

SPECIAL ISSUE

HEMISPHERIC ASYMMETRIES IN MEMORY PROCESSES AS MEASURED IN A FALSE RECOGNITION PARADIGM

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ABSTRACT

Although memory differs in important ways between the left and right cerebral hemispheres, the nature of these differences remains controversial. We examined this issue in two experiments using a false memory paradigm that allowed novel tests of two theories that have not been assessed in a common paradigm previously. Lists of semantically related words (e.g., bed, rest, wake...), all highly associated to one “critical” word (e.g., sleep), were presented auditorily during a study phase. Memory for both the related words and the critical words was measured in a subsequent old/new recognition test using divided-visual-field word presentations. The most important results were that the ability to correctly reject previously unrepresented words was greater when test items were presented to the right visual field/left hemisphere (RVF/LH) than to the left visual field/right hemisphere (LVF/RH) and that participants were more confident in correctly rejecting unrepresented words when test items were presented to the RVF/LH than to the LVF/RH. Results were in line with the theory that associative activation of semantic information is restricted in the left hemisphere but diffuse in the right; however, these results contrasted with the theory that memory traces are interpretive in the left hemisphere but veridical in the right. A potential resolution to the seemingly contradictory theories of asymmetries in memory processing is briefly discussed.

Key words: divided visual field, false memory, functional hemispheric differences, recognition memory, semantic memory

INTRODUCTION

An important but unresolved issue in the neural basis of memory is how best to characterize hemispheric differences in memory, especially concerning the role of the right hemisphere in memory for verbal information (for a recent debate, see Chiarello and Beeman, 1997; Metcalfe et al., 1995). Two main approaches have emerged. By one view, the veridicality of memory traces differs across hemispheres. By another, stimulus items elicit different degrees of associative activation across hemispheres which affects memory for the items. In this article, we directly test these alternatives in a novel manner, using a false memory paradigm.

In one theoretical perspective, memory traces are stored in a relatively interpretive (i.e., inferential) manner in the left hemisphere but in a relatively veridical (i.e., accurate) manner in the right hemisphere (Metcalfe et al., 1995; cf. Zaidel, 1994). According to this theory, the left hemisphere stores traces that

include not only the information that was perceived during encoding, but also inferred information. This creates a situation in which category and schema-consistent events often are mistakenly remembered as being presented when actually they were not. In contrast, the right hemisphere stores traces that are more veridical, capturing relatively accurate information about only the events that actually occurred. These traces are fairly resistant to any confusions that could follow from activation of categories or schema-consistent information during encoding.

Evidence from recognition memory experiments supports this view. For example, after studying a list of words within a common category (e.g., words naming different fruits), a split-brain patient was better able to correctly reject new words from the same category in a subsequent recognition task when the test items were presented to the left visual field/right hemisphere (LVF/RH) than to the right visual field/left hemisphere (RVF/LH; Metcalfe et al., 1995). Similar results were observed in memory for individual slides presented within a slide show that depicted a schematic event (Phelps and Gazzaniga, 1992). These findings appear to indicate that right-hemisphere memory traces reflect actually presented information very accurately (i.e., veridically), whereas left-hemisphere memory traces reflect the results of a more interpretive process (i.e., inferring that items in a category or schema were presented).

In another perspective, both hemispheres store memories in a fairly interpretive manner, but they differ in the extent to which a to-be-remembered item activates associated semantic information during encoding or the extent to which a test item activates associated semantic information during retrieval. Relatively restricted (i.e., local) activation occurs in the left hemisphere, whereas relatively diffuse activation occurs in the right hemisphere (Chiarello and Beeman, 1997; Chiarello, 1998). According to this theory, when an item is processed in the left hemisphere, activation spreads locally only to concepts highly related to the input item. In the right hemisphere, however, activation spreads in a broader and more diffuse manner, resulting in activation of fairly distantly related information.

Evidence from semantic priming experiments supports this view. For example, when measured in lexical decision experiments, semantic priming from distantly related prime words (e.g., “deer” priming decisions on “pony”) was greater when the test items were presented to the LVF/RH than to the RVF/LH, even though priming from more directly related primes (e.g., “bee” priming decisions on “honey”) did not yield a hemisphere difference (Chiarello et al., 1990). Similarly, summation priming from three distantly related words was greater when test items were presented to the LVF/RH than to the RVF/LH, whereas direct priming from one strongly related word was greater when test items were presented to the RVF/LH than to the LVF/RH (Beeman et al., 1994). Due to this difference in the diffuseness of semantic activation, memory traces in the right hemisphere may reflect actually presented information *less* accurately than memory traces in the left hemisphere.

In general, the evidence in favor of the interpretive/veridical trace theory largely stems from recognition memory experiments, whereas the evidence in favor of the restricted/diffuse activation theory largely stems from short-term

semantic priming effects. This limits the comparability of evidence for the two views. One way to overcome this limitation is to use a common task, old/new recognition, but in an experiment in which the activation theory can be tested without compromising any important applications of that theory. A method that is well suited for this role is the false memory paradigm originally introduced by Deese (1959) and subsequently revived by Roediger and McDermott (1995).

In the false recognition version of this paradigm, lists of semantically related words (e.g., sour, candy, sugar,...tart, pie), all related to one “critical” word (e.g., sweet), are presented auditorily during an encoding phase. Subsequently, participants are given an old/new recognition test which includes a subset of the previously presented “related” words, as well as previously unrepresented critical words. Participants very frequently respond “old” to the new critical words. In other words, they exhibit an inability to correctly reject the critical words as not being presented during the encoding phase. Several studies have demonstrated that false recognition in this paradigm is likely due to encoding processes rather than retrieval processes (Gallo et al., 2001b; Neuschatz et al., 2001; Anastasi et al., 2000). When warned before the encoding phase that people frequently mis-remember hearing the critical word as part of the presented word lists, participants are able to significantly increase their ability to correctly reject the critical words. However, when warned after encoding but before the recognition test, participants still correctly reject the critical words at low rates comparable to experiments in which participants are not warned about the nature of the paradigm. The most widely accepted explanation for the poor ability to correctly reject critical words is that, during encoding, activation spreads in an associative manner from the related words to the critical words, which increases the subsequently judged familiarity of the critical words (see Roediger and McDermott, 1995; Wickens and Hirshman, 2000; Wixted and Stretch, 2000; Underwood, 1965). In this literature, activation that spreads from presented words to a word related to the presented words but not necessarily presented itself is known as associative activation (Wixted and Stretch, 2000; cf. Underwood, 1965). Such activation can be understood as the sort of spreading activation posited by the activation theory described above.

The interpretive/veridical trace theory and the restricted/diffuse activation theory produce different predictions for the patterns of correct rejections in this paradigm. If right-hemisphere memory traces are more veridical than those in the left, correct rejections of previously unrepresented items (i.e., lures) that are related to the actually presented words should be greater when test items are presented to the LVF/RH than to the RVF/LH. This hemisphere difference should be especially evident in the false recognition paradigm because the lures share schema and other semantic information with the actually presented words. In contrast, if right-hemisphere associative activation of items during encoding is more diffuse than that in the left, and if it is because of such associative activation that the lures are subsequently judged to be highly familiar at test, then correct rejections of lures should be *poorer* when test items are presented to the LVF/RH than to the RVF/LH. This hemisphere difference should be

especially evident in the false recognition paradigm because the broader the associative activation during encoding, the greater the likelihood that lures that are related to the actually presented words will have been activated during encoding and hence will be judged as “old” during the recognition test. We tested these predictions in the following experiments. During the study phase, lists of words were presented auditorily (as is standard for experiments using this paradigm), to ensure that the false memory effect would be robust; the effect is reduced when both encoding and test words are presented visually (see Smith and Hunt, 1998; Gallo et al., 2001a). To examine potential hemispheric asymmetries in memory, for each test trial, words were presented briefly in the left or right visual field, giving systems and processes in one hemisphere timing and stimulus-quality advantages over those in the other hemisphere.

EXPERIMENT 1

Method

Participants

Ninety-six undergraduate students at the University of Minnesota participated in this experiment in exchange for course credit. All were right-handed (mean laterality quotient = .84) as assessed through the Edinburgh Handedness Inventory (Oldfield, 1971). Only right-handed participants were used because they tend to exhibit greater functional lateralization effects than do left-handed people (e.g., Hellige, 1993). All participants also had normal or corrected-to-normal vision. Half of the participants were male, and the other half were female.

Materials

Thirty-two lists composed of 15 related words (e.g., sour, candy, sugar, ... tart, pie) related to one “critical” word (e.g., sweet) were used as experimental lists. Two additional lists of related words were used as fillers for each participant, one presented at the beginning and one presented at the end of the encoding phase, to attenuate primacy and recency effects. All of the these lists were selected from the Stadler et al. (1999) norms. Additionally, to help decrease the likelihood that participants would develop idiosyncratic study strategies during encoding after noticing the related nature of many of the word lists, and similarly to decrease development of idiosyncratic retrieval strategies during test, four lists of unrelated words were generated by the authors and also presented. These were presented as filler lists during encoding and individual words from these lists were presented as filler items during test.

The stimuli were presented using an Apple Power Macintosh 7600/132. During the encoding phase, the words were presented auditorily over headphones. For the recognition test, words were presented visually, in 24-point bold Helvetica font in black against a white background on an AppleVision 1710AV display. Words in the recognition test were presented to either the left

or right visual field such that the center of each word was 4.6° from the center of the monitor, and the inner edge of a word never appeared closer than 2.5° from the center. A 2 mm black dot was used as a fixation point in the center of the monitor, and a chin rest was used to ensure that participants' eyes were approximately 50 cm from the display. It is not yet clear whether any nasotemporal overlap exists along the vertical meridian of the visual field (Brysbaert, 1994), but even if a retinal midline of approximately 1° in width projects directly to both hemispheres (Bunt et al., 1977), the words presented in the recognition test were very likely lateralized. When instructed to fixate at a central point, participants have been shown to (mis)fixate 0.5° or more away from the fixation point on 12% of trials in divided-visual-field presentations (Jordan et al., 1998) but more than 1° from the fixation point on less than 1% of trials (Figure 1 of Jordan et al., 1998). Given that the inner edges of our words were never less (and often farther) than 2.5° from the fixation point, a part of a word may have fallen just within the retinal midline on very few trials if any (certainly no more than 1%).

Procedure

All participants were tested in individually conducted sessions. The initial encoding phase was immediately followed by the test phase.

Encoding Phase. Thirty-two related word lists and four filler lists were presented during encoding. Participants were instructed to focus on a central fixation point on the computer display while listening to each list of words presented over headphones at a rate of 1.5 sec per word. Following each list, the fixation point disappeared, and this was the signal for participants to attempt to complete a visual maze before the next list was presented. The maze task was included to separate the list presentations in a manner that prevented rehearsal of the previously presented list during the interlist intervals. After 20 sec, a short tone indicated that the next list would be presented in 2.5 sec. Participants were instructed to try to remember the words that they heard when they were presented, and they were told that their memories for these words would be tested later in the experiment.

The related words in each list were presented in order of association strength to the corresponding critical word (strongest association first, weakest association last). For half of the lists, the critical word was not presented during encoding. These critical words would be used as critical-word lures during the recognition test. In the other half of the lists, the critical word was actually presented, displacing one of the related words in the list. These critical words would be used as critical-word targets in the recognition test. The selection of which ordinal position would include the critical word was counterbalanced across participants and included all of the odd-numbered 1-15 ordinal positions. When a related word was replaced, this word would be used as related-word lure in the recognition test. When a related word was not replaced, it could be used as a related-word target. Counterbalancing across participants assured that all critical words and all odd-numbered related words were used as distractors and targets equally often across participants in the experiment.

Test Phase. The sequence of events for trials in the test phase was as follows. Participants looked directly at the central fixation point which appeared for 500 msec in the center of the computer display. Immediately following the fixation point, a word was presented briefly in the left or right visual field for 183 msec, followed by a blank display. Participants decided whether the word was old (presented previously during encoding) or new (not presented during encoding). If they judged that the word was old, they pressed the top button on a button box with their index finger, and if they judged that it was new, they pressed the bottom button with their thumb. Half of the participants used their right hand to respond, and the other half used their left hand. They were urged to respond as quickly and accurately as possible.

Sixty-four words from the related lists and 32 filler words were presented during the test phase. Of the 64 experimental words, half were lures (words that were not presented during encoding), and the other half were targets (words that were presented during encoding). The lures included 16 critical words and 16 related words, and the targets included 16 critical words and 16 related words. Within each of these subgroups of 16 words, eight were presented to the LVF/RH and eight were presented to the RVF/LH. The order of presentation of words during the recognition test was pseudorandom, with the constraints that no more than three consecutive trials included words that were presented in the same visual field, words that were of the same type (critical, related, or filler), or words that had the same correct response (new or old).

Results and Discussion

Hemispheric Asymmetries in Memory Processing

Correct Rejections of Lures. To test the most important prediction for this experiment, a two-way repeated-measures analysis of variance was conducted using correct-rejection rates (proportions of lures given “new” responses) as the dependent measure. The independent variables were lure type (critical lures vs. related lures) and visual field of test presentation (LVF/RH vs. RVF/LH). Both were manipulated within participants. The means and standard deviations for these conditions are presented in Table I.

Most important, the main effect of visual field of test presentation was significant, $F(1, 95) = 4.50$, $MSe = .02188$, $p < .05$. Lures were correctly rejected significantly more frequently when presented to the RVF/LH (.427) than to the LVF/RH (.395). In addition, the main effect of lure type was significant, $F(1, 95) = 328$, $MSe = .03342$, $p < .001$. Related lures (.580) were correctly rejected more often than critical lures (.242), replicating many previous studies (e.g., Miller and Wolford, 1999; Roediger and McDermott, 1995). The interaction between visual field of test presentations and lure type did not approach significance ($F < 1$).

The finding of a greater ability to correctly reject previously unrepresented words when they were presented directly to the RVF/LH than to the LVF/RH is in line with predictions from the restricted/diffuse activation theory but not with predictions from the interpretive/veridical trace theory. As described in the

TABLE I
Proportion Correct Rejections and Response Times for Correct Rejections (in msec) by Condition in Experiment 1 (Standard Deviations in Parentheses)

Dependent measure	Lure type	
	Critical	Related
Correct rejections		
LVF/RH	.224 (.166)	.567 (.232)
RVF/LH	.261 (.188)	.594 (.194)
Response times		
LVF/RH	1294 (443)	1235 (384)
RVF/LH	1235 (468)	1224 (364)

Note. LVF/RH = left visual field/right hemisphere; RVF/LH = right visual field/left hemisphere.

Introduction, the activation theory predicts relatively restricted associative activation from encoding items to other representations in the left hemisphere, and hence a significant *RVF/LH* advantage in correctly rejecting previously unrepresented lures that are related to the actually encoded items. In contrast, the interpretive/veridical trace theory predicts relatively veridical storage of encoding items in the right hemisphere, without inferential activation of associated information, and hence a significant *LVF/RH* advantage in correctly rejecting previously unrepresented lures that are related to the actually encoded items.

Response Times for Correct Rejections. An analogous two-way repeated-measures analysis of variance was conducted using response times for correctly rejected lures as the dependent variable. The independent variables were the same as those used in the analysis of correct-rejection rates (lure type and visual field of test presentation). The means and standard deviations for these conditions are presented in Table I. None of the effects approached significance in this analysis (all p s > .25), demonstrating that the significant effects in the analysis of correct-rejection rates were not compromised by any tradeoffs between speed and accuracy of response.

False Memory Effects

Probability of "Old" Responses. Another important prediction for this experiment was that the false memory effect per se would be observed. The traditional way to measure false recognition in this paradigm is to measure the probability of "old" responses given to the critical lures (i.e., the false-alarm rate for critical words) and to compare that value against the probability of "old" responses given to the related targets (i.e., the hit rate for related words). Typically, the false-alarm rate for critical words is at least equal to, if not greater than, the hit rate for related words, indicative of "false" or "illusory" recognition of the critical lures. Therefore, a three-way repeated-measures analysis of variance was conducted using the probability of "old" responses as the dependent measure. The three independent variables were word type (critical words vs. related words), visual field of test presentation (LVF/RH vs. RVF/LH), and presentation status (target vs. lure). All were manipulated within participants. The means and standard deviations for these conditions are presented in Table II.

TABLE II
Proportion "Old" Responses and Response Times for "Old" Responses (in msec) by Condition in Experiment 1 (Standard Deviations in Parentheses)

Dependent measure	Lures (false alarms)		Targets (hits)	
	Critical words	Related words	Critical words	Related words
Proportion "old"				
LVF/RH	.776 (.166)	.433 (.233)	.840 (.160)	.591 (.210)
RVF/LH	.739 (.188)	.406 (.194)	.815 (.157)	.603 (.201)
Response times				
LVF/RH	953 (252)	1090 (378)	898 (233)	1004 (293)
RVF/LH	909 (268)	1155 (313)	877 (240)	1015 (318)

Note. LVF/RH = left visual field/right hemisphere; RVF/LH = right visual field/left hemisphere.

Most important, the interaction between word type and presentation status was significant, $F(1, 95) = 20.0$, $MSe = .02768$, $p < .001$. In fact, when the false-alarm rate for critical words (.758) was directly tested against the hit rate for related words (.600), the simple effect contrast was significant, $F(1, 285) = 88.5$, $MSe = .02803$, $p < .001$. This replicated the typical false recognition effect of disproportionately high false-alarm rates for critical words compared against hit rates for related words (e.g., Roediger and McDermott, 1995).

In addition, the main effect of word type was significant in this analysis, $F(1, 95) = 616$, $MSe = .02519$, $p < .001$, indicating that participants responded "old" to critical words more often than to related words (.793 vs. .508, respectively). Also, the main effect of presentation status was significant, $F(1, 95) = 93.9$, $MSe = .03121$, $p < .001$, simply verifying that participants responded "old" more often to targets (.712) than to lures (.589). More interesting, the main effect of visual field of test presentation approached significance, $F(1, 95) = 3.25$, $MSe = .02219$, $p < .08$, indicating that participants responded "old" more frequently overall when test items were presented directly to the LVF/RH (.660) than to the RVF/LH (.641). Although it should be interpreted with caution because the effect only approached significance, this latter result also is in line with the restricted/diffuse activation theory. More diffuse activation in the right hemisphere during encoding may result in an overall larger amount of information being activated in the right hemisphere than in the left. If so, both old and new test items should generally reactivate recently activated representations to a greater degree in the right hemisphere than in the left, in a manner that causes a general tendency to respond "old." No other effects in this analysis approached significance (all $ps > .20$).

Response Times for "Old" Responses. An analogous three-way repeated-measures analysis of variance was conducted with response times for "old" responses as the dependent measure. The independent variables were the same as those used in the analysis of probability "old" responses (word type, visual field of test presentation, and presentation status). The means and standard deviations for these conditions are presented in Table II.

All three of the significant effects in the analysis of proportion "old" responses also were significant (in the same directions) in the analysis of response times. This indicates that the significant effects in the analysis of

proportion “old” responses were not compromised by any tradeoffs between speed and proportion “old” responses. For the main effect of word type, critical words given “old” responses were responded to faster than related words given “old” responses (909 msec vs. 1066 msec, respectively), $F(1, 95) = 77.9$, $MSe = 60,541$, $p < .001$. For the main effect of presentation status, targets given “old” responses (949 msec) were responded faster to than lures given “old” responses (1027 msec), $F(1, 95) = 5.32$, $MSe = 219,559$, $p < .05$. Most interesting, the interaction between word type and presentation status was significant, $F(1, 95) = 4.91$, $MSe = 47,073$, $p < .05$. This interaction reflects a novel measure of false recognition in this paradigm: Response times for false alarms to critical words (931 msec) were significantly faster than response times for hits to related words (1,010 msec), $F(1, 285) = 5.45$, $MSe = 109,058$, $p < .05$ (similar to the analogous effect in the proportion “old” responses). The only other significant effect in this response-time analysis was an interaction between word type and visual field of test presentation, $F(1, 95) = 5.31$, $MSe = 44,746$, $p < .05$. For critical words, RVF/LH presentations were responded to slightly faster than LVF/RH (893 msec vs. 926 msec, respectively). For related words, RVF/LH presentations were responded to slightly slower (1085 msec) than LVF/RH presentations (1047 msec). However, neither of the simple effect contrasts were significant ($ps > .08$). Even if these simple effects had been significant though, they would not have compromised the main finding from this experiment, that participants more accurately distinguished the new words from the old words (to reject the new words) when they were presented to the RVF/LH than when they were presented to the LVF/RH.

EXPERIMENT 2

The most important result from Experiment 1 was that correct rejections of lures related to the encoded items but not presented during encoding was greater when they were presented to the RVF/LH than to the LVF/RH. This difference was statistically significant, but we considered it prudent to attempt to extend the finding given that the proportion difference was not numerically very large (.032). Therefore, we conducted a second experiment using an alternative dependent measure. Experiment 2 was conducted in the same manner as Experiment 1, except that participants were asked to rate their confidence on a one-to-six scale after each of their old/new recognition decisions during the test phase. In this way, finer-grained distinctions in the participants’ appraisals of memory strength for test words could be measured, compared against the binary old/new distinction used in Experiment 1. If the restricted/diffuse activation theory accurately predicts differences in left- and right-hemisphere memory processes (as suggested by results from Experiment 1), participants should exhibit higher levels of confidence when they correctly reject lures presented to the RVF/LH than when they correctly reject lures presented to the LVF/RH.

Method

Participants

Forty-eight undergraduate students at the University of Minnesota participated in the experiment in exchange for course credit. All were right-handed (mean laterality quotient = .86) as assessed through the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. Half of the participants were male, and the other half were female.

Materials and Procedure

The materials used in this experiment were the same as those used in Experiment 1, and the procedure for the encoding phase was identical to that used in Experiment 1. The test phase was also the same as that used in Experiment 1, but with the following exception. Immediately following each old/new judgment, participants indicated their level of confidence in the judgment on a one-to-six scale (1 = definitely old, 6 = definitely new) by pressing a number on the keyboard that corresponded to their perceived confidence. The rating scale was thoroughly explained to each participant immediately before the test phase.

Results and Discussion

Hemispheric Asymmetries in Memory Processing

Confidence Ratings for Correct Rejections. To test the novel and important prediction for Experiment 2, a two-way repeated-measures analysis of variance was conducted using the confidence ratings given to correctly rejected lures as the dependent measure. The independent variables were lure type (critical lures vs. related lures) and visual field of test presentation (LVF/RH vs. RVF/LH). These were manipulated within participants. The means and standard deviations for these conditions are presented in Table III.

Most important, the main effect of visual field of test presentation was significant, $F(1, 47) = 5.52$, $MSe = .22328$, $p < .05$. When correctly rejected lures were presented to the RVF/LH, participants were more confident that they were new than when they were presented to the LVF/RH (mean confidence

TABLE III
Mean Confidence Ratings for Correctly Rejected Lures by Condition in Experiment 2 (Standard Deviations in Parentheses)

Visual field	Lure type	
	Critical	Related
LVF/RH	4.61 (.772)	4.77 (.543)
RVF/LH	4.85 (.622)	4.85 (.432)

Note. LVF/RH = left visual field/right hemisphere; RVF/LH = right visual field/left hemisphere.

TABLE IV
Proportion Correct Rejections and Response Times for Correct Rejections (in msec) by Condition in Experiment 2 (Standard Deviations in Parentheses)

Dependent measure	Lure type	
	Critical	Related
Correct rejections		
LVF/RH	.239 (.192)	.537 (.245)
RVF/LH	.263 (.212)	.563 (.182)
Response times		
LVF/RH	1696 (596)	1607 (411)
RVF/LH	1592 (474)	1586 (409)

Note. LVF/RH = left visual field/right hemisphere; RVF/LH = right visual field/left hemisphere.

ratings for RVF/LH = 4.85; LVF/RH = 4.69). None of the other effects in this analysis approached significance ($ps > .15$).

The finding of greater confidence in correctly rejecting lures when they were presented to the RVF/LH than to the LVF/RH is consistent with the theory that activation is relatively restricted in the left hemisphere and more diffuse in the right hemisphere. It is not in line with the theory that memory traces in the left hemisphere are more interpretive and less veridical than memory traces in the right hemisphere.

Correct Rejections of Lures. As in Experiment 1, a two-way repeated-measures analysis of variance was conducted with correct-rejection rates as the dependent measure, and lure type and visual field of test presentation as the (within-participants) independent variables. The means and standard deviations for these conditions are presented in Table IV.

Replicating Experiment 1, the main effect of lure type was significant, $F(1, 47) = 138$, $MSe = .03102$, $p < .001$. Related lures were correctly rejected more frequently than critical lures (.550 vs. .251, respectively). The interaction between lure type and visual field of test presentation did not approach significance ($F < 1$). More important, lures were correctly rejected more frequently when presented to the RVF/LH (.413) than to the LVF/RH (.388), in a numerical difference (.025) that was similar in size to the corresponding difference in Experiment 1 (.032) but that did not approach significance in a main effect in this experiment ($p > .20$). It is important to note though that half as many participants were tested in this experiment ($n = 48$) compared with Experiment 1 ($n = 96$); 48 participants sufficed to achieve the significant main effect of visual field of test presentation in the aforementioned analysis of confidence ratings. But, because the main effect of visual field in the analysis of correct rejections was significant in Experiment 1 but not in Experiment 2, we conducted an additional analysis to directly assess the reliability of this effect. We combined these main effect results from the two experiments, using a meta-analytic procedure (the adding probabilities method) recommended in Rosenthal (1978). The effect was reliable ($p = .039$). Thus, we conclude that, although the effect may not be large, an apparently reliable finding is that the ability to correctly reject previously unrepresented words (that are related to previously presented words) is greater when they are presented directly to the RVF/LH than to the

TABLE V
Proportion "Old" Responses and Response Times for "Old" Responses (in msec) by Condition in Experiment 2 (Standard Deviations in Parentheses)

Dependent measure	Lures (false alarms)		Targets (hits)	
	Critical words	Related words	Critical words	Related words
Proportion "old"				
LVF/RH	.761 (.192)	.463 (.245)	.771 (.229)	.650 (.207)
RVF/LH	.737 (.212)	.438 (.182)	.753 (.221)	.625 (.210)
Response times				
LVF/RH	1446 (398)	1524 (439)	1331 (403)	1463 (418)
RVF/LH	1397 (386)	1626 (519)	1271 (325)	1418 (299)

Note. LVF/RH = left visual field/right hemisphere; RVF/LH = right visual field/left hemisphere.

LVF/RH. This finding is in line with predictions from the restricted/diffuse activation theory but not with predictions from the interpretive/veridical trace theory.

Response Times for Correct Rejections. As in Experiment 1, a two-way repeated-measures analysis of variance was conducted using response times for correctly rejected lures as the dependent measure, and lure type and visual field of test presentation as the (within-participants) independent variables. The means and standard deviations for these conditions are presented in Table IV. None of the effects in this analysis approached significance (all p s > .15), indicating no tradeoff between speed and accuracy of correct-rejection responses.

False Memory Effects

Probability of "Old" Responses. To ensure that the false memory effect was also observed in Experiment 2, a three-way repeated-measures analysis of variance was conducted using the probability of "old" responses as the dependent measure. The (within-participants) independent variables were word type, visual field of test presentation, and presentation status. The means and standard deviations for these conditions are reported in Table V.

Most important and replicating Experiment 1, the interaction between word type and presentation status was significant, $F(1, 47) = 20.2$, $MSe = .03599$, $p < .001$. The simple effect contrast directly testing the false-alarm rate for critical words (.749) against the hit rate for related words (.638) was significant, $F(1, 141) = 19.1$, $MSe = .03139$, $p < .001$. The false-alarm rate for critical words was higher than the hit rate for related words, reflecting "false" memories for critical words.

Also replicating Experiment 1, the main effect of word type was significant, $F(1, 47) = 155$, $MSe = .02776$, $p < .001$, as was the main effect of presentation status, $F(1, 47) = 31.7$, $MSe = .03043$, $p < .001$. Participants responded "old" more frequently to critical words (.756) than to related words (.544), and also responded "old" more frequently to targets (.700) than to lures (.600). No other effects approached significance (all p s > .15).

Response Times for "Old" Responses. Finally, an analogous three-way repeated-measures analysis of variance was conducted using response times for

“old” responses as the dependent measure. Word type, visual field of test presentation, and presentation status were the (within-participants) independent variables. The means and standard deviations for these conditions are presented in Table V.

As in Experiment 1, the main effect of word type was significant, $F(1, 47) = 23.1$, $MSe = 89,658$, $p < .001$, as was the main effect of presentation status, $F(1, 47) = 14.7$, $MSe = 106,389$, $p < .001$. “Old” responses to critical words (1361 msec) were faster than “old” responses to related words (1508 msec), and “old” responses to targets (1371 msec) were faster than “old” responses to lures (1498 msec). No other effects approached significance (all $ps > .15$). The results from this analysis indicate that none of the significant effects in the analysis of proportion “old” responses were compromised by tradeoffs between speed and proportion “old” responses.

GENERAL DISCUSSION

The results from these experiments help to clarify the respective roles of left- and right-hemisphere processes in memory for words. Participants correctly rejected previously unrepresented items that were related to the previously presented items more effectively when they were presented to the RVF/LH than to the LVF/RH. This finding supports the restricted/diffuse activation theory (Chiarello and Beeman, 1997; Chiarello, 1998) and also runs counter to the interpretive/veridical trace theory (Metcalf et al., 1995; cf. Zaidel, 1994) for characterizing hemispheric differences in memory for words. In addition, results from these experiments replicate the typical false-memory effects that have been found in previous experiments using central-visual-field test presentations (e.g., Miller and Wolford, 1999; Roediger and McDermott, 1995).

It is important to note that the present pattern of results differs from the analogous pattern of results reported in Metcalfe et al. (1995). Metcalfe et al. found a greater ability to correctly reject lures that were related to previously encoded words when those lures were presented to the LVF/RH than to the RVF/LH. Two possible explanations may be offered for this discrepancy. First, Metcalfe et al. tested one split-brain patient, JW, and this patient exhibited an opposite-to-normal lateralization in visual spatial processing (see Chapter 9 of Kosslyn and Koenig, 1992) despite normal lateralization in visual shape processing and other tasks (e.g., Funnell et al., 1998). Testing multiple split-brain patients would be needed to determine whether JW’s lateralization in word memory is in the direction exhibited by most normal control participants. A second possibility stems from the fact that Metcalfe et al. (1995) used lists of words composed of members of categories (e.g., list of fruits), however in the present experiment, we used lists of words that were associatively related to each other (each was composed by compiling the strongest free associates to the critical word). Previous research indicates that correct-rejection rates for critical words in the false recognition paradigm are quite high when the lists are composed of members of categories, inconsistent with the typical false recognition effect, but very low when they are composed of associatively related

words, consistent with the typical false recognition effect (Buchanan et al., 1999). It is plausible that, in the present experiment, the left-hemisphere advantage for correctly rejecting lures that are related to previously encoded words reflects a left-hemisphere advantage in restricted associative activation during encoding of the to-be-remembered words. In contrast, because Metcalfe et al. used category lists, it is plausible that their right-hemisphere advantage for correctly rejecting lures related to previously encoded words reflects a right-hemisphere advantage in storing words without activating their (non-associative, but more hierarchical) category labels. In line with this possibility, Metcalfe et al. did not observe a hemisphere difference in correctly rejecting lures that belonged to categories that were not presented during encoding. In addition, a different study of category membership judgments made to laterally presented items suggests that storage of similarity- and typicality-based semantic representations occurs effectively in the right hemisphere but storage of more strictly categorical semantic representations occurs effectively in the left hemisphere (Zaidel, 1987). If activation of category-label representations is less likely to occur in the right hemisphere than in the left, then a right-hemisphere advantage may be observed for correctly rejecting within-category lures in particular.

As described above, we interpret the left-hemisphere advantage for correctly rejecting lures in terms of hemispheric differences in post-perceptual memory processes. An alternative possibility is that the finding is due to hemispheric differences in perceptual *word recognition* processes, such as those necessary to identify words but not judge whether they have been processed recently. We suspect that word recognition asymmetries are not responsible for the results in the present article for two reasons. First, by that hypothesis, a left-hemisphere advantage should have been observed for the hit rates as well as for the correct-rejection rates in the present study, and this was not observed. Second, the results from Metcalfe et al. (1995) run counter to this hypothesis, as a right-hemisphere advantage in correct rejections was observed in their experiments with word stimuli. Furthermore, the most relevant hemispheric differences in perceptual word recognition processes that have been found in previous studies also run counter to this hypothesis. Although left-hemisphere advantages have been observed in recognizing the abstract category to which a stimulus word belongs (e.g., that the word is “pen,” not “cup”), right-hemisphere advantages have been observed in recognizing the specific exemplars to which an input word corresponds (e.g., that the word is “pen” and not “PEN” or “Pen”; Marsolek et al., 1992, 1994, 1996). The relatively more veridical word recognition processes appear to be performed more effectively in the right hemisphere than in the left.

To conclude, any differences in memory encoding that may occur across distinct brain regions must be uncovered for a complete explanation of the neural implementation of memory. Hemispheric asymmetries appear to be an important example of such differences in memory processing, and the present results help to clarify these hemispheric differences. Furthermore, the present investigation helps to further our understanding of the mental processes underlying false recognition. Associative activation appears to play an important

role in the creation of false memories, especially the kind of associative activation that takes place effectively in the right hemisphere. Finally, broader, more diffuse activation of associative information in the right hemisphere than in the left may prove to be crucial for a complete understanding of other memory-based phenomena. For example, this hemisphere difference may lead to important predictions for how inferences are generated during narrative comprehension (e.g., Beeman et al., 1994). Additional research currently is underway in our laboratory to investigate this possibility.

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