming was also examined to determine of each Proportion Condition influenced the overall magnitude of priming. Unrelated RTs were subtracted by Antonym and Synonym RTs to obtain an index of semantic priming. These values were entered into a 2 (Pair Type: Antonym, Synonym) X 2 (Proportion Condition) mixed factor ANOVA. No significant main effects or interactions were observed for overall priming magnitudes.

Omnibus Memory Accuracy.

Initial analyses focused on hit rates for old items, and false recognition rates for foil items (proportion of old responses). These data were entered into a 2 (Visual Field: Left, Right) X 2 (Proportion Condition: 50%, 70%) X 2 (Pair Type: Antonym, Synonym) X 3 (Foil Type: Old, Opposite, New) mixed factor ANOVA. The proportion of old responses across all conditions is seen in Figure 16 (LVF-RH) and Figure 17 (RVF-LH). A main effect of Foil Type was observed [$F(2, 186) = 515.80$, $p < .001$, $\eta_\rho^2 = .840$]. Pair-wise comparisons indicated that the proportion of old responses for Old pairs ($M = .80$, $SE = .012$) was higher than Opposite foil pairs ($M = .33$, $SE = .021$; $t(94) = 20.47$, $p < .001$) and New foil pairs ($M = .22$, $SE = .017$; $t(94) = 30.54$, $p < .001$). The proportion of old responses was higher for Opposite pair foils compared to New pair foils, $t(94) = 6.60$, $p < .001$. Several significant interactions were observed. A Pair Type X Proportion Condition interaction was observed [$F(1, 93) = 4.77$, $p = .031$, $\eta_\rho^2 = .049$]. An independent sample t-test indicated that the proportion of old responses for Antonym pairs was only marginally higher in the 50% Synonym Proportion condition ($M = .47$, $SE = .022$) than in the 70% Synonym Proportion condition ($M = .41$, $SE = .018$; $t(93) = 1.89$, $p = .061$). No significant difference was observed for Synonym pairs. There was a significant Foil Type X Proportion Condition interaction [$F(2, 186) = 5.45$, $p = .005$, $\eta_\rho^2 = .055$]. An independent sample t-test showed that Opposite foil pairs had a significantly higher proportion of old responses in the 50% Synonym Proportion condition ($M = .38$, $SE = .03$) versus the 70% Synonym Proportion condition ($M = .28$, $SE = .03$), $t(93) = 2.35$, $p = .021$. No other significant comparisons were observed. Finally, a significant Pair Type X Foil Type interaction was observed [$F(2, 186) = 10.52$, $p < .001$, $\eta_\rho^2 =$

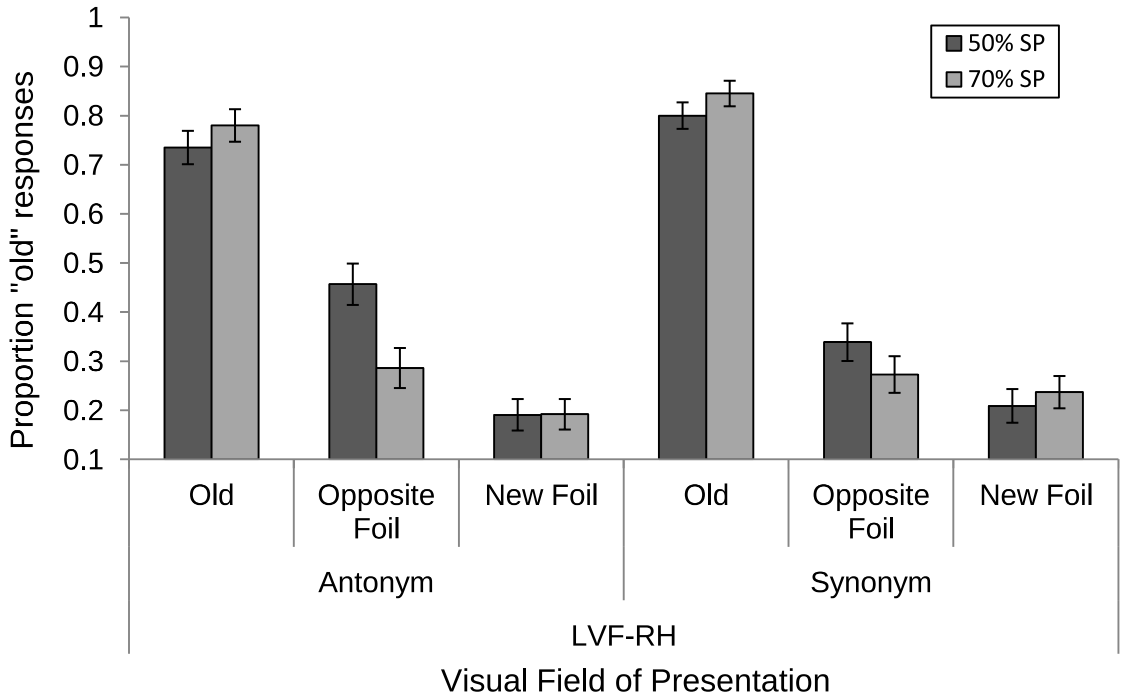

Figure 16. Proportion of old responses for the LVF-RH in Experiment 5, by Pair Type, Foil Type, and Proportion Condition. Error bars are standard errors. Note: SP refers to "Synonym Proportion."

.102]. Pair-wise comparisons showed that the proportion of old responses was lower for Old Antonym pairs (*M* = .76, *SE* = .017) compared to Old Synonym pairs (*M* = .84, *SE* = .012), *t*(94) = -4.08, *p* < .001. Additionally, Opposite Antonym foil pairs (*M* = .36, *SE* = .03) had a marginally higher proportion of old responses compared to Opposite Synonym foil pairs (*M* = .30, *SE* = .021), *t*(94) = 2.37, *p* =.020. There was no statistical difference between New Antonym Foil pairs and New Synonym Foil pairs. No other significant main effects or interactions were observed for the accuracy data.

Finally, signal detection analyses were conducted to determine if there were hemispheric differences in discriminating between old and new items. Old Antonym and Synonym pairs were collapsed in this analysis, then compared to false recognition rates to Opposite and New foils. Similar to Experiments 3 and 4, false memory and veridical

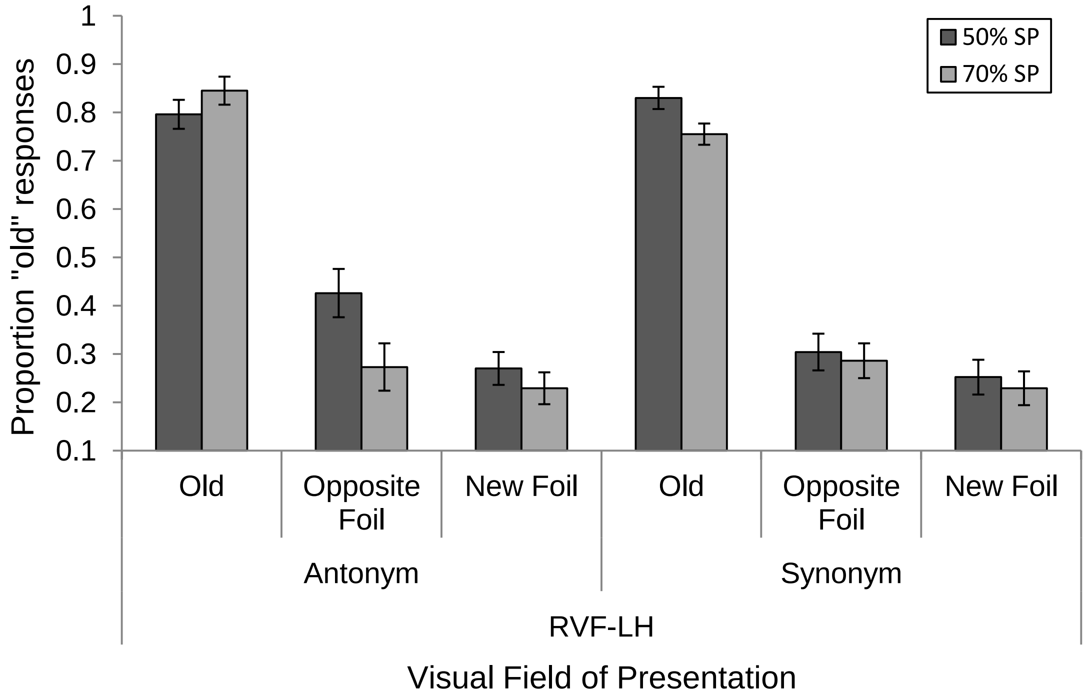

Figure 17. Proportion of old responses for the RVF-LH in Experiment 5, by Pair Type, Foil Type, and Proportion Condition. Error bars are standard errors. Note: SP refers to "Synonym Proportion."

memory was examined. For false memory, hit rates to Old pairs and false recognition rates to Opposite foils were collapsed into *d'* and *C* values. For veridical memory, hit rates for Old pairs and false recognition rates for New foils used to calculate *d'* and *C*. These were entered into a 2 (Visual Field) X 2 (Proportion Condition) mixed factor ANOVA. For false memory *d'* values, there was a main effect of Proportion Condition indicating that the 70% Synonym Proportion condition (M = 1.71, SE = .10) had a higher *d'* value than the 50% Synonym Proportion condition (M = 1.28, SE = 1.28), [$F(1, 93) = 8.20$, $p = .005$, $\eta_\rho^2 = .081$]. No other significant main effects or interactions were observed. Additionally, no significant main effects or interactions were observed for false memory *C* values. For veridical memory *d'* values, no significant main effects or interactions were observed. For veridical memory *C* values, there was a main effect of Visual Field, which showed that the LVF-RH (*M* = .017, *SE* = .050) had a more conservative response bias than the RVF-LH (*M* = -.084, *SE* = .049), [$F(1, 93) = 4.63$, $p = .034$, $\eta_\rho^2 = .047$]. There was also a significant Visual Field X Proportion Condition interaction [$F(1, 93) = 4.97$, $p = .028$, $\eta_\rho^2 = .051$]. Pair-wise comparisons indicated there was significant visual field differences for response bias in the 50% Synonym Proportion condition (LVF-RH: *M* =.079, *SE* =-.126; RVF-LH: *M* = -.126, *SE* = .07), $t(45) = 3.08$, $p = .004$. No significant visual field difference was observed for the 70% Synonym Proportion condition.

Response Time Analysis.

Similar to Experiments 3 and 4, several participants recorded hit rates and false recognition rates equal to zero, which left missing response time data across several conditions. A linear mixed model was used to estimate missing data using a maximum likelihood algorithm. Response times for old responses were then entered in to the linear mixed model for a full analysis. This yielded a significant main effect of Visual Field [$F(1, 793) = 5.62$, $p = .018$]. This indicated that old response times were faster in the RVF-LH (*M* = 876, *SE* = 31) than the LVF-RH (*M* = 937, *SE* = 31). There was also a significant main effect of Foil Type [$F(2, 798) = 34.50$, $p < .001$]. Old responses to Old pairs (*M* = 766, *SE* = 32) were significantly faster compared to Opposite foil pairs (*M* = 946, *SE* = 34) and New foil pairs (*M* = 1008, *SE* = 35). There was also a significant Proportion Condition X Foil Type interaction [$F(2, 798) = 3.80$, $p = .023$]. All pair-wise comparisons for this interaction were significant (*p*s < .01), except the comparison between Opposite foil pairs and New foil pairs in the 70% Synonym Condition (p = 1). No other significant effects were observed for RTs.

Discussion

In Experiment 5, participants made relatedness judgments to pairs of related words (Antonym and Synonym pairs) and unrelated words. Participants were assigned to one of two conditions. In one condition, there were an even number of Antonym and Synonym pairs (50% Synonym Proportion condition). In the other condition, there were a greater number of Synonym pairs than Antonym pairs (70% Synonym Proportion condition). It was predicted that in the 70% Synonym Proportion condition, there would be a stronger bias to engage in more controlled semantic processing. Specifically, participants would be more likely to generate related synonym associates during study phase. After the study phase, participants were given a surprise memory test. It was predicted that if controlled processing was invoked more strongly in the 70% Synonym Proportion condition, hit rates to old Synonym pairs and false recognition rates to Synonym foil pairs would be greater in the LH than in the RH. Conversely, hit and false recognition rates were predicted not to greatly differ across proportion conditions in the RH.

While semantic priming magnitudes did not significantly differ across proportion conditions, there was some indication that the 70% Synonym Proportion condition fostered greater controlled processing. Synonym pairs were responded to more quickly in the 70% Synonym Proportion condition relative to the 50% Synonym Proportion condition. This provided some evidence that participants were engaging in more controlled semantic processing in the 70% Synonym Proportion condition. However, one surprising finding was that there was a trend for RTs to be faster for Antonym and Unrelated pairs as well (although pair-wise comparisons did not find significant differences). There were no methodological differences across conditions, aside from the proportion manipulation. It is unclear why relatedness decisions were faster overall in the 70% Synonym Proportion condition.

A second surprising finding was that there were no observed hemispheric differences amongst any of the conditions. Hit and false recognition rates, as well as *d'* values were not influenced by visual field manipulations. It was initially predicted that the LH would be more likely to use controlled processing to strongly activate representations for old and foil pairs in memory. If participants engaged in more controlled processing in the 70% Synonym Proportion condition, they would be more likely to generate related associates, which likely include Antonym words. This should have leaded to greater hit and false recognition rates in the LH, relative to the 50% Synonym Proportion condition. This was not the case, as data from both hemispheres mirrored each other across all conditions.

The lack of hemispheric differences in Experiment 5 was surprising given that other studies have shown that the manipulation pair type proportion can induce controlled semantic processing (e.g., Davie et al., 2004). The current method may have invoked more bilateral, rather than hemispheric-specific processes. Experiment 5 resembled tasks used to measure associative memory (Murdock, 1982). In associative memory tasks, participants study stimulus pairings, then are tested on old pairs, and new foil pairs. Brain areas associated with associative memory have been shown to be more bilaterally distributed (De Chastelaine, Wang, Minton, Muftuler, & Rugg, 2011; Giovanello, Schnyer, & Verfaellie, 2004). Unlike traditional associative memory tasks, participants in Experiment 5 were unaware of the memory test. Semantic priming tasks typically engage left prefrontal areas more strongly, so processing should have been biased for the LH (e.g., Wagner, Paré-Blagoev, Clark, & Poldrack, 2001). Another alternative explanation is that memory retrieval tapped into more bilaterally distributed memory processes, such as recollection. However, this would still not explain why false recognition rates were the same in both hemispheres. False recognitions are thought to be more familiarity based, and imaging evidence has suggested that familiarity may be more RH-lateralized (Dobbins et al., 2004). There is a possibility that the study task may have not strongly biased hemispheric processing in general. Different results may have been obtained if prime-target pairs in the study task were lateralized, along with items used during the memory test.

General Conclusions

The primary goal for Experiments 1-5 was to explore and clarify the nature of top-down mechanisms that potentially influence hemispheric asymmetries in verbal memory. Two theoretical frameworks have attempted to explain hemispheric asymmetries in verbal processing. The Fine Coarse Semantic Coding Theory suggests that hemispheric asymmetries in verbal processing are due to inherent differences in the coding of representations between the cerebral hemispheres. The Production Affects Reception in the Left Only (PARLO) framework suggests that verbal processing differences are driven by how each hemisphere utilizes top-down mechanisms during processing. PARLO suggests that the LH processing is more expectancy-based: The LH is able to use top-down mechanisms to predict and pre-activate information based on incoming bottom-up language input. This enables the LH to extract the gist of information rapidly, and to only process the most relevant information necessary. According to PARLO, the use of controlled processing by the LH is its most distinct feature. In contrast, the RH is viewed as a more passive processor of information. The RH processes information in a bottom-up, veridical manner, only integrating it when necessary.

Experiments 1 and 2 explored the influence of top-down mechanisms on hemispheric verbal memory, through the use of item-method directed forgetting. Overall recognition memory did not differ between hemispheres in these experiments. Response time differences suggested that the LH and RH differ in the ability to modulate the strength of encoded verbal memories. Experiment 1 indicated that LH verbal memory was more influenced by maintenance mechanisms compared to RH verbal memory. Both Experiments 1 and 2 provided evidence that inhibitory mechanisms did not preferentially influence one hemisphere over another.

Experiments 3 and 4 examined how cognitive load manipulations influenced false and veridical memory in the cerebral hemispheres. Experiment 3 examined the influence of visual and verbal cognitive load during memory encoding, while Experiment 4 examined the influence of these cognitive loads on memory retrieval. Results from these experiments showed that there are significant effects of cognitive load during memory encoding, but not during retrieval. Cognitive load did not influence hemispheric false memory, but instead selectively impaired hemispheric veridical memory. Data from

Experiments 3 and 4 indicated that task difficulty (and to some degree, material specific processing) influenced veridical memory differently in the LH and the RH. Finally, Experiment 5 explored the potential association between controlled processes used in semantic priming, and top-down mechanisms in verbal memory. No hemispheric differences were observed in Experiment 5, which suggested that bilateral processes contribute the retrieval of word pairs from verbal memory.

The PARLO framework defines top-down mechanisms as “controlled” processes associated with the prediction and selection of appropriate semantic information from ongoing language input. In her original outline of PARLO, Federmeier (2007) first proposed that this was more of an inherent property of the LH. Lower levels of processing in the LH receive many more feedback connections from higher levels of processing (presumably from semantic and contextual levels). It was initially unclear what underlying cognitive mechanisms were responsible for this additional feedback in the LH. More recent conceptualizations of the PARLO framework suggest top-down mechanisms are a reflection of controlled semantic selection processes (Kandhadai & Federmeier, 2010b). This controlled semantic processing has been shown to be associated with domain general cognitive control processes, such as attentional control, executive functioning, and working memory (Hutchison, 2007; Rosen & Engle, 1997). Neuro-imaging studies also reveal that the brain areas involved with controlled semantic processing often overlap with brain areas that sub-serve working memory and executive functioning as well (Gabrieli, Poldrack, & Desmond, 1998; Kapur et al., 1994; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997). This suggests that top-down mechanisms proposed by the PARLO framework are biased to aid in more language specific processing, but also are involved with domain general cognitive control mechanisms.

The outlined experiments support this idea (to varying degrees) and help provide some boundary conditions for PARLO's definition of top-down mechanisms used by the LH. Top-down mechanisms used by the LH seem to be primarily language-specific and verbal in nature. Results from Experiment 1 suggest maintenance processes influence information encoded in the LH more than in the RH. Mechanisms not specialized for any type of modal information, such as inhibition, do not preferentially influence processing in one hemisphere over another. This is surprising, as inhibitory processes have been shown to be more right lateralized to the prefrontal cortex / inferior frontal gyrus. These areas are likely a single part of a larger interconnected cortical network that is involved with cognitive control (Fassbender et al., 2006; Wang et al., 2010).

Findings from Experiments 3 and 4 provide additional evidence for the language specific and domain general nature of top-down mechanisms used by the LH. Veridical memory differed based on the type of secondary task completed during encoding. The Verbal Task impacted veridical memory in the LH more so than veridical memory in the RH. This suggests two things: First, cognitive load disrupts maintenance and rehearsal processes that are better utilized by the LH. Second, source monitoring processes used by the LH have a more difficult time reinstating item and context specific information for old words. This appears to support the idea that the hemispheres engage in more material specific processing. However, veridical memory was equally disrupted in the LH for Visual Task condition. Veridical memory was disrupted even more in the RH for the

Visual Task condition. These particular data indicate that top-down mechanisms used by the LH are biased for the processing of verbal information to some degree, but can also operate in a more domain general fashion under processing conditions that require more attentional and executive resources.

The role of the RH in verbal / language processing is notably vaguer. In Experiment 3, the RH is also shown to be more impervious to the effects of verbal interference. Only a more demanding secondary task, the Visual Task, caused a significant decline in RH veridical memory. This suggests that monitoring processes are not entirely absent during RH memory retrieval, but exert a lesser degree of influence compared to LH memory retrieval. The steep decline of RH veridical memory in the Visual Task condition is also interesting because it indicates that only more severe disruptions during encoding influence RH memory. Mild disruptions may have less of an impact on RH memory. This is also supported by evidence that has shown that memory impairments tend to be less severe following RH damage compared to LH damage (De Renzi & Nichelli, 1975). The RH may be storing additional episodic details for verbal information that the LH does not, such as less relevant semantic features for words (Beeman & Chiarello, 1998). Aside from semantic information, the RH has access to lower level perceptual information, such as visual form information for printed words, and voice information for spoken words (González & McLennan, 2007; Marsolek, 2004). The PARLO framework does not make it clear as to why the RH should have this ability. PARLO suggests that the RH operates as a bottom-up processor of information, used to maintain distant semantic relationships, and to integrate such information when necessary. However, this does not provide a more mechanistic explanation for why RH representations are less susceptible to disruptions. Right hemisphere abilities are better explained through the Fine Coarse Semantic Coding Theory. Jung-Beeman (2005) notes that broadly organized “semantic-fields” in the RH are advantageous for the activation and maintenance of less relevant semantic features. Further, patients with RH damage exhibit relatively subtle processing deficits, usually in language comprehension. These individuals tend to misinterpret non-literal information and are less able to bridge or integrate gaps in larger discourse (Brownell, Potter, Bihrle, & Gardner, 1986). Right hemisphere damage may potentially leave dominant and frequent semantic information intact at the expense of more less related semantic information. Coarsely coded information in the RH may be advantageous: damage is less likely to affect the entirety of the representation itself, leaving some information intact. Additional investigations to examine the precise nature of verbal information stored in the RH are warranted.

With regards to the Visual Task and RH memory, it is more probable that decreases in memory performance were due to task difficulty rather than the visuo-spatial nature of the task. Decreases in memory performance were observed in both hemispheres in the Visual Task condition, which potentially suggest there was bilateral recruitment of more central, executive resources. As in the discussion of Experiments 3 and 4, task difficulty may cause additional recruitment of prefrontal areas. Further, individuals with higher working memory capacity are able to recruit bilateral frontal areas when cognitive processing demands become more difficult. This has been observed outside of the memory domain. When individuals are required to create and bridge inferences to comprehend discourse information, left and right prefrontal areas are strongly activated (Virtue, Parrish, & Jung-Beeman, 2008). It is likely that these frontal regions sub-serve both memory and language, perhaps reflecting the influences of more domain general processing mechanisms.

Future Directions

Two possible directions could be taken that may extend the findings reported in Experiments 1 and 2 (Item-Method Directed Forgetting). First, the lateralization of Remember and Forget words during the study phase may provide more direct evidence for maintenance and inhibition mechanisms used by either hemisphere. The current method indirectly probes each hemisphere for evidence of these mechanisms via performance on the memory test. Embedding probe tasks, such as ones used by Fawcett and Taylor (2008, 2010) may allow for more direct observation of maintenance and inhibition mechanisms. Second, repetition in Experiment 2 did not have the intended effect of increasing the memorial strength for Forget words. Other type of manipulations may more readily influence maintenance and rehearsal mechanisms. For example, increasing presentation time may allow participants to rehearse words more, leading to improvement to overall memory performance (Ratcliff, Clark, & Shiffrin, 1990)

For Experiments 3 and 4, the difficulty of the secondary task influences veridical memory in each hemisphere differently. Increasing the task difficult for *only* the Verbal Task would provide additional evidence that the LH is more influenced by cognitive load manipulations, and that results from each experiment were more due to task difficulty rather than material specific processing. One way to increase the difficulty for the Verbal Task is to employ a manipulation that is commonly used in to increase difficulty another type of task, the *N*-back task (Kirchner, 1958). In the *N*-back task, participants see a series of stimuli sequentially, and are asked if the current presentation of a stimulus identically matches another stimulus *n* number of trials back. To manipulate difficulty, participants can be asked to match stimuli 1 trial back, 2 trials back, or 3 trials back. Experiments 3 and 4 closely mimic a 1-back task, as participants only had to determine if a number or shape was different compared to the trial immediately preceding it. If difficulty did drive the results observed in Experiment 3, a 2-back or 3-back task may replicate memory performance observed in the original Visual Task. This would provide additional evidence that veridical memory is directly influenced by processing demands, ultimately influencing how the hemispheres actively use maintenance and monitoring mechanisms for memory encoding and retrieval. Finally, in Experiment 4, secondary tasks did not influence memory performance during retrieval. Increasing difficulty of the secondary task at memory retrieval may alter memory performance, potentially revealing hemispheric differences during memory retrieval.

Despite the unique method employed in Experiment 5, no hemispheric effects were observed. As discussed previously, it is possible that encoding and retrieval processes in Experiment 5 invoked more bilateral processing of stimuli. Many prior hemispheric semantic priming studies have lateralized prime-target. This is usually done to obtain a clearer picture of semantic processing mechanisms that may differ between hemispheres (see Fassbinder & Tompkins, 2006). Lateralizing prime-target pairs during the study phase and memory test may reveal more hemisphere specific processes that are associated with both semantic priming and verbal memory. In addition, manipulating SOA of prime-target pairs, instead of RP, may provide a better contrast between automatic and controlled semantic processing. One limitation of Experiment 5 was that

Synonym proportion could not go below 50%. If Synonym proportion was below 50%, this would have created an uneven number of target items across conditions for the subsequent memory test. The inclusion of a short and long SOA condition could provide a better contrast between automatic and controlled processing, and may reveal hemispheric differences in the use of these processes in a later memory test.

In a similar vein, a potential limitation across the studies reported here is the use of central presentation of target words in all study phases in each experiment. Central presentation of words during each study phase was used in order to reduce potential perceptual biases may occur with the lateral presentation of words. Words presented to the RVF-LH can be seen more clearly, and are likely to be processed more easily than words presented to the LVF-RH (see Jordan & Patching, 2004). Participants may have a harder time seeing words and processing words presented to the LVF-RH. If they study words in the LVF-RH, and resulting memory performance is worse, poor memory could be attributed to perceptual degradation of words presented to the LVF-RH, rather than a specific memory process. However, it has been suggested that the central presentation of stimuli may obscure hemispheric contributions during processing (Evans & Federmeier, 2009). For example, Wlotko and Federmeier (2007) found hemispheric differences in the processing of sentences with highly predictable contexts. They noted that the N400 differed between hemispheres (with greater facilitation observed in the LH). More importantly, when ERP waveforms from both hemispheres were summed, they resembled N400 signatures from studies utilizing only centralized presentation (e.g., Kutas & Hillyard, 1984). Lateralizing words during encoding may provide additional details regarding potential hemispheric asymmetries in the use of top-down mechanisms.

General Summary

In conclusion, the present investigation suggests that hemispheric asymmetries in verbal memory can also be attributed to differences in the utilization of top-down mechanisms between hemispheres. It was previously suggested that the type of representational coding between the cerebral hemispheres accounted for verbal memory and language processing differences. It is more likely that a combination of factors, which include both coding differences, and differences in the use of top-down mechanisms, contributes to hemispheric asymmetries in verbal memory and language processing. The present study also adds to a growing body of evidence to suggest that more general processing constructs are involved with the encoding of verbal information in the cerebral hemispheres. While top-down mechanisms used by the LH are predominately verbally oriented, these mechanisms are only a part of a larger domain general construct that involves cognitive control and executive functions.

References

Abernethy, M., & Coney, J. (1993). Associative priming in the hemispheres as a function of SOA. *Neuropsychologia*, *31*(12), 1397–1409. doi:10.1016/0028-3932(93)90106-A

Abernethy, M., & Coney, J. (1996). Semantic category priming in the left cerebral hemisphere. *Neuropsychologia*, *34*(5), 339–350. doi:10.1016/0028-3932(95)00144-1

Anaki, D., Faust, M., & Kravetz, S. (1998). Cerebral hemispheric asymmetries in processing lexical metaphors. *Neuropsychologia*, *36*(7), 691–700. doi:10.1016/S0028-3932(97)00141-3

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, *8*(4), 170–7. doi:10.1016/j.tics.2004.02.010

Atchley, R. A., Burgess, C., & Keeney, M. (1999). The effect of time course and context on the facilitation of semantic features in the cerebral hemispheres. *Neuropsychology*, *13*(3), 389–403. doi:10.1037//0894-4105.13.3.389

Atchley, R. A., Keeney, M., & Burgess, C. (1999). Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval and creativity. *Brain and Cognition*, *40*(3), 479–99. doi:10.1006/brcg.1999.1080

Awh, E., Jonides, J., & Smith, E. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science*, *7*(1), 25–31. Retrieved from http://www.jstor.org/stable/10.2307/40062903

Badre, D., Poldrack, R. A., Paré-Blagoev, E. J., Insler, R. Z., & Wagner, A. D. (2005). Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. *Neuron*, *47*(6), 907–18. doi:10.1016/j.neuron.2005.07.023

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia*, *45*(13), 2883–901. doi:10.1016/j.neuropsychologia.2007.06.015

Balota, D., Cortese, M., Duchek, J., Adams, D., Roediger, H., McDermott, K. B., & Yerys, B. (1999). Veridical and false memories in healthy older adults and in dementia of the Alzheimer’s type. *Cognitive Neuropsychology*, *16*, 361–384. Retrieved from http://www.tandfonline.com/doi/full/10.1080/026432999380834

Basden, B. H., Basden, D. R., & Gargano, G. J. (1993). Directed forgetting in implicit and explicit memory tests: A comparison of methods. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(3), 603–616. doi:10.1037//0278-7393.19.3.603

Beeman, M. J., Friedman, R. B., Grafman, J., Perez, E., Diamond, S., & Lindsay, M. B. (1994). Summation Priming and Coarse Semantic Coding in the Right Hemisphere. *Journal of Cognitive Neuroscience*, *6*(1), 26–45. doi:10.1162/jocn.1994.6.1.26

Beeman, M. J., Bowden, E., & Gernsbacher, M. (2000). Right and left hemisphere cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language*, *71*(2), 310–36. doi:10.1006/brln.1999.2268

Beeman, M. J., & Chiarello, C. (1998). Complementary Right- and Left-Hemisphere Language Comprehension. *Current Directions in Psychological Science*, *7*(1), 2–8. doi:10.1111/1467-8721.ep11521805

Bellamy, K. J., & Shillcock, R. (2007). A right hemisphere bias towards false memory. *Laterality*, *12*(2), 154–66. doi:10.1080/13576500601051648

Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology*, *21*(4), 458–69. doi:10.1037/0894-4105.21.4.458

Ben-Artzi, E., Faust, M., & Moeller, E. (2009). Hemispheric asymmetries in discourse processing: evidence from false memories for lists and texts. *Neuropsychologia*, *47*(2), 430–8. doi:10.1016/j.neuropsychologia.2008.09.021

Benson, D. F., & Ardila, A. (1996). *Aphasia: A clinical perspective*. Oxford University Press on Demand.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. *Varieties of memory & consciousness*, 309–330.

Brainerd, C., Reyna, V., & Kneer, R. (1995). False-Recognition Reversal: When Similarity is Distinctive. *Journal of Memory and Language*, *34*(2), 157–185. doi:10.1006/jmla.1995.1008

Brownell, H. H., Potter, H. H., Bihrle, A. M., & Gardner, H. (1986). Inference deficits in right brain-damaged patients. *Brain and Language*, *27*(2), 310–321.

Buckner, R. L. (1996). Beyond HERA: Contributions of specific prefrontal brain areas to long-term memory retrieval. *Psychonomic Bulletin & Review*, *3*(2), 149–158. doi:10.3758/BF03212413

Burgess, C., & Simpson, G. B. (1988). Cerebral hemispheric mechanisms in the retrieval of ambiguous word meanings. *Brain and Language*, *33*(1), 86–103. doi:10.1016/0093-934X(88)90056-9

Challis, B. H., & Sidhu, R. (1993). Dissociative effect of massed repetition on implicit and explicit measures of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(1), 115–27. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8423430

Chiarello, C., Burgess, C., Richards, L., & Pollock, A. (1990). Semantic and associative priming in the cerebral hemispheres: some words do, some words don't ... sometimes, some places. *Brain and Language*, *38*(1), 75–104. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2302547

Chiarello, C., Liu, S., Shears, C., Quan, N., & Kacinik, N. (2003). Priming of strong semantic relations in the left and right visual fields: a time-course investigation. *Neuropsychologia*, *41*(6), 721–732. doi:10.1016/S0028-3932(02)00220-8

Chiarello, C., Maxfield, L., & Kahan, T. (1995). Initial right hemisphere activation of subordinate word meanings is not due to homotopic callosal inhibition. *Psychonomic Bulletin & Review*, *2*(3), 375–380. doi:10.3758/BF03210975

Chiarello, C., & Richards, L. (1992). Another look at categorical priming in the cerebral hemispheres. *Neuropsychologia*, *30*(4), 381–392. doi:10.1016/0028-3932(92)90111-X

Collins, A. M., & Loftus, E. F. (1975). A Spreading-Activation Theory of Semantic Processing. *Psychological Review*, *75*.

Collins, M. (1999). Differences in semantic category priming in the left and right cerebral hemispheres under automatic and controlled processing conditions. *Neuropsychologia*, *37*(9), 1071–85. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10468370

Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology*, *33A*(4), 497–505. Retrieved from http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm

Coney, J., & Macdonald, S. (1988). The effect of retention interval upon hemispheric processes in recognition memory. *Neuropsychologia*, *26*(2), 287–295. doi:10.1016/0028-3932(88)90081-4

Coulson, S., & Wu, Y. C. (2005). Right hemisphere activation of joke-related information: an event-related brain potential study. *Journal of Cognitive Neuroscience*, *17*(3), 494–506. doi:10.1162/0898929053279568

Craik, F. I., Govoni, R., Naveh-Benjamin, M., & Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, *125*(2), 159–80. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9747524

Crane, D., Maillet, D., Floden, D., Valiquette, L., & Rajah, M. N. (2011). Similarities in the patterns of prefrontal cortex activity during spatial and temporal context memory retrieval after equating for task structure and performance. *NeuroImage*, *54*(2), 1549–64. doi:10.1016/j.neuroimage.2010.09.001

Damasio, A. R. (1992). Aphasia. *New England Journal of Medicine*, *326*(8), 531–9. doi:10.1056/NEJM199202203260806

Davie, J. E., Azuma, T., Goldinger, S. D., Connor, D. J., Sabbagh, M. N., & Silverberg, N. B. (2004). Sensitivity to expectancy violations in healthy aging and mild cognitive impairment. *Neuropsychology*, *18*(2), 269–75. doi:10.1037/0894-4105.18.2.269

De Chastelaine, M., Wang, T. H., Minton, B., Muftuler, L. T., & Rugg, M. D. (2011). The effects of age, memory performance, and callosal integrity on the neural correlates of successful associative encoding. *Cerebral Cortex*, *21*(9), 2166–76. doi:10.1093/cercor/bhq294

De Renzi, E., & Nichelli, P. (1975). Verbal and non-verbal short-term memory impairment following hemispheric damage. *Cortex*, *11*(4), 341–354.

Delaney, P., & Sahakyan, L. (2007). Unexpected costs of high working memory capacity following directed forgetting and contextual change manipulations. *Memory & Cognition*, *35*(5), 1074–1082. Retrieved from http://www.springerlink.com/index/58P0322084TQ7727.pdf

Dobbins, I. G., Simons, J. S., & Schacter, D. L. (2004). fMRI evidence for separable and lateralized prefrontal memory monitoring processes. *Journal of Cognitive Neuroscience, 16*(6), 908–20. doi:10.1162/0898929041502751

Dulaney, C. L., Marks, W., & Link, K. E. (2004). Aging and directed forgetting: pre-cue encoding and post-cue rehearsal effects. *Experimental Aging Research*, *30*(1), 95–112. doi:10.1080/03610730490251504

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of Experimental Psychology: General*, *128*(3), 309–331. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10513398

Evans, K. M., & Federmeier, K. D. (2007). The memory that's right and the memory that's left: event-related potentials reveal hemispheric asymmetries in the encoding and retention of verbal information. *Neuropsychologia*, *45*(8), 1777–90. doi:10.1016/j.neuropsychologia.2006.12.014

Evans, K. M., & Federmeier, K. D. (2009). Left and right memory revisited: electrophysiological investigations of hemispheric asymmetries at retrieval. *Neuropsychologia*, *47*(2), 303–13. doi:10.1016/j.neuropsychologia.2008.08.027

Fabiani, M., Stadler, M. A., & Wessels, P. M. (2000). True but not false memories produce a sensory signature in human lateralized brain potentials. *Journal of Cognitive Neuroscience*, *12*(6), 941–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11177415

Fassbender, C., Simoes-Franklin, C., Murphy, K., Hester, R., Meaney, J., Robertson, I. H., & Garavan, H. (2006). The Role of a Right Fronto-Parietal Network in Cognitive Control. *Journal of Psychophysiology*, *20*(4), 286–296. doi:10.1027/0269-8803.20.4.286

Fassbinder, W., & Tompkins, C. A. (2006). Hemispheric differences in word-meaning processing: Alternative interpretations of current evidence. *Aphasiology*, *20*(2-4), 110–122. doi:10.1080/02687030500472397

Faust, M., Ben-Artzi, E., & Harel, I. (2008). Hemispheric asymmetries in semantic processing: evidence from false memories for ambiguous words. *Brain and Language*, *105*(3), 220–8. doi:10.1016/j.bandl.2007.12.002

Faust, M., & Lavidor, M. (2003). Semantically convergent and semantically divergent priming in the cerebral hemispheres: lexical decision and semantic judgment. *Cognitive Brain Research*, *17*(3), 585–597. doi:10.1016/S0926-6410(03)00172-1

Fawcett, J. M., & Taylor, T. L. (2008). Forgetting is effortful: evidence from reaction time probes in an item-method directed forgetting task. *Memory & Cognition*, *36*(6), 1168–81. doi:10.3758/MC.36.6.1168

Fawcett, J. M., & Taylor, T. L. (2010). Directed forgetting shares mechanisms with attentional withdrawal but not with stop-signal inhibition. *Memory & Cognition*, *38*(6), 797–808. doi:10.3758/MC.38.6.797

Federmeier, K. D. (2002). Picture the difference: electrophysiological investigations of picture processing in the two cerebral hemispheres. *Neuropsychologia*, *40*(7), 730–747. doi:10.1016/S0028-3932(01)00193-2

Federmeier, K. D. (2007). Thinking ahead: the role and roots of prediction in language comprehension. *Psychophysiology*, *44*(4), 491–505. doi:10.1111/j.1469-8986.2007.00531.x

Federmeier, K. D., & Benjamin, A. S. (2005). Hemispheric asymmetries in the time course of recognition memory. *Psychonomic Bulletin & Review*, *12*(6), 993–998. doi:10.3758/BF03206434

Federmeier, K. D., Mai, H., & Kutas, M. (2005). Both sides get the point: Hemispheric sensitivities to sentential constraint. *Memory & Cognition*, *33*(5), 871–886. doi:10.3758/BF03193082

Fernandes, M. A., & Moscovitch, M. (2000). Divided attention and memory: evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology: General*, *129*(2), 155–76. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10868332

Fernandes, M. A., & Moscovitch, M. (2002). Factors modulating the effect of divided attention during retrieval of words. *Memory & Cognition*, *30*(5), 731–44. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12219890

Gabrieli, J. D. E., Desmond, J. E., Demb, J. B., Wagner, A. D., Stone, M. V., Vaidya, C. J., & Glover, G. H. (1996). Functional Magnetic Resonance Imaging of Semantic Memory Processes in the Frontal Lobes. *Psychological Science*, *7*(5), 278–283. doi:10.1111/j.1467-9280.1996.tb00374.x

Gabrieli, J. D. E., Poldrack, R. A., & Desmond, J. E. (1998). The role of left prefrontal cortex in language and memory. *Proceedings of the National Academy of Sciences of the United States of America*, *95*(3), 906–13. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=33815&tool=pmcentrez&rendertype=abstract

Gallo, D. A., Roberts, M. J., & Seamon, J. G. (1997). Remembering words not presented in lists: Can we avoid creating false memories? *Psychonomic Bulletin & Review*, *4*(2), 271–6. doi:10.3758/BF03209405

Gallo, D. A., Roediger, H. L., & McDermott, K. B. (2001). Associative false recognition occurs without strategic criterion shifts. *Psychonomic Bulletin & Review*, *8*(3), 579–86. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11700910

Gallo, D. A. (2010). False memories and fantastic beliefs: 15 years of the DRM illusion. *Memory & Cognition*, *38*(7), 833–48. doi:10.3758/MC.38.7.833

Gallo, D. A., McDermott, K. B., Percer, J. M., & Roediger, Henry L., I. (2001). Modality effects in false recall and false recognition. *Journal of Experimental Psychology:*

Learning, Memory, and Cognition, *27*(2), 339–353. doi:10.1037//0278-7393.27.2.339

Geiselman, R. E., & Bagheri, B. (1985). Repetition effects in directed forgetting: evidence for retrieval inhibition. *Memory & Cognition*, *13*(1), 57–62. doi:10.3758/BF03198444

Geschwind, N. (1971). Current concepts: aphasia. *New England Journal of Medicine*, *284*(12), 654–6. doi:10.1056/NEJM197103252841206

Giammattei, J., & Arndt, J. (2012). Hemispheric asymmetries in the activation and monitoring of memory errors. *Brain and Cognition*, *80*(1), 7–14. doi:10.1016/j.bandc.2012.04.003

Giovanello, K. S., Schnyer, D. M., & Verfaellie, M. (2004). A critical role for the anterior hippocampus in relational memory: evidence from an fMRI study comparing associative and item recognition. *Hippocampus*, *14*(1), 5–8. doi:10.1002/hipo.10182

González, J., & McLennan, C. T. (2007). Hemispheric differences in indexical specificity effects in spoken word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(2), 410–24. doi:10.1037/0096-1523.33.2.410

Habib, R., Nyberg, L., & Tulving, E. (2003). Hemispheric asymmetries of memory: the HERA model revisited. *Trends in Cognitive Sciences*, *7*(6), 241–245. doi:10.1016/S1364-6613(03)00110-4

Harrington, A. (1987). Medicine, mind, and the double brain: A study in nineteenth-century thought. Princeton University Press (Princeton, NJ).

Heit, E., Brockdorff, N., & Lamberts, K. (2004). Strategic processes in false recognition memory. *Psychonomic Bulletin & Review*, *11*(2), 380–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15260209

Hellige, J. B. (1993). Unity of Thought and Action: Varieties of Interaction Between the Left and Right Cerebral Hemispheres. *Current Directions in Psychological Science*, *2*(1), 21–25. doi:10.1111/1467-8721.ep10770559

Hellige, J. B. (1995). Hemispheric asymmetry for components of visual information processing. *Brain Asymmetry* (pp. 99–121). The MIT Press.

Hintzman, D. L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review*, *95*(4), 528–551. doi:10.1037//0033-295X.95.4.528

Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(4), 645–62. doi:10.1037/0278-7393.33.4.645

Ito, Y. (2001). Hemispheric asymmetry in the induction of false memories. *Laterality*, *6*(4), 337–346. doi:10.1080/13576500143000050

Jacoby, L. L., & Whitehouse, K. (1989). An illusion of memory: False recognition influenced by unconscious perception. *Journal of Experimental Psychology: General*, *118*(2), 126–135. doi:10.1037//0096-3445.118.2.126

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, *114*(1), 3–28.

Jordan, T. R., & Patching, G. R. (2004). What do lateralized displays tell us about visual word perception? A cautionary indication from the word-letter effect. *Neuropsychologia*, *42*(11), 1504–1514. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15246288

Jordan, T. R., Patching, G. R., & Thomas, S. M. (2003). Assessing the Role of Hemispheric Specialisation, Serial-Position Processing, and Retinal Eccentricity in Lateralised Word Recognition. *Cognitive Neuropsychology*, *20*(1), 49–71. doi:10.1080/02643290244000185

Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences*, *9*(11), 512–8. doi:10.1016/j.tics.2005.09.009

Kandhadai, P., & Federmeier, K. D. (2010a). Hemispheric differences in the recruitment of semantic processing mechanisms. *Neuropsychologia*, *48*(13), 3772–81. doi:10.1016/j.neuropsychologia.2010.07.018

Kandhadai, P., & Federmeier, K. D. (2010b). Automatic and controlled aspects of lexical associative processing in the two cerebral hemispheres. *Psychophysiology*, *47*(4), 774–85. doi:10.1111/j.1469-8986.2009.00969.x

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. (A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse, Eds.)*Variation in working memory*. Oxford University Press.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 336–358. doi:10.1037//0278-7393.26.2.336

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, *9*(4), 637–671. doi:10.3758/BF03196323

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*(2), 189–217. doi:10.1037/0096-3445.133.2.189

Kapur, S., Rose, R., Liddle, P., Zipursky, R., Brown, G., Stuss, D., Houle, S., et al. (1994). The role of the left prefrontal cortex in verbal processing: semantic processing or willed action? *Neuroreport*, *5*, 2193–2196. Retrieved from http://psycnet.apa.org/psycinfo/1995-16398-001

Kelley, W. M., Miezin, F. M., McDermott, K. B., Buckner, R. L., Raichle, M. E., Cohen, N. J., Ollinger, J. M., et al. (1998). Hemispheric specialization in human dorsal frontal cortex and medial temporal lobe for verbal and nonverbal memory encoding. *Neuron*, *20*(5), 927–936. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9620697

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of Experimental Psychology*, *55*(4), 352.

Knott, L. M., & Dewhurst, S. A. (2007a). Divided attention at retrieval disrupts knowing but not remembering. *Memory*, *15*(6), 664–74. doi:10.1080/09658210701467137

Knott, L. M., & Dewhurst, S. A. (2007b). The effects of divided attention at study and test on false recognition: a comparison of DRM and categorized lists. *Memory & Cognition*, *35*(8), 1954–65. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18265611

Koivisto, M., & Laine, M. (2000). Hemispheric asymmetries in activation and integration of categorical information. *Laterality*, *5*(1), 1–21. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15513126

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Dartmouth Publishing Group.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, *307*(5947), 161–163. doi:10.1038/307161a0

Laeng, B., Øvervoll, M., & Ole Steinsvik, O. (2007). Remembering 1500 pictures: the right hemisphere remembers better than the left. *Brain and Cognition*, *63*(2), 136–44. doi:10.1016/j.bandc.2006.10.009

Lee, A., Robbins, T., Pickard, J., & Owen, A. (2000). Asymmetric frontal activation during episodic memory: the effects of stimulus type on encoding and retrieval. *Neuropsychologia*, *38*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0028393299000949

Lim, C., & Alexander, M. P. (2009). Stroke and episodic memory disorders. *Neuropsychologia*, *47*(14), 3045–58. doi:10.1016/j.neuropsychologia.2009.08.002

Lindell, A. K. (2006). In your right mind: right hemisphere contributions to language processing and production. *Neuropsychology Review*, *16*(3), 131–48. doi:10.1007/s11065-006-9011-6

MacLeod, C. M. (1999). The item and list methods of directed forgetting: test differences and the role of demand characteristics. *Psychonomic Bulletin & Review*, *6*(1), 123–9. doi:10.3758/BF03210819

Macmillan, N. A., & Kaplan, H. L. (1985). Detection theory analysis of group data: Estimating sensitivity from average hit and false-alarm rates. *Psychological Bulletin*, *98*(1), 185–199. doi:10.1037/0033-2909.98.1.185

Mangels, J. A., Craik, F. I. M., Levine, B., Schwartz, M. L., & Stuss, D. T. (2002). Effects of divided attention on episodic memory in chronic traumatic brain injury: a function of severity and strategy. *Neuropsychologia*, *40*(13), 2369–85. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12417466

Marsolek, C. J. (2004). Abstractionist versus exemplar-based theories of visual word priming: a subsystems resolution. *The Quarterly Journal of Experimental Psychology*, *57*(7), 1233–59. doi:10.1080/02724980343000747

Marsolek, C. J., Kosslyn, S. M., & Squire, L. R. (1992). Form-specific visual priming in the right cerebral hemisphere. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(3), 492–508. doi:10.1037//0278-7393.18.3.492

Mashal, N., Faust, M., & Hendler, T. (2005). The role of the right hemisphere in processing nonsalient metaphorical meanings: application of principal components analysis to fMRI data. *Neuropsychologia*, *43*(14), 2084–100. doi:10.1016/j.neuropsychologia.2005.03.019

McClelland, J. L., & Chappell, M. (1998). Familiarity breeds differentiation: A subjective-likelihood approach to the effects of experience in recognition memory. *Psychological Review*, *105*(4), 724–760. doi:10.1037/0033-295X.105.4.734-760

McDermott, K. B. (1997). Priming on perceptual implicit memory tests can be achieved through presentation of associates. *Psychonomic Bulletin & Review, 4*(4), 582–586. Retrieved from http://link.springer.com/article/10.3758/BF03214353

McDermott, K. B., & Watson, J. M. (2001). The Rise and Fall of False Recall: The Impact of Presentation Duration. *Journal of Memory and Language*, *45*(1), 160–176. doi:10.1006/jmla.2000.2771

Metcalfe, J., Funnell, M., & Gazzaniga, M. S. (1995). Right-Hemisphere Memory Superiority: Studies of a Split-Brain Patient. *Psychological Science*, *6*(3), 157–164. doi:10.1111/j.1467-9280.1995.tb00325.x

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, *90*(2), 227.

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, *27*(3), 272–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4937273

Mitchell, K. J., & Johnson, M. K. (2009). Source monitoring 15 years later: what have we learned from fMRI about the neural mechanisms of source memory? *Psychological Bulletin*, *135*(4), 638–77. doi:10.1037/a0015849

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, *76*(2), 165–178.

Mummery, C. J., Shallice, T., & Price, C. J. (1999). Dual-process model in semantic priming: A functional imaging perspective. *NeuroImage*, *9*(5), 516–525. doi:10.1006/nimg.1999.0434

Murdock, B. B. (1982). A theory for the storage and retrieval of item and associative information. *Psychological Review*, *89*(6), 609–626.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. B. G. W. Humphreys (Ed.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (2004). The University of South Florida free association, rhyme, and word fragment norms. *Behavior Research Methods*, *36*(3), 402–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15641430

Nowicka, A., Marchewka, A., Jednoróg, K., Tacikowski, P., & Brechmann, A. (2011). Forgetting of emotional information is hard: an fMRI study of directed forgetting. *Cerebral Cortex*, *21*(3), 539–49. doi:10.1093/cercor/bhq117

Nyberg, L., Cabeza, R., & Tulving, E. (1996). PET studies of encoding and retrieval: The HERA model. *Psychonomic Bulletin & Review*, *3*(2), 135–148. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=1996-04621-001

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4

Ozen, L. J., Skinner, E. I., & Fernandes, M. A. (2010). Rejecting familiar distracters during recognition in young adults with traumatic brain injury and in healthy older adults. *Journal of the International Neuropsychological Society*, *16*(3), 556–65. doi:10.1017/S1355617710000202

Perry, R., & Hodges, J. (1999). Attention and executive deficits in Alzheimer's disease A critical review. *Brain*, 383–404. Retrieved from http://brain.oxfordjournals.org/content/122/3/383.short

Ratcliff, R., Clark, S. E., & Shiffrin, R. M. (1990). List-strength effect: I. Data and discussion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(2), 163–178. doi:10.1037//0278-7393.16.2.163

Rizio, A. A., & Dennis, N. A. (2013). The neural correlates of cognitive control: successful remembering and intentional forgetting. *Journal of Cognitive Neuroscience*, *25*(2), 297–312. doi:10.1162/jocn_a_00310

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(4), 803–814. doi:10.1037/0278-7393.21.4.803

Roediger, H. L., Watson, J. M., McDermott, K. B., & Gallo, D. A. (2001). Factors that determine false recall: A multiple regression analysis. *Psychonomic Bulletin & Review*, *8*(3), 385–407. doi:10.3758/BF03196177

Rosen, V. M., & Engle, R. W. (1998). Working Memory Capacity and Suppression. *Journal of Memory and Language*, *39*(3), 418–436. doi:10.1006/jmla.1998.2590

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*(3), 211–227. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9281831

Rossell, S., Bullmore, E., Williams, S., & David, A. (2001). Brain activation during automatic and controlled processing of semantic relations: a priming experiment using lexical-decision. *Neuropsychologia*, *39*(11), 1167–1176. doi:10.1016/S0028-3932(01)00049-5

Rossell, S., Price, C. J., & Nobre, A. C. (2003). The anatomy and time course of semantic priming investigated by fMRI and ERPs. *Neuropsychologia*, *41*(5), 550–564.

Rypma, B., Prabhakaran, V., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. (1999). Load-dependent roles of frontal brain regions in the maintenance of working memory. *NeuroImage*, *9*(2), 216–26. doi:10.1006/nimg.1998.0404

Schacter, D., Israel, L., & Racine, C. (1999). Suppressing false recognition in younger and older adults: The distinctiveness heuristic. *Journal of Memory and Language*, *24*, 1–24. Retrieved from http://www.sciencedirect.com/science/article/pii/S0749596X98926110

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User's guide*. Psychology Software Incorporated.

Sego, S. A., Golding, J. M., & Gottlob, L. R. (2006). Directed forgetting in older adults using the item and list methods. *Aging, Neuropsychology, and Cognition*, *13*(1), 95–114. doi:10.1080/138255890968682

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: an individual differences approach. *Journal of Experimental Psychology: General*, *125*(1), 4–27. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8851737

Smith, E. E., Jonides, J., & Koeppe, R. A. (1996). Dissociating Verbal and Spatial Working. *Cerebral Cortex*, *6*, 11–20.

Stadler, M. A., Roediger, H. L., & McDermott, K. B. (1999). Norms for word lists that create false memories. *Memory & Cognition*, *27*(3), 494–500. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10355238

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: a reevaluation. *Proceedings of the National Academy of Sciences of the United States of America*, *94*(26), 14792–7. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=25116&tool=pmcentrez&rendertype=abstract

Toglia, M. P., Neuschatz, J. S., & Goodwin, K. A. (1999). Recall accuracy and illusory memories: when more is less. *Memory*, *7*(2), 233–56. doi:10.1080/741944069

Ullsperger, M., Mecklinger, A., & Muller, U. (2000). An electrophysiological test of directed forgetting: The role of retrieval inhibition. *Journal of Cognitive Neuroscience*, *12*(6), 924–940. doi:10.1162/08989290051137477

Unsworth, N., & Brewer, G. A. (2009). Examining the relationships among item recognition, source recognition, and recall from an individual differences perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(6), 1578–85. doi:10.1037/a0017255

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*(1), 104–32. doi:10.1037/0033-295X.114.1.104

Vanderploeg, R. D., Crowell, T. A., & Curtiss, G. (2001). Verbal learning and memory deficits in traumatic brain injury: encoding, consolidation, and retrieval. *Journal of Clinical and Experimental Neuropsychology*, *23*(2), 185–195. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18443942

Vilkki, J. (1987). Incidental and deliberate memory for words and faces after focal cerebral lesions. *Neuropsychologia*, *25*(1), 221–230. doi:10.1016/0028-3932(87)90133-3

Virtue, S., Parrish, T., & Jung-Beeman, M. (2008). Inferences during story comprehension: cortical recruitment affected by predictability of events and working memory capacity. *Journal of Cognitive Neuroscience*, *20*(12), 2274–84. doi:10.1162/jocn.2008.20160

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory: a meta-analysis. *Cognitive, Affective & Behavioral Neuroscience*, *3*(4), 255–74. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15040547

Wagner, A. D., Desmond, J. E., Demb, J. B., Glover, G. H., & Gabrieli, J. D. E. (1997). Semantic Repetition Priming for Verbal and Pictorial Knowledge: A Functional MRI Study of Left Inferior Prefrontal Cortex. *Journal of Cognitive Neuroscience*, *9*(6), 714–726. doi:10.1162/jocn.1997.9.6.714

Wagner, A., Paré-Blagoev, E., Clark, J., & Poldrack, R. A. (2001). Recovering meaning: left prefrontal cortex guides controlled semantic retrieval. *Neuron*, *31*(2), 329–38. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11502262

Wagner, A., Poldrack, R. A., & Eldridge, L. (1998). Material-specific lateralization of prefrontal activation during episodic encoding and retrieval. …, *9*(16), 3711–3717. Retrieved from http://journals.lww.com/neuroreport/Abstract/1998/11160/Material_specific_lateralization_of_prefrontal.26.aspx

Wang, L., Liu, X., Guise, K. G., Knight, R. T., Ghajar, J., & Fan, J. (2010). Effective connectivity of the fronto-parietal network during attentional control. *Journal of Cognitive Neuroscience*, *22*(3), 543–53. doi:10.1162/jocn.2009.21210

West, B., Welch, K. B., & Galecki, A. T. (2006). *Linear mixed models: a practical guide using statistical software*. CRC Press.

Westerberg, C. E., & Marsolek, C. J. (2003). Hemispheric Asymmetries in Memory Processes as Measured in a False Recognition Paradigm. *Cortex*, *39*(4-5), 627–642. doi:10.1016/S0010-9452(08)70857-8

Wetzel, C. D., & Hunt, R. E. (1977). Cue delay and the role of rehearsal in directed forgetting. *Journal of Experimental Psychology: Human Learning and Memory*, *3*(2), 233–245. Retrieved from http://login.ezproxy1.lib.asu.edu/login?url=http://search.proquest.com/docview/614323607?accountid=4485

Whitehouse, P. J. (1981). Imagery and verbal encoding in left and right hemisphere damaged patients. *Brain and Language*, *14*(2), 315–332.

Wiegner, S., & Donders, J. (1999). Performance on the California Verbal Learning Test after traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *21*(2), 159–170. Retrieved from http://acn.oxfordjournals.org/content/14/8/783.1.full.pdf+html

Wlotko, E. W., & Federmeier, K. D. (2007). Finding the right word: hemispheric asymmetries in the use of sentence context information. *Neuropsychologia*, *45*(13), 3001–14. doi:10.1016/j.neuropsychologia.2007.05.013

Wylie, G. R., Foxe, J. J., & Taylor, T. L. (2008). Forgetting as an active process: an FMRI investigation of item-method-directed forgetting. *Cerebral Cortex*, *18*(3), 670–82. doi:10.1093/cercor/bhm101

Zacks, R. T., Radvansky, G., & Hasher, L. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(1), 143–156. doi:10.1037/0278-7393.22.1.143

APPENDIX A

STIMULI USED IN EXPERIMENTS 1 AND 2

adult
angle
arc
arm
avenue
baby
ball
band
bank
bar
beach
bear
bed
bible
boat
bottle
boy
brain
bread
bridge
bright
camp
car
cast
cattle
cell
chief
city
clay
cloth
club
coffee
college
cook
corner
court
cover
cross
crowd
cry
cut
dark
deep
design
desk
dinner
dollar
dust
edge
enemy
estate
eye
fair
father
fellow
figure
fire
firm
food
forest
form
fort
frame
front
gas
goal
gold
grass
guy
hair
hard
hawk
heart
heat
heavy
hold
home
horse
human
husband
ice
inch
income
iron
jack
judge
kid
king
lady
lake
land
lawyer
lead
leader
library
liquid
liquor
load
lord
machine
mantle
march
market
master
match
metal
mine
morning
mouth
murder
night
nine
nose
page
paper
party
path
phone
pick
plane
plant
poet
porch
prison
product
race
record
red
region
rifle
river
salt
scale
school
seat
seed
sex
shape
sheet
show
sick
site
sky
sleep
smoke
snow
song
sound
spoke
spot
stand
step
store
story
suit
sun
tall
task
taste
tax
team
teeth
test
throat
title
tone
top
touch
tree
truck
uniform
union
valley
wage
walk
wall
war
watch
wave
weapon
well
wet
white
wife
wind
window
wire
wood
world
yellow
youth

APPENDIX B

WORD LISTS USED IN EXPERIMENTS 3 AND 4

ANGER	BREAD	CITY	DOCTOR	FRUIT
mad	*butter*	*town*	*nurse*	*apple*
fear	*food*	*crowded*	*sick*	*vegetable*
hate	*eat*	*state*	*lawyer*	*orange*
rage	*sandwich*	*capital*	*medicine*	*kiwi*
temper	*rye*	*streets*	*health*	*citrus*
fury	*jam*	*subway*	*hospital*	*ripe*
ire	*milk*	*country*	*dentist*	*pear*
wrath	*flour*	*New York*	*physician*	*banana*
happy	*jelly*	*village*	*ill*	*berry*
fight	*dough*	*metropolis*	*patient*	*cherry*
hatred	*crust*	*big*	*office*	*basket*
mean	*slice*	*Chicago*	*stethoscope*	*juice*

ARMY	CAR	COLD	FLAG	GIRL
navy	*truck*	*hot*	*banner*	*boy*
solider	*bus*	*snow*	*American*	*dolls*
United States	*train*	*warm*	*symbol*	*female*
rifle	*automobile*	*winter*	*stars*	*young*
Air Force	*vehicle*	*ice*	*anthem*	*dress*
draft	*drive*	*wet*	*stripes*	*pretty*
military	*jeep*	*frigid*	*pole*	*hair*
marines	*Ford*	*chilly*	*wave*	*niece*
march	*race*	*heat*	*raised*	*dance*
infantry	*keys*	*weather*	*national*	*beautiful*
captain	*garage*	*freeze*	*checkered*	*cute*
war	*highway*	*air*	*emblem*	*date*

BLACK	CHAIR	CUP	FOOT	HIGH
white	*table*	*mug*	*shoe*	*low*
dark	*sit*	*saucer*	*hand*	*clouds*
cat	*legs*	*tea*	*toe*	*up*
charred	*seat*	*measuring*	*kick*	*tall*
night	*couch*	*coaster*	*sandals*	*tower*
funeral	*desk*	*lid*	*soccer*	*jump*
color	*recliner*	*handle*	*yard*	*above*
grief	*sofa*	*coffee*	*walk*	*building*
blue	*wood*	*straw*	*ankle*	*noon*
death	*cushion*	*goblet*	*arm*	*cliff*
ink	*swivel*	*soup*	*boot*	*sky*
bottom	*stool*	*stein*	*inch*	*over*

LAMP	MOUNTAIN	PEN	RUBBER	SLOW
light	*hill*	*pencil*	*elastic*	*fast*
shade	*valley*	*write*	*bounce*	*lethargic*
table	*climb*	*fountain*	*gloves*	*stop*
bulb	*summit*	*leak*	*tire*	*listless*
post	*top*	*quill*	*ball*	*snail*
black	*molehill*	*felt*	*eraser*	*cautious*
cord	*peak*	*Bic*	*springy*	*delay*
desk	*plain*	*scribble*	*foam*	*traffic*
bright	*glacier*	*crayon*	*galoshes*	*turtle*
lighter	*goat*	*Cross*	*soles*	*hesitant*
read	*bike*	*tip*	*latex*	*speed*
on	*climber*	*marker*	*glue*	*quick*

LION	MUSIC	RIVER	SHIRT	SMELL
tiger	*note*	*water*	*blouse*	*nose*
circus	*sound*	*stream*	*sleeves*	*breathe*
jungle	*piano*	*lake*	*pants*	*sniff*
tamer	*sing*	*Mississippi*	*tie*	*aroma*
den	*radio*	*boat*	*button*	*hear*
cub	*band*	*tide*	*shorts*	*see*
Africa	*melody*	*swim*	*iron*	*nostril*
mane	*horn*	*flow*	*polo*	*whiff*
cage	*concert*	*run*	*collar*	*scent*
feline	*instrument*	*barge*	*vest*	*reek*
roar	*symphony*	*creek*	*pocket*	*stench*
fierce	*jazz*	*brook*	*jersey*	*fragrance*

MAN	NEEDLE	ROUGH	SLEEP	SOFT
woman	*thread*	*smooth*	*bed*	*hard*
husband	*pin*	*bumpy*	*rest*	*light*
uncle	*eye*	*road*	*awake*	*pillow*
lady	*sewing*	*tough*	*tired*	*plush*
mouse	*sharp*	*sandpaper*	*dream*	*loud*
male	*point*	*jagged*	*wake*	*cotton*
father	*prick*	*ready*	*snooze*	*fur*
strong	*thimble*	*coarse*	*blanket*	*touch*
friend	*haystack*	*uneven*	*doze*	*fluffy*
beard	*thorn*	*riders*	*slumber*	*feather*
person	*hurt*	*rugged*	*snore*	*furry*
handsome	*injection*	*sand*	*nap*	*downy*

SPIDER	TRASH
web	*garbage*
insect	*waste*
bug	*can*
fright	*refuse*
fly	*sewage*
arachnid	*bag*
crawl	*junk*
tarantula	*rubbish*
poison	*sweep*
bite	*scraps*
creepy	*pile*
animal	*dump*

SWEET	WINDOW
sour	*door*
candy	*glass*
sugar	*pane*
bitter	*shade*
good	*ledge*
taste	*sill*
tooth	*house*
nice	*open*
honey	*curtain*
soda	*frame*
chocolate	*view*
heart	*breeze*

THIEF	WISH
steal	*want*
robber	*dream*
crook	*desire*
burglar	*hope*
money	*well*
cop	*think*
bad	*star*
rob	*bone*
jail	*ring*
gun	*wash*
villain	*thought*
crime	*get*

APPENDIX C

WORD PAIRS USED IN EXPERIMENT 5

Prime Word	**Antonym Target**	**Synonym Target**	**New Related Foil**
above	*below*	*top*	*over*
absent	*present*	*missing*	*blank*
abstract	*concrete*	*vague*	*art*
add	*subtract*	*sum*	*total*
admit	*deny*	*confess*	*acknowledge*
awake	*asleep*	*conscious*	*alert*
basement	*attic*	*cellar*	*dungeon*
buy	*steal*	*purchase*	*sell*
calm	*hyper*	*mellow*	*relaxed*
candy	*vegetable*	*lollipop*	*mint*
capture	*release*	*trap*	*seize*
careful	*reckless*	*cautious*	*fragile*
catch	*throw*	*toss*	*pitch*
child	*adult*	*kid*	*baby*
circle	*square*	*sphere*	*loop*
clumsy	*graceful*	*awkward*	*careless*
coward	*brave*	*wimp*	*courage*
crazy	*sane*	*insane*	*nuts*
crooked	*straight*	*uneven*	*bent*
cry	*laugh*	*sob*	*weep*
cure	*infection*	*remedy*	*antidote*
dad	*mom*	*father*	*pop*
dark	*light*	*shadow*	*night*
dawn	*dusk*	*sunrise*	*early*
defend	*attack*	*protect*	*block*
dog	*cat*	*hound*	*puppy*
easy	*difficult*	*simple*	*basic*
enemy	*friend*	*opponent*	*foe*
exit	*enter*	*escape*	*outlet*
expensive	*cheap*	*valuable*	*priceless*
expert	*novice*	*pro*	*amateur*
fake	*real*	*pretend*	*fraud*
fancy	*plain*	*elaborate*	*elegant*
fast	*slow*	*quick*	*swift*
fix	*break*	*repair*	*mend*
fresh	*stale*	*crisp*	*raw*
girl	*boy*	*gal*	*doll*
grass	*weed*	*lawn*	*yard*
ground	*sky*	*earth*	*floor*
hand	*foot*	*finger*	*palm*

Prime Word	**Antonym Target**	**Synonym Target**	**New Related Foil**
hear	*deaf*	*listen*	*ear*
hero	*villain*	*idol*	*legend*
hidden	*obvious*	*secret*	*obscure*
husband	*wife*	*spouse*	*mate*
illusion	*reality*	*mirage*	*magic*
late	*early*	*tardy*	*delay*
leader	*follower*	*commander*	*captain*
lie	*truth*	*fib*	*deceive*
liquid	*solid*	*fluid*	*pint*
loose	*tight*	*lenient*	*free*
loser	*winner*	*failure*	*failure*
love	*hate*	*adore*	*passion*
low	*high*	*deep*	*shallow*
metal	*plastic*	*steel*	*bronze*
mountain	*valley*	*hill*	*cliff*
native	*foreign*	*local*	*indian*
neat	*messy*	*tidy*	*orderly*
nice	*mean*	*kind*	*friendly*
normal	*weird*	*ordinary*	*regular*
number	*letter*	*digit*	*math*
orange	*apple*	*citrus*	*peel*
pain	*pleasure*	*agony*	*torture*
perfume	*cologne*	*scent*	*fragrance*
permit	*forbid*	*allow*	*parking*
private	*public*	*personal*	*diary*
problem	*solution*	*conflict*	*crisis*
push	*pull*	*shove*	*pump*
quiet	*loud*	*silent*	*tranquil*
read	*write*	*print*	*book*
remember	*forget*	*recall*	*remind*
rest	*work*	*relax*	*nap*
reward	*punish*	*prize*	*medal*
rich	*poor*	*wealth*	*poverty*
rigid	*flexible*	*stiff*	*uptight*
rot	*decay*	*erode*	*decompose*
sad	*happy*	*depressed*	*sorrow*
safe	*danger*	*secure*	*guard*
sew	*rip*	*stitch*	*knit*
shout	*whisper*	*yell*	*scream*
shy	*outgoing*	*timid*	*modest*
sick	*healthy*	*ill*	*virus*

Prime Word	**Antonym Target**	**Synonym Target**	**New Related Foil**
sink	*float*	*drown*	*faucet*
sit	*stand*	*kneel*	*lay*
slim	*fat*	*skinny*	*lean*
small	*big*	*tiny*	*compact*
smile	*frown*	*laugh*	*cheerful*
smooth	*rough*	*flat*	*slick*
snow	*rain*	*frost*	*hail*
soft	*hard*	*fluffy*	*tender*
son	*daughter*	*brother*	*nephew*
sour	*sweet*	*bitter*	*honey*
start	*finish*	*begin*	*stop*
strong	*weak*	*powerful*	*brave*
student	*teacher*	*pupil*	*class*
success	*failure*	*achieve*	*prosper*
thin	*thick*	*slender*	*fine*
ugly	*pretty*	*repulsive*	*gross*
unique	*original*	*rare*	*special*
victory	*defeat*	*win*	*conquest*
wet	*dry*	*moist*	*damp*

APPENDIX D

INSTITUTIONAL REVIEW BOARD APPROVAL

Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Tamiko Azuma COOR
From:	Mark Roosa, Chair Soc Beh IRB
Date:	01/27/2012
Committee Action:	**Exemption Granted**
IRB Action Date:	01/27/2012
IRB Protocol #:	1201007301
Study Title:	Memory for Words in the Cerebral Hemispheres

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.