Brain & Language 123 (2012) 145–153

Contents lists available at SciVerse ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Hemispheric differences in the organization of memory for text ideas

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ARTICLE INFO

Article history:
Accepted 13 August 2012
Available online 22 October 2012

Keywords:
Recognition memory
Discourse processing
Laterality

ABSTRACT

The goal of this study was to examine hemispheric asymmetries in episodic memory for discourse. Access to previously comprehended information is essential for mapping incoming information to representations of "who did what to whom" in memory. An item-priming-in-recognition paradigm was used to examine differences in how the hemispheres represent discourse. Both hemispheres retained accurate information about concepts from short passages, but the information was organized differently. The left hemisphere was sensitive to the structural relations among concepts in a text, whereas the right hemisphere differentiated information that appeared in one passage from information that appeared in another. Moreover, the right hemisphere, but not the left hemisphere, retained information about the spatial/temporal proximity among concepts in a passage. Implications of these results for the roles of the right and left hemispheres in comprehending connected discourse are discussed.

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1. Introduction

Reading is a multi-component skill. Processes at the word-level are involved in mapping letter strings to their sound representations and accessing lexcial/semantic information. Processes at the sentence level are involved in parsing a sentence into its constituent units and extracting explicit ideas that represent its meaning. Processes at the discourse level are involved in interpreting and organizing text ideas in light of world knowledge in order to construct a representation of the situation that is described in a text (i.e., a discourse model).

Considerable evidence suggests a division of labor in language processing across the hemispheres. The left hemisphere appears to be dominant for processes involved in mapping orthographic representations to phonological ones, rapid access to lexical/semantic information, syntactic analysis of sentences, and the creation of message-level representations. Although the left hemisphere is dominant for most language processes, the right hemisphere appears to play an important role; evidence suggests that it is responsible for the activation of a broad range of word meanings (Anaki, Faust, & Kravetz, 1998; Beeman, 1998; Koivisto, 1999), inferences to create a coherent discourse model, and processing figurative language.

Claims about the involvement of the right hemisphere in discourse comprehension are supported by neuropsychological studies. Right-hemisphere-damaged patients appear to be impaired in their ability to both integrate disparate linguistic elements to create links across sentences and make inferences that are necessary to create a coherent text representation (Beeman, 1993; Brownell, Gardner, Prather, & Martino, 1995; Brownell, Potter, Bihrle, & Gardner, 1986; Delis, Wapner, Gardner, & Moses, 1983; Hough, 1990; Myers, 1994; Rehak, Kaplan, & Gardner, 1992). Significant impairment in the processing of non-literal discourse is also found after right-hemisphere damage (Winner & Gardner, 1977). Right-hemisphere-damaged patients have deficits in understanding metaphor, humor, and in using pragmatic information to understand a speaker's intention (Marini, Carlomagno, Caltagirone, & Nocentini, 2005). Moreover, right-hemisphere-damaged patients have significant deficits in reinterpreting sentences when initial syntactic or semantic analyses are found to be inappropriate in the discourse context, as is the case in garden-path sentences or in the reinterpretation that is often necessary for understanding humor or metaphor (Brownell et al., 1986).

Behavioral, electrophysiological, and neuroimaging evidence also support a role for the right hemisphere in language comprehension. Divided visual-field (VF) studies suggest that the right hemisphere maintains a broader range of word meanings than does the left hemisphere (Beeman, 1998; Faust & Chiarello, 1998). These findings have led to the proposal that the right hemisphere codes word meanings in a "coarse" manner, activating peripheral features that have distant semantic relations to incoming words (Beeman, 1998; Burgess & Lund, 1998; Chiarello, 1998; Jung-Beeman, 2005; Koivisto & Laine, 2000). For example, studies have shown that the right hemisphere activates both contextually appropriate and inappropriate meanings in response to ambiguous words in a sentence.

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http://dx.doi.org/10.1016/j.bandl.2012.08.006

Electrophysiological studies have also revealed hemispheric asymmetries in discourse processing. The right hemisphere appears to be sensitive to the integration of words into the developing representation of sentences in a manner that involves the "bottom-up" fit between an incoming word and the immediately preceding context. For example, the right hemisphere is sensitive to the semantic overlap between an incoming word and preceding words even when the incoming word is tangentially related to the overall message of a sentence. Moreover, neuroimaging studies have shown a role for the right hemisphere in the type of processing that is necessary to integrate ideas across sentences (Gernsbacher & Kaschak, 2003).

Most studies of hemispheric asymmetries in discourse comprehension have focused on how readers/listeners construct discourse representations "on-line," as comprehenders process immediate input in light of preceding information. Less attention has been paid to how discourse is represented in episodic memory once comprehension is complete. This is unfortunate because episodic memory for text information plays an important role in discourse comprehension. Consider the following example (Albrecht & O'Brien, 1993):

(1) Today, Mary was meeting a friend for lunch. She arrived, early at the restaurant and decided to get a table. After she sat down, she started looking at the menu.

This was Mary's favorite restaurant because it had fantastic health food. Mary, a health nut, has been a strict vegetarian for 10 years. Her favorite food was cauliflower. Mary was so serious about her diet that she refused to eat anything which was fried or cooked in grease.

[Six intervening sentences introducing a new character to the narrative.]
Mary ordered a cheeseburger and fries.

When Mary is described as a vegetarian, readers typically detect the inconsistency in the final sentence, showing long reading times for the final sentence. This occurs even though the character description is not in working memory at the time that the target sentence is read; it has been replaced by information in the intervening sentences. The finding suggests that information in the target sentence functions to reactivate the backgrounded information from episodic memory. Research using this type of paradigm has suggested that the reactivation process is cue-dependent. The greater the featural overlap between information in an incoming sentence and information in episodic memory the greater the likelihood that the background information will be retrieved. More is necessary, however, than memory cueing. Readers must have a structural representation in which the concept *vegetarian* is associated with Mary rather than with the new character and that identifies Mary as the agent of the eating and healthy food as the object of the eating. Recent evidence suggests that the two hemispheres represent verbal information in memory in a somewhat different manner and that these memory asymmetries may have implications for hemispheric differences in discourse comprehension.

2. Hemispheric asymmetries in the representation of verbal information in memory

2.1. Memory for word lists

Most studies of hemispheric asymmetries in the retention of verbal materials have involved memory for word lists. Considerable research shows that both hemispheres encode verbal material in episodic memory, but they retain somewhat different information about a verbal stimulus. The left hemisphere appears to retain the meanings of words in memory, whereas the right hemisphere appears to retain more information about a word's physical form. For example, divided VF studies have shown that the right hemisphere is more sensitive than the left hemisphere to changes in font and letter case (Burgund & Marsolek, 1997; Deason & Marsolek, 2005; Lavidor & Ellis, 2001; Marsolek, Kosslyn, & Squire, 1992). Findings such as these have led some researchers to claim that the right hemisphere processes words as physical objects, encoding a representation in memory that is veridical and holistic, whereas the left hemisphere processes words more abstractly, encoding a representation that is more conceptual and categorical (Deason & Marsolek, 2005; Marsolek, Schacter, & Nicholas, 1996).

Hemispheric asymmetries have also been found in patterns of false alarms in the recognition of items from word lists. False alarms to semantically related lures tend to be greater when study and test items are presented to the right visual-field/left hemisphere (RVF/LH) than when they are presented to the left visual-field/right hemisphere (LVF/RH) (Metcalfe, Funnell, & Gazzaniga, 1995, but see, Westerberg & Marsolek, 2003). Moreover, event-relation potential (ERP) measures show that the left hemisphere has similar brain responses to true items and semantic lures, whereas the right hemisphere shows different brain responses, primarily involving early components related to attentional and memory processes (Fabiani, Stadler, & Wessels, 2000). In addition, research has shown hemispheric asymmetries in the time course of memory retention using a continuous recognition paradigm. Evans and Federmeier (2007) found that the left and right hemispheres represented verbal information similarly when the retention interval was relatively short (1–20 intervening words), whereas the right hemisphere discriminated old and new items better than the left hemisphere at longer intervals (30–50 intervening words). Together, results from word-list studies suggest that the right hemisphere engages in a type of orthographic "pattern matching," in which veridical information about the physical characteristics of words is critical to right-hemisphere performance.

Studies examining hemispheric asymmetries in the retention of verbal information have focused on *what* information is represented in episodic memory. Our focus in this study is on how verbal information is *organized* in memory. This issue is critical in understanding the role of the two hemispheres is discourse comprehension.

2.2. Memory for discourse

Long and her colleagues, to our knowledge, have conducted the only investigations of hemispheric asymmetries in how discourse is represented in episodic memory (Long & Baynes, 2002; Long, Baynes, & Prat, 2005; Prat, Long, & Baynes, 2007). They have used an item-priming-in-recognition paradigm to examine what information is encoded in memory and how the information is organized (see McKoon and Ratcliff (1980) for details about the procedure). The logic of the paradigm is that discourse is represented in memory as a network of concepts from the text and from relevant world knowledge. The retrieval of one concept from the representation can facilitate the retrieval of other concepts as a function of their connection strength (e.g., featural overlap). If two concepts are "close" in the network, that is, strongly connected, then one concept will act as a prime or cue for the other. (It should be noted that the term "item-priming" is not used in its usual sense of lexical–semantic priming. It is better thought of as memory cueing.)

Consider the following short passage from Long and Baynes (2002):

(2) Round after round, the visitor tried to find his opponent's weakness. When the instructor blew his whistle, the visitor lowered his foil.

Fig. 1 depicts the concepts that are explicit in the passage and some of the relations among them. Note that some concepts in the network are more closely (strongly) connected than others. For example, *instructor* and *whistle* are more closely connected than are *visitor* and *whistle* because the former pair is part of the same idea unit, whereas the latter pair is part of different idea units. If the text concepts are organized in this manner, then *instructor* should be a better cue for *whistle* than is *visitor*, even though both *instructor* and *visitor* are close to *whistle* in the surface structure of the sentence.

Long and her colleagues have used the item-priming-in-recognition paradigm to investigate the representation of discourse in the two hemispheres in divided VF and patient experiments (Baynes, Gillette, Mostofian, Long, & Dronkers, 2002; Baynes, Long, Gillette, Dronkers, & Davis, 2002; Long & Baynes, 2002; Long, Baynes, & Prat, 2005, 2007; Prat et al., 2007). The paradigm involves examining responses to targets as a function of the relation between primes and targets in the passages and VF presentation. In patient experiments, the paradigm involves presenting primes and targets to groups with various neurological impairments.

(Long & Baynes, 2002; Long et al., 2005) have argued that discourse representation in the left hemisphere is likely to be more structured than the representation in the right hemisphere. Their claim has its foundation in research showing that the LH has much better syntactic processing abilities than does the RH (Baynes & Gazzaniga, 1988; Zaidel, 1978, 1990). Syntactic analysis is critical in identifying and representing text ideas because the ideas are defined by predicate and argument relations among words in a sentence. Moreover, text ideas are often connected to one another by means of referential relations. These relations rely on readers' representation of "who did what to whom" in a sentence (see Example 1).

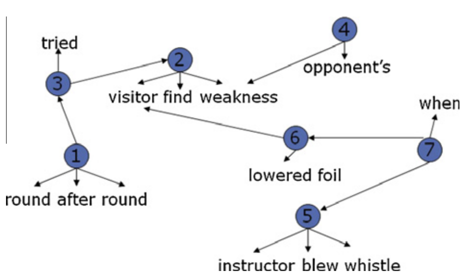

Fig. 1. Graphic depiction of the explicit concepts and their relations in the passage "Round after round, the visitor tried to find his opponent's weakness. When the instructor blew his whistle, the visitor lowered his foil."

Long et al. (2005) studied the organization of explicit text ideas in memory by assessing the strength with which one concept in a sentence primed (cued) another concept by means of their structural relations. Participants read blocks of passages and then received recognition tests consisting of single words presented one at a time. Four types of prime–target pairs were embedded in the test list. Table 1 contains sample passages and test items. In the *same-idea condition*, a target from one of the sentences (e.g., hunter) was preceded by a prime from the same idea (e.g., pheasant). In the *different-idea condition*, the target was preceded by a prime from a different idea in the same sentence (e.g., deer). In the *different-sentence condition*, the target was preceded by a prime from a different sentence in the same passage (e.g., birds). Finally, in the *different-passage condition*, the target was preceded by a prime from a different passage in the same block of passages (e.g., apples). Primes were presented centrally and targets were presented to the LVF/RH or to the RVF/LH. It is important to note that the primes and targets in all of the within-passage conditions (same-idea, different-idea, and different-sentence conditions) were semantically related, whereas the primes and targets in the different-passage condition were unrelated.

The priming results appear in Fig. 2. Long et al. (2005) found that the left hemisphere was sensitive to the distance between the prime and the target in the structure of the passages, as expected. They observed the greatest priming in the same-idea condition and the least priming in the between-passage condition. They found no within-passage priming in the LVF/RH. The right hemisphere was sensitive to between passage relations, but insensitive to structural relations among concepts in the within-passage conditions; that is, responses to targets that followed within-passage primes (i.e., same-idea, different-idea, and different-sentence conditions) were faster than those that followed different-passage primes. Thus, the right hemisphere appeared to represent concepts within a passage as distinct from those in other passages.

Long et al. (2005) interpreted this pattern of findings as evidence that the left hemisphere represents discourse in a manner that preserves information about predicate-argument relations. This type of representation is critical for integrating ideas across sentences when new, incoming text ideas require mapping agent and object relations across sentences. One problem with this interpretation, however, is that it ignores the possibility that subtle differences in pre-existing semantic relations among concepts in a scenario are responsible for the hemispheric asymmetries. Consider the sample materials in Table 1. The passage contains a number of content words (e.g., hunter, stalked, pheasant, deer, birds). Pre-existing knowledge about how these concepts are related to each other and to associates of the content words (e.g., duck, turkey) may have driven the priming results. Given the combination of words, the target *hunter* may have had a stronger connection to the prime *pheasant* in memory than it did to the prime *deer* particularly in the context of hunting-related objects (e.g., bird, turkey,

Table 1
Example passages and prime–target pairs.

Priming relation	Prime	Target
While the hunter stalked the pheasant, the deer ate leaves in the meadow. The birds sang as they roosted in the trees and watched the creatures below		
Same-idea	Pheasant	Hunter
Different-idea	Deer	Hunter
Different-sentence	Birds	Hunter
Different-passage	Apples	Hunter
The children laughed at the silly sight. The elephant pulled the cart, while the monkey juggled the apples		
Same-idea	Elephant	Cart
Different-idea	Monkey	Cart
Different-sentence	Sight	Cart
Different-passage	Creatures	Cart

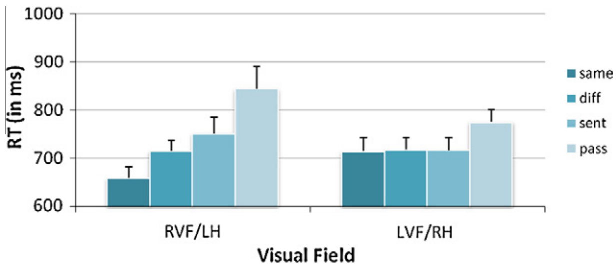

Fig. 2. Mean reaction time and standard errors from Long et al. (2005; Experiment 1) as a function of structural distance.

duck). Thus, the left hemisphere may represent these relations in a graded fashion giving rise to the structural distance effect that Long et al. observed.

Experiment 1 tests this possibility. We manipulated the presence or absence of predicate-argument relations by including a condition in which participants received the text concepts in a word list. If the LH represents pre-existing semantic relations among a cluster of concepts in a manner different than does the RH, then we should see the same set of priming results in the word-list condition as in the passage condition.

3. Experiment 1

We manipulated structural relations by comparing priming in passages and by creating versions in which the primes and targets were in the same physical locations as they were in the original passages, but the remaining words were scrambled. Coherent versions (the original passages from Long et al., 2005) and word-list versions were presented; priming was assessed with lists of recognition items as in Long et al. If the left hemisphere represents predicate-argument relations as a function of the structural information in the sentences, then we should see different patterns of priming in the coherent and scrambled conditions. Priming in the coherent condition should be linearly related to the structural relations in the passages, whereas priming in the scrambled condition should resemble the pattern observed previously in the right hemisphere, priming only in the different-passage condition. The right hemisphere, in contrast, should be insensitive to the scrambling manipulation.

3.1. Method

3.1.1. Participants

Participants were 136 undergraduates at the University of California, Davis. All were right-handed native English speakers with no diagnosed reading or learning disability nor any diagnosed neurological condition. Students received course credit for their participation.

3.1.2. Materials and procedure

The experimental materials were presented in 12 study-test blocks. A block consisted of 4 study passages (or word lists) and its associated test list. Participants studied each passage (or word list) in the block and then received a recognition test consisting of single words presented one at a time on the screen. Some words had been presented at study; others were new. Participants then made yes/no recognition judgments to each word in the list. We manipulated the coherence of the study materials in two conditions: the coherent and the scrambled conditions.

In the coherent condition, we used the same study/test materials as those used in Long et al. (2005). The study materials consisted of 48 two-sentence passages. (The passages can be found in the Appendix of Long et al., 2005.) Example passages and their associated test words appear in Table 1. The passages were analyzed to determine structural relations among words. This involved identifying idea units consisting of a verb and its arguments (see Kintsch, 1974). Each passage contained a sentence with at least two idea units with a NVN structure. (e.g., *While the hunter stalked the pheasant, the deer ate leaves in the meadow*).

Five nouns were selected from each passage to be used as items in the recognition tests. One noun was selected to be a target (e.g., hunter). The remaining nouns were selected as "primes" such that they varied in their propositional distance from the target. The prime–target pairs were: (1) same-idea pairs consisting of the target noun (e.g., hunter) that was preceded by another noun from the same idea unit (e.g., pheasant), (2) different-idea pairs consisting of a target noun (e.g., hunter) that was preceded by a noun from a different idea unit in the same sentence (e.g., deer), (3) different-sentence pairs, consisting of the target noun (e.g., hunter) that was preceded by a noun from a different idea unit in a different sentence (e.g., birds), and (4) different-passage pairs, consisting of the target noun (e.g., hunter) that was preceded by a noun from an idea unit that was from a different passage in the same block of passages (e.g., apples).

In selecting the test words, we controlled for two factors. First, we controlled for the proximity between the prime and target words as they appeared in the original passages such that the same number of words, on average, intervened between the nouns in the same-idea and different-idea conditions. That is, across passages, the physical proximity of the prime and target in the same-idea condition (e.g., pheasant-hunter) was the same as prime and target in the different-idea condition (e.g., deer-hunter). Second, we controlled for order. Some of the words that were selected as primes had preceded the targets in the passages; others had followed the target. For example, in Table 1, the prime *elephant* preceded the target *cart* in the second passage, whereas the target *hunter* preceded the prime *pheasant* in the first passage. We controlled for order such that that the words that we selected as primes had followed or preceeded the selected targets in the passages an equal number of times.

Four additional passages with the same structure were used for practice to familiarize participants with the study/test procedure. The total set of 52 passages was segregated into 13 study blocks of 4 passages in each block: 12 experimental study blocks and 1 practice block.

In the scrambled condition, we used the same set of study materials except that we scrambled all of the words in the passages (including the function words), with the exception that the test words (the words that were selected as primes and targets for the recognition tests) were in the same physical location as they were in the coherent condition (e.g., sang as *hunter* trees in *pheasant* watched *deer* the the and ate below while *birds* the stalked the leaves the in the they creature meadow the roosted).

Two groups of participants were randomly assigned to the coherent and scrambled condition ($N = 68$ each condition) and to response hand. Participants were seated 57 cm from a computer screen. The study/test blocks proceeded as follows: Participants received the first block of study materials. The passages (or word lists) were presented one at a time on the computer screen. Participants were given 14 s to study each passage (or word list) before the next one was presented. Once participants had received all study materials in the block (for a total of 56 s of study), they received the recognition test. The test consisted of 24 single words. Embedded in each test list were the four types of critical prime–target pairs (one from each passage in a block). Thus, there were eight critical items (4 prime–target pairs) in each test block. There were also 16 filler items: 4 words that had appeared at study and 12 new words. It is important to note that the recognition test was presented as a running list of single words—the designation of items as primes and targets was invisible to the participants. The test list was preceded by a fixation point in the middle of the screen as a cue that the test was about to begin. The fixation point remained on the screen throughout the test. Participants were told to keep their gaze on the fixation point at all times. Test items were presented for 150 ms each and appeared in one of three positions: (1) immediately above the fixation point, (2) in the LVF/RH such that the end of the word was 1.5 degrees of visual angle to the left of fixation, (3) in the RVF/LH such that the beginning of the word was 1.5 degrees of visual angle to the right of fixation. Primes were always presented centrally; targets were presented to the RVF/LH or the LVF/RH (counterbalanced across lists). Filler items were distributed across the VFs such that there were an equal number of items that were presented centrally and in the RVF and LVF. Thus, the presentation location of the test items was unpredictable from the perspective of the participants. Participants made a yes/no recognition judgment to each item on the list. Once participants finished the test list, the next study/test block began.

3.2. Results and discussion

Two participants were excluded from the analyses due to exceptionally high error rates. Outliers in the reaction-time data were identified as values that exceeded the participant's mean plus three standard deviations. These values were excluded from the analyses. Analyses were performed on correct responses only. Errors and outliers together accounted for approximately 5% of the data.

Both reaction times and accuracy to targets were analyzed by means of a 2(VF) × 2(response hand) × 2(coherence) × 4(prime) repeated measures ANOVA. VF (LVF/RH, RVF/LH) and prime–target relation (same idea, different idea, different sentence, and different passage) were within-subjects variables; response hand (left, right) and coherence (coherent, scrambled) were between-subjects variables. All effects were reliable at a significance level of $p < .05$ unless otherwise indicated.

3.2.1. Reaction-time data

Mean reaction times are depicted in Fig. 3. The analyses yielded no reliable effect of response hand, so the data were collapsed across this variable. We found reliable main effects of VF, prime condition, and coherence, $F(1,132) = 40.54$, MSe = 13,252; $F(3,396) = 67.35$, MSe = 14,047; $F(1,132) = 6.74$, MSe = 7923, respectively. These effects were modified by the critical VF × prime × condition interaction, $F(3,396) = 11.84$, MSe = 13,115. Responses to targets in the coherent condition revealed that the left hemisphere was sensitive to the structural relations among concepts in the passages, as in Long et al., 2005. We conducted post hoc analyses to examine the nature of the 3-way interaction. We examined differences as a function of propositional distance in each visual field separately in the coherent and the scrambled condition. In the coherent condition, latencies to same-idea targets in the RVF/LH were faster than those to different-idea targets, $F(1,66) = 23.00$, MSe = 11,145; latencies to different-idea targets were marginally faster than those to different-sentence targets, $F(1,66) = 3.86$, MSe = 10,704, and latencies to different-sentence targets were faster than those to different-passage targets, $F(1,66) = 6.19$, MSe = 9764. Responses to targets in the LVF/RH showed a different pattern. No differences were found among responses to targets in same-idea, different-idea, and different-sentence conditions (all Fs < 1). Responses in the different-passage condition, however, were slower than those in the different-sentence condition, $F(1,66) = 14.51$, MSe = 10,225.

Our primary interest was priming in the scrambled condition. As can be seen in Fig. 3, only the left hemisphere was sensitive to the scrambling manipulation, showing the same pattern of priming as observed in the right hemisphere. In both the RVF/LH and LVF/RH, we found no differences in responses to targets in the same-idea, different-idea, and different-sentence conditions, all Fs < 1. In the RVF/LH, responses to targets in the different-passage condition were marginally slower than to those in the different-sentence condition, $F(1,66) = 3.31$, MSe 22,231; in the LVF/RH the mean difference was reliable, $F(1,66) = 11.22$, MSe = 8826.

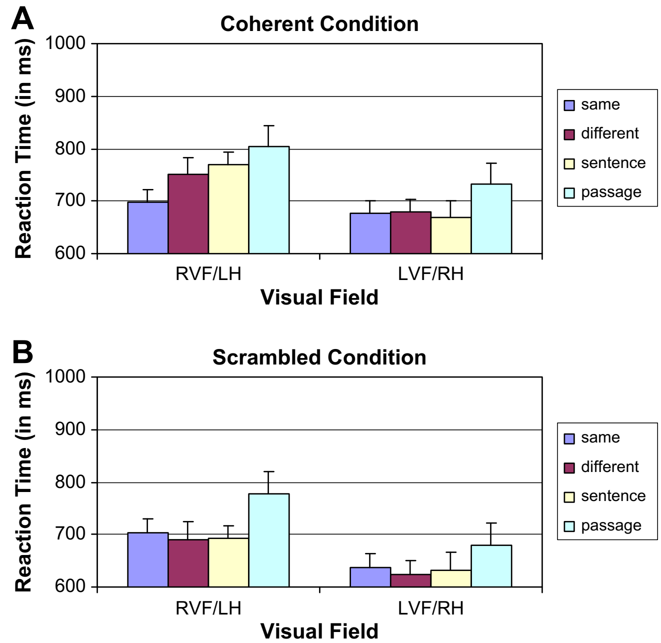

Fig. 3. Mean reaction time and standard errors to targets as a function of structural distance. Panel (a) depicts results from the coherent condition and Panel (b) depicts results from the scrambled condition.

3.2.2. Accuracy

Our analysis yielded only one reliable effect. Responses in the RVF/LH were more accurate ($M = 98.03$) than those in the LVF/RH ($M = 96.7$), $F(1,132) = 23.91$, MSe = 1.26).

In summary, the pattern of priming in the coherent passage condition replicated the results that were observed in Long et al. (2005) (see Fig. 2). Participants showed a structural distance effect when targets were presented in the RVF/LH, whereas priming in the LVF/RH was found only in comparison of the within-passage conditions to the between-passage condition. We found a different pattern of results in the scrambled condition. The left hemisphere showed the pattern that was associated with the right hemisphere in the coherent condition. In both VFs, participants responded slower to targets that were preceded by primes from the different passages relative to primes from the same passages.

These results suggest that the priming results in the coherent passages did not reflect pre-existing semantic relations among clusters of concepts. The left hemisphere showed sensitivity to structural relations among concepts only when the words appeared in coherent passages. In contrast, the right hemisphere was insensitive to the coherence manipulation. It showed sensitivity only to concepts that appeared in the same passage relative to those that appeared in different passages. The right hemisphere's insensitivity to the structural relations in a passage suggests that it does not represent passages in terms of the messages that they convey. It is important to note, however, that this claim concerns the representation of message-level content in *long-term* memory. Research on right-hemisphere sensitivity to message-level content "on line" during the comprehension process has produced inconsistent findings; some studies have found that the right hemisphere is unable to integrate syntactic and semantic information to construct a message-level representation (Faust, 1998; Faust, Babkoff, & Kravetz, 1995; Faust & Gernsbacher, 1996; Faust, Kravetz, & Babkoff, 1993), whereas other studies have found that the right hemisphere does represent message-level content and is involved in the integration of content across sentences (Chiarello, Liu, & Faust, 2001; Coulson, Federmeier, Van Petter, & Kutas, 2005; Faust, Bar-lev, & Chiarello, 2003; Federmeier, Mai, & Kutas, 2005). However, even if the right hemisphere is sensitive to message-level content during the comprehension process, our findings suggests that this representation is not maintained for an extended period of time.

4. Experiment 2

Our previous experiment showed that the right hemisphere did not represent structural or message-level relations among concepts, but it provided limited information about the types of relations that the right hemisphere does represent. Our data suggest only that the right hemisphere stores semantic relations among concepts based on our findings that the right hemisphere represented each passage as distinct from other passages, consistent with substantial research showing semantic priming in the right hemisphere (Chiarello, Richards, & Pollock, 1992; Faust & Chiarello, 1998). In Experiment 2, we asked whether the right hemisphere may be sensitive to properties of the passages other than semantic ones, specifically, whether it is sensitive to temporal/spatial relations among sentences.

Considerable research has shown that the right hemisphere has spatial/temporal abilities that are greater than those in the left hemisphere. This has been found in behavioral, neuroimaging, and lesion studies (Kosslyn, Maljkovic, Hamilton, Horwitz, & Thompson, 1995; Kounios & Holcomb, 1994; Laeng, Zarrinpar, & Kosslyn, 2003; Lincoln, Prat, Long, & Baynes, 2007). Moreover, as we discussed in the introduction, research on the retention of verbal information in the right hemisphere suggests that it stores a more veridical representation of words in lists than does the left hemisphere.

In Long and colleagues' experiments (Long et al., 2003, 2005; Prat et al., 2007), the two sentences in each coherent passage were presented simultaneously, on the same screen, and different passages were presented on different screens. Thus, spatial/temporal proximity was confounded with the manipulation of structural distance. That is, explicit concepts that were later used as primes and targets in the within-passage conditions were presented simultaneously, whereas explicit concepts that were later used as primes and targets in the different passage condition were presented on separate screens. Our goal in the current experiment was to examine the extent to which the temporal/spatial proximity of the primes and targets in the within-passage conditions influenced the pattern of priming.

We investigated the extent to which the right hemisphere represents spatial relations among sentences by manipulating the presentation of the passages in a between-subjects design. In the simultaneous condition, the two-sentence passages were presented simultaneously (as in the coherent condition of Experiment 1). In the sequential condition, the two sentences were presented one at a time on separate screens. If the left hemisphere represents structural relations among passages as our previous results indicate, then the same pattern of structural priming should be found in both the simultaneous and sequential conditions. If the right hemisphere represents spatial information about the passages as well as semantic information, then we should find the same pattern of results in the simultaneous condition as we have found previously. In contrast, priming in the sequential condition should reflect proximity. Responses to targets in the same- and different-idea conditions should be faster than those in the different-sentence and different-passage conditions.

4.1. Participants

Participants were 128 undergraduate students at the University of California, Davis. All were native English speakers and none had any diagnosed learning disabilities or neurological conditions. All participants were right handed. Students received course credit for their participation.

4.2. Materials and procedure

We used stimuli from the coherent condition in Experiment 1: Fifty-two passages were presented in blocks of 4 passages each and 24 recognition items followed each block of passages.

Passages in the simultaneous condition were presented using the procedure in Experiment 1. In the sequential condition, each passage was presented one sentence at a time; asterisks preceded the first sentence and followed the second sentence to indicate that the two sentences were to be comprehended as a coherent pair. Each sentence was presented for 7 s and each block of four passages was followed by the same set of recognition items as in the simultaneous condition. The procedure was the same as in Experiment 1.

4.3. Results and discussion

We analyzed the reaction time and accuracy data as in Experiment 1. VF and prime were within-subjects variables; proximity (simultaneous, sequential) was a between-subjects variable. Outliers were identified using the procedure in Experiment 1. Outliers and errors together accounted for 7% of the data.

4.3.1. Reaction times

The priming results appear in Fig. 4. The analyses revealed reliable effects of prime condition, $F(3,378) = 16.79$, MSe = 25,594. More importantly, we found a reliable VF × proximity × prime interaction, $F(3,378) = 4.56$, MSe = 19,372.

We conducted post hoc analyses to examine the 3-way interaction. The results for targets that were presented in the RVF/LH replicated the pattern that we found in the previous experiment (see also Long et al., 2005). In both the simultaneous and sequential conditions, priming was a function of distance in the structural representation of the passage. In the simultaneous condition, targets from the same ideas were faster than those from different ideas, $F(1,63) = 5.84$, MSe = 21,804. Targets from different ideas were faster than those from different sentences, but not reliably so, $F(1,63) = 1.81$, MSe = 23,219. Targets from different sentences were faster than those from different passages, $F(1,63) = 7.04$, MSe = 19,517. In the sequential condition, the results were similar. Targets from same ideas were faster than those from different ideas, $F(1,63) = 4.99$, MSe = 16,037. Targets from the different ideas were faster than those from different sentences, $F(1,63) = 4.30$, MSe = 20,538. Targets from different sentences were faster than targets from different passages, although not reliably so $F < 1$. Thus, the left hemisphere represented the passages as a coherent message even when the two sentences of a passage were presented on separate screens.

We found a different pattern of results in the LVF/RH. Responses to targets in the simultaneous condition replicated our previous findings, faster responses in the different sentence condition than in the different-passage condition, $F(1,63) = 13.14$, MSe = 22,105, whereas responses in the within passage conditions were not reli-

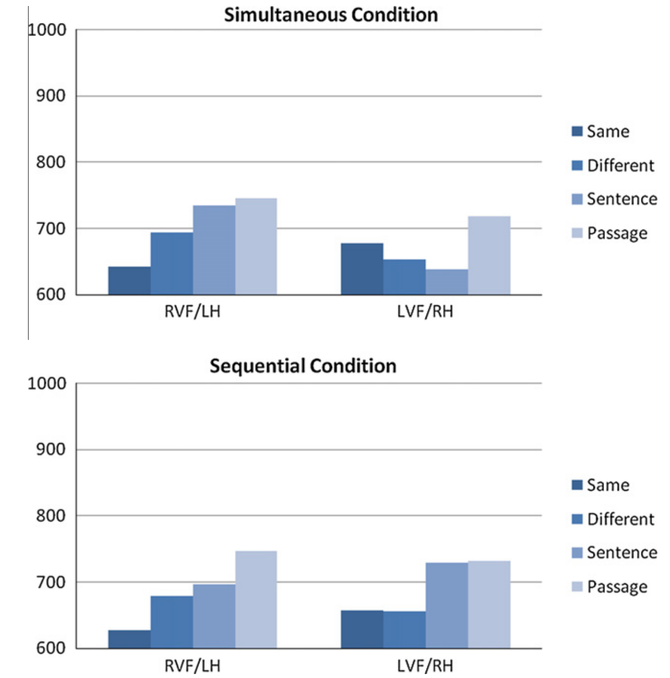

Fig. 4. Mean reaction time and standard errors to targets as a function of structural distance. Panel (a) depicts results from the simultaneous condition and Panel (b) depicts results from the sequential condition.

ably different. In the sequential condition, however, the right hemisphere showed sensitivity to proximity. Responses to targets that were presented on the same screen (the same-idea and different idea conditions) showed no reliable difference, $F < 1$; moreover, the contrast between the different-sentence and different-passage conditions were not reliably different, $F < 1$. In contrast, priming in the right hemisphere was found in the comparison of conditions across screens; responses to targets in the different idea condition were faster than to targets in the different-sentence condition, $F(1,63) = 7.12$, MSe = 25,347. Thus, the right hemisphere stored stronger connections among concepts when they were presented simultaneously than when they were presented sequentially. This was the case even though concepts in the between-sentence condition were thematically related to concepts in the same-sentence conditions (same ideas and different ideas) by virtue of the passage content.

4.3.2. Accuracy

Our analysis of the accuracy data revealed only a main effect of VF, $F(1,126) = 5.13$, MSe = .03. Accuracy was higher in the RVF/LH ($M = 95.6\%$) than in the LVF/RH ($M = 94.2\%$).

In summary, our priming results in the right hemisphere were consistent with our hypothesis that the spatial/temporal abilities of the right hemisphere affected its representation of discourse concepts. We do not claim, however, that the right hemisphere is insensitive to semantic relatedness even though we did not find greater priming in the between-sentence than between-passage condition when the passages were presented sequentially. Although primes and targets in the between-sentence condition were related, they were not strong associates. Moreover, the primes and targets were not members of the same semantic category; they were related by virtue of a schema or scenario that was relevant to the situation described in the passage (e.g., birds are a target of hunters). We discuss the relevance of our findings for theories of discourse processing in the next section.

5. Discussion

Our findings in this study have implications for understanding how the right hemisphere participates in understanding discourse. Our results indicate that both the left and the right hemispheres store explicit concepts from discourse, but these concepts are organized in different ways. The left hemisphere preserves structural information concerning "who did what to whom" in memory. The right hemisphere, in contrast, appears to be sensitive to temporal/spatial information. It clusters concepts more closely when they are presented simultaneously than when they are presented sequentially. We found that this occurred even when sequentially presented information was semantically related.

Our claim that the right hemisphere is insensitive to structural relations among concepts in a sentence may seem inconsistent with the wealth of neuroimaging data showing substantial right hemisphere activation during text comprehension (Bottini, Corcoran, Sterzi, & Paulesu, 1994; Mashal, Faust, Hendler, & Jung-Beeman, 2008; Mason & Just, 2004; Robertson et al., 2000; St. George, Kutas, Martinez, & Sereno, 1999). This inconsistency may not be as great as it first appears, however. The extent of right hemisphere activation during text comprehension is strongly related to the nature of the experimental contrasts that are reported. Ferstl, Neumann, Bogler, and von Cramon (2008) recently conducted a meta-analysis of 23 neuroimaging studies in which the comprehension of connected, coherent discourse was examined. When connected discourse was contrasted with a resting baseline, a large bilateral, fronto-temporal network of regions was identified, with the size of the temporal activations similar in the two hemispheres. When connected discourse was compared to an incoherent language baseline (e.g., words lists, unrelated sentences), however, the network was much more left lateralized. Bilateral activation was found only in the anterior temporal lobes; all other activated regions were in the left hemisphere. Fertstl et al. concluded that the left dominant network that is revealed in the contrast between coherent and incoherent discourse is evidence against the claim that the right hemisphere is essential for coherence processes in text comprehension such as sentence integration and inference generation.

Neuropsychological evidence for the role of the right hemisphere in constructing a coherent discourse representation is also not clear-cut. Some studies have found that right-hemisphere-damaged patients are impaired in using thematic information to establish coherence (Delis et al., 1983; Schneiderman, Murasagi, & Saddy, 1992). Other research has found that right-hemisphere-damaged patients extract the main ideas from discourse as accurately as do left-hemisphere patients (Brookshire & Nicholas, 1984; Hough, 1990; Wegner, Brookshire, & Nicholas, 1984). Consider, also, the literature on inference generation after right-hemisphere damage. Numerous studies have shown that right-hemisphere-damaged patients are impaired in generating inferences to construct a coherent discourse representation (Beeman, 1993; Brownell et al., 1986; Harden, Cannito, & Dagenais, 1995; Myers & Brookshire, 1996), whereas other studies have found no such deficits (Lehman-Blake & Lesniewick, 2005; Leonard & Baum, 1998; Leonard, Waters, & Caplan, 1997a, 1997b; McDonald & Wales, 1986; Tompkins, Fassbiner, Lehman-Blake, Baumgaertner, & Jayaram, 2004).

Two issues may be important in reconciling inconsistencies in the literature on right-hemisphere language comprehension. The first issue concerns the distinction between inferences that are based on activation of concepts in a semantic network and inferences that require knowledge about predicate-argument relations. Many studies of hemispheric asymmetries in inference generation have focused on inferences that can be made based on the semantic information that is activated by incoming words and ideas. Previous results suggest that both hemispheres show considerable lexical/semantic priming. Indeed, the right hemisphere may have some advantage in activating certain types of semantic information. Jung-Beeman (2005) has argued that both hemispheres contribute to semantic processing, but do so somewhat differently. The left hemisphere has a finely coded network that supports the strong activation of dominant and context-appropriate features of words, whereas the right hemisphere has a coarsely-coded network that supports the weak, diffuse activation of distantly related or subordinate semantic features. These distantly related concepts can provide information that is essential for elaborating a discourse representation with inferences or for reinterpreting a word when the LH has selected an inappropriate meaning.

Not all inferences, however, can be generated solely on the basis of semantic overlap. Some inferences require access to knowledge about predicate-argument relations. Consider, for example, inferences that are necessary to establish referential relations as in the following:

(3) John saw Paul fall down the stairs. He ran to get help.

Some of the information that is relevant to understanding this short passage can be activated by means of priming in a semantic network. For example, the concept *fall* is semantically related to the concept *hurt*. It is also necessary, however, to represent exactly *who* fell in order to understand who ran to get help. This involves the representation of *Paul* as the agent of *fall*, in addition to world knowledge that the person who falls is unlikely to be the person who runs for help. This information is critical for the inference that *John* is the agent of the verb *ran*. If the right hemisphere is limited in its representation of predicate-argument relations then its ability to generate inferences of this type will be limited, even though it may have some advantage in generating inferences that are supported by lexical–semantic relations.

A second issue that may be important in reconciling inconsistent findings in the literature on right-hemisphere language comprehension is the distinction between the temporary activation of concepts and their more permanent representation in memory. Consider a recent study by Tompkins and her colleagues. Tompkins, Scharp, Meigh, and Fassbinder (2008) found that right-hemisphere-damaged patients were impaired in maintaining the peripheral features of words, but not in activating them. Similarly, Lehman-Blake and Lesniewick (2005) found that right-hemisphere-damaged patients generated inferences during comprehension, but did not maintain these inferences over time unless they were supported by strong semantic associates in the discourse context. These findings are consistent with our claim that the early activation of concepts does not necessarily lead to the integration of these concepts into a long-term memory representation of discourse.

Finally, our finding that the right hemisphere represents temporal/spatial properties of texts may be relevant to understanding the right hemisphere's role in repair processes. Studies have found that the right hemisphere is involved in the reinterpretation of discourse when initial interpretations are inconsistent with previously processed information (Rehak et al., 1992; Schneiderman & Saddy, 1988), including syntactic revision after misanalysis (Meyer, Friederici, von Cramon, 2000). The right hemisphere representation of temporal/spatial information about concepts in sentences may offer a mechanism by which repair can occur. Memory for the temporal order of information would be very helpful in revising an interpretation when an initial analysis is inappropriate.

In summary, our results suggest both similarities and differences in the way discourse is stored in episodic memory by each hemisphere. Both hemispheres maintain representations of explicit text concepts, but organize the information somewhat differently. The left hemisphere maintains structural relations among explicit text concepts involving information about predicate-argument relations, whereas the right hemisphere has a more veridical representation, maintaining some spatial/temporal information about sentence presentation. Our findings fill an important gap in the literature on hemispheric asymmetries in memory for verbal information and suggest interesting questions for future research.

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