Discourse Representation in the Two Cerebral Hemispheres

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Abstract

■ Readers construct at least two interrelated representations when they comprehend a text: (a) a propositional representation containing the individual ideas that are derived from each sentence and the relations among them and (b) a discourse model, a representation of the context or situation to which the text refers. We used a paradigm called ''item priming in recognition'' to examine how these representations are stored in the cerebral hemispheres. In Experiment 1, the priming paradigm was used in combination with a lateralized visual field (VF) procedure. We found evidence that readers' representations were structured according to propositional relations, but only in the left hemisphere. Item recognition was facilitated when a concept was preceded by another concept from the same proposition when targets were presented to the left, but not to the right, hemisphere. We found priming in both hemispheres, however, when targets were context-appropriate senses of ambiguous words or topics of passages. In Experiment 2, we replicated the priming effects in three callosotomy patients. We argue that the distinction between a propositional representation and a discourse model is important with respect to how discourse is represented in the brain. The propositional representation appears to reside in the left hemisphere, whereas aspects of the discourse model appear to be represented in both hemispheres. ■

INTRODUCTION

Research on language representation in the brain has begun to yield some consensus about the language processing abilities of the left and right hemispheres. Decades of research has shown that the left hemisphere is dominant for language processing; nonetheless, the right hemisphere appears to process language to some extent. Its word recognition abilities are fairly well developed, although it has impoverished speech output and little ability to use phonological analysis to recognize words (see Baynes, 1990; Baynes & Eliassen, 1998; Zaidel, 1990; Gazzaniga & Sperry, 1967, for relevant reviews). With respect to sentence-level processing, the right hemisphere is poorer at syntactic analysis than is the left (Baynes & Gazzaniga, 1988; Zaidel, 1978, 1990). It has difficulty understanding syntactic constructions that require coordination of subject/object and direct object/indirect object relations and relies heavily on word order in parsing. Of particular interest in this study is the evidence that the right hemisphere plays an important role in understanding language as a connected whole (Meyers, 1994; Beeman, 1993; Joanete, Goulet, & Hannequin, 1990; Brownell, Potter, Bihrle, & Gardner, 1986; Brownell, Gardner, Prather, & Martino, 1995; Delis, Wapner, Gardner, & Moses, 1983). It appears to be involved in integrating ideas across sentences (Brownell et al., 1986), in identifying main ideas and themes (Rehak, Kaplan, & Gardner, 1992; Hough, 1990), and in understanding figurative language and humor (Van Lancker & Kempler, 1987; Bihrle, Brownell, Powelson, & Gardner, 1986; Wapner, Hamby, & Gardner, 1981; Winner and Gardner, 1977).

Although researchers generally agree that the right hemisphere plays a nontrivial role in language comprehension, the precise nature of its role is poorly understood. Several factors hinder the development of a satisfactory model of right hemisphere language comprehension. First, laterality research has often produced inconsistent results. For example, some studies have found that right-hemisphere–damaged patients exhibit inference problems in a variety of comprehension tasks (Brownell et al., 1986; Tompkins & Mateer, 1985; Cicone, Wapner, & Gardner, 1980); other studies have failed to find inference deficits (Tompkins, 1991; McDonald & Wales, 1986), even when attempting to replicate earlier results (Tompkins, 1991). Second, laterality studies are often not grounded in current theories of sentence and discourse processing (Stemmer & Joanette, 1998; Fayol & Lemaire, 1993). This is unsurprising since psycholinguists have only recently developed discourse processing models that are sophisticated enough to be usefully applied to the study of language representation in the brain. Finally, neuropsychologists and psycholinguists often use different paradigms, making it difficult to compare and integrate empirical findings.

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Our goal in this study was to examine language representation in the cerebral hemispheres using the theoretical constructs and paradigms that have become standard in psycholinguistics. A basic question in psycholinguistic research concerns the nature of the sentence and discourse representations stored in memory. We extended this question to the study of language comprehension in the brain by asking about the nature of sentence and discourse representation in the two cerebral hemispheres. Our particular focus was on how memory representations in the right hemisphere might differ from those in the left hemisphere.

How is Discourse Represented in Memory?

Psycholinguists generally agree that readers construct and store in memory at least two interrelated representations when they comprehend a text: a propositional representation and a discourse model (Graesser, Singer, & Trabasso, 1994; Greene, McKoon, & Ratcliff, 1992; Gernsbacher, 1990; McKoon & Ratcliff, 1990, 1992, 1998; Kintsch & van Dijk, 1978; Kintsch, 1988). A propositional representation contains the individual ideas (propositions) that are derived from each sentence and the relations among them (Kintsch, 1974). A proposition is a structured, coherent unit consisting of a predicate (e.g., verb, adjective, adverb) and one or more associated arguments (i.e., concepts that are related or modified by the predicate). The propositional representation is ''locally'' coherent, that is, propositions in each incoming sentence are mapped to propositions currently active in working memory, usually those from the immediately preceding sentence or two. The relations among propositions are primarily referential (McKoon & Ratcliff, 1980; Ratcliff & McKoon, 1978; Kintsch, 1974); propositions are connected when their arguments refer to the same entity. Propositions that cannot be connected by means of a referential link require inferences to fill the gap.

The propositional representation serves as a foundation for the discourse model (Graesser et al., 1994, Greeene et al., 1992; McKoon & Ratcliff, 1990, 1992, 1998). The discourse model is a representation of what the text is about and is ''globally'' coherent. Global coherence involves relating ideas in terms of the specific situation or context to which a text refers. These relations often require inferences to be made from the reader's general world knowledge. Such inferences may involve the causes and consequences of events, the spatial arrangement of objects, the procedure for performing a task, or the goals of individuals.

Our goal in this study was to examine how the propositional representation and the discourse model might be stored in the left and right hemispheres. Previous research on the language comprehension abilities of the two hemispheres suggests that they may represent discourse quite differently. The right hemisphere appears to have limited syntactic-processing abilities (Zaidel, 1978, 1990); this may impair its ability to construct a propositional representation. Propositions often correspond to individual syntactic constituents. Moreover, propositions are typically connected by means of referential relations, establishing these relations would seem to depend on knowledge about ''who did what to whom'' in a sentence. Thus, a reasonable hypothesis is that the propositional representation resides in the left hemisphere. The right hemisphere, in contrast, may represent the discourse model. Considerable evidence suggests that the right hemisphere is involved in integrating ideas among sentences and in making inferences (Meyers, 1994; Beeman, 1993; Brownell et al., 1986), processes that are essential to constructing a coherent and referential discourse model.

One difficulty with this view of discourse representation in the two hemispheres (i.e., the propositional representation in the left hemisphere and the discourse model in the right hemisphere) is that the two representations are strongly interrelated (Graesser et al., 1994; McKoon & Ratcliff, 1990; Kintsch, 1988). Thus, it may be unreasonable to think that the two representations are stored independently in different hemispheres. So, how else might the propositional representation and the discourse model be stored? One possibility is that both representations are stored in the left hemisphere. This possibility is founded on the view that the left hemisphere has the syntactic processing abilities necessary for deriving propositions from sentences. If the propositional representation resides in the left hemisphere, then the discourse model, which is based on this representation, may reside in the left hemisphere as well. If this were the case, then the challenge would be in understanding how the right hemisphere plays an important role in constructing the discourse model in the absence of access to the propositional representation on which it is based. At the very least, limited access to the propositional representation would place constraints on the means by which the right hemisphere could be involved in constructing the discourse model. We return to this issue in the discussion of our results.

A second possibility for how the propositional representation and discourse model may be stored in the brain is that both representations may be distributed across the two hemispheres, even though the hemispheres have different roles in constructing them. For example, the left hemisphere may be responsible for deriving and connecting propositions, but once the propositional representation has been constructed, it may be stored such that both hemispheres have equal access to it.

Our goal in Experiment 1 was to discriminate among these possibilities. We used a standard psycholinguistic paradigm for examining how discourse is represented in memory and adapted it to study discourse representation in the two hemispheres. This paradigm, involving item priming in recognition memory, is described in the next section.

Item Priming in Recognition Memory

Priming in item recognition is a standard paradigm in psycholinguistic research used to examine the structure of readers' sentence and discourse representations. The logic of the paradigm is that activation of a concept in memory facilitates recognition of other concepts to which it is linked. The paradigm was first used by Ratcliff and McKoon (1978) to show that the structure of sentences in memory is propositional (see also Long, Oppy, & Seely, 1997; McKoon & Ratcliff, 1980). Participants in their experiment received a series of study-test trials. During the study phase of each trial, participants read a list of four unrelated sentences. Table 1 contains two sample sentences and their propositional structure. Immediately after reading the last sentence in the list, participants received a recognition memory test. The test list contained single words, presented one at a time. Participants decided whether or not each test word had been in one of the sentences that they studied.

Ratcliff and McKoon (1978) manipulated the order of the test words such that some of the items were arranged in prime–target pairs. The target, a word from the sentence (e.g., wind), was preceded by a prime word that was (a) in the same proposition as the target (e.g., clouds), (b) in the same sentence, but in a different proposition, than the target (e.g., horizon), or (c) in a different sentence than the target (e.g., wine). Participants responded to all items (primes, targets, and fillers) and participants had no information that some items were arranged in pairs.

Ratcliff and McKoon (1978) found that the size of the priming effect depended on the relation between the prime and the target in the propositional structure of the sentence. The priming effect was largest when the prime and target were from the same proposition, suggesting that the concepts were strongly linked in memory. The priming effect was somewhat smaller when the prime and target were from different propositions in the same sentence, suggesting that the mental distance between concepts was greater in the different- than in the same-proposition condition.

Table 1. Sample Sentences and Their Propositional Structure (From Ratcliff & McKoon, 1978)

Sentence	*Propositions*
Geese crossed the horizon as wind shuffled the clouds	P1 (crossed, geese, horizon)
	P2 (shuffled, wind, clouds)
	P3 (as, P1, P2)
The host mixed a cocktail but the guest wanted wine.	P1 (mixed, host, cocktail)
	P2 (wanted, guest, wine)
	P3 (but, P1, P2)

The propositions are listed according to standard notation (Kintsch, 1974). In each proposition (P), the predicate is listed first, followed by its arguments.

In Experiment 1, we used this paradigm in combination with a lateralized visual field (VF) procedure to examine how discourse is represented in the two cerebral hemispheres. In Experiment 2, we used the paradigm with a group of callosotomy participants to examine how discourse was represented in the absence of substantial hemispheric cooperation during comprehension.

EXPERIMENT 1

We replicated an earlier experiment by Long et al. (1997), who used the item-priming-in-recognition paradigm to study individual differences in readers' sentence and discourse representations. We added to their experiment a VF manipulation to determine whether the left and right hemispheres had similar sentence representations. Participants received several study-test trials in which a set of brief two-sentence passages was presented for study, followed by a recognition test consisting of single words. Test items were presented very briefly, one item at a time. Primes were presented in the center of a computer screen; targets were lateralized to the left visual field/right hemisphere (LVF/RH) or to the right visual field/left hemisphere (RVF/LH).

We used the priming manipulation to examine three aspects of readers' sentence representations. First, we examined the memory representations for evidence of propositional structure. If both hemispheres have access to sentence representations that are structured by means of propositional relations, then both should show a propositional priming effect, faster responses to targets that are preceded by primes from the same propositions relative to primes from different propositions. Second, we examined readers' discourse representations for evidence that the hemispheres represented important semantic relations. Specifically, we asked whether the representations contained information about the context-appropriate senses of ambiguous words and information about the themes or topics of the passages.

Sample passages and prime–target pairs appear in Table 2. Each passage was two sentences long and contained a homograph that appeared as the final word of either the first or the second sentence in the passage. Each test list contained three types of priming pairs: (1) propositional-priming pairs consisted of a target (e.g., structure) that was preceded by a prime from the same proposition (e.g., disaster) or by a prime from a different proposition in the same sentence (e.g., danger); (2) associate-priming pairs consisted of a target that was either the appropriate (e.g., money) or the inappropri-

Table 2. Sample Passages and Example Prime–Target Pairs

Priming Relation	*Prime*	*Target*
The townspeople were amazed to find that all the buildings had collapsed except the mint. Obviously, the architect had foreseen the danger because the structure withstood the natural disaster.		
Propositional priming pairs		
Same-proposition	disaster	structure
Different-proposition	danger	structure
Associate priming pairs		
Appropriate-associate	townspeople	money
Inappropriate associate	townspeople	candy
Topic priming pairs		
Appropriate-topic	architect	earthquake
Inappropriate-topic	architect	breath
The guest ate garlic in his dinner, so the waiter brought a mint. The worried guest soon felt comfortable socializing with his friends.		
Propositional priming pairs		
Same-proposition	guest	garlic
Different-proposition	waiter	garlic
Associate priming pairs		
Appropriate-associate	dinner	candy
Inappropriate associate	dinner	money
Topic priming pairs		
Appropriate-topic	friends	breath
Inappropriate-topic	friends	earthquake

ate associate (e.g., candy) of a homograph in the sentence and was preceded by a prime from the sentence containing the homograph (e.g., townspeople); and (3) topic-priming pairs consisted of a target that was either the topic of a passage (e.g., earthquake) or was an unrelated word (e.g., breath) and was preceded by a prime from the final sentence of the passage (e.g., architect). It should be noted that the correct response to the associates and to the topic words is ''no.'' These items did not appear in the sentences.

Long et al. (1997) found a strong propositional-priming effect. Readers recognized targets faster when they were preceded by primes from the same rather than different propositions. They also found reliable priming for targets in associate- and topic-priming pairs. Readers had difficulty rejecting appropriate associates and topic words. Long et al. argued that readers had incorporated the context-appropriate senses of the ambiguous words and information about the topics of the passages into their discourse representations; thus, these items were difficult to reject at test because they resonated with information in their memory representation. It should be noted that Long et al. attributed the priming effect in the associate- and topic-priming conditions to the relation between the target and the passage representation stored in memory and not to the relation between the target and the prime in the test list. Targets were preceded by primes in the recognition test only to facilitate access to the relevant passages in memory.[1] Thus, the priming effect in the associate- and topic-priming conditions should be thought of as ''long-term'' priming from the passages.

If the left and right hemispheres have access to similar discourse representations, then we should see these same priming effects both when targets are lateralized to the RVF/LH and when they are lateralized to the LVF/RH.

Results and Discussion

We performed separate 2 (Priming) × 2 (VF) repeated-measures ANOVAs on errors and reaction times to

Table 3. Mean Reaction Times (RT, in msec) and Accuracy Rates (AR, in Percentages) as a Function of Priming Condition and Visual Field (Standard Errors Appear in Parentheses)

	Visual Field			
	RVF/LH		*LVF/RH*	
Priming Condition	*RT*	*AR*	*RT*	*AR*
Propositional				
Same	808 (14)	87 (0.26)	944 (33)	70 (0.33)
Different	922 (30)	73 (0.28)	932 (25)	69 (0.31)
Associate				
Appropriate	1074 (40)	64 (0.32)	1082 (40)	64 (0.32)
Inappropriate	946 (17)	81 (0.26)	1005 (38)	85 (0.26)
Topic				
Appropriate	1008 (36)	65 (0.33)	1045 (30)	66 (0.33)
Inappropriate	977 (35)	90 (0.27)	1004 (36)	86 (0.22)

Means in the propositional-priming condition are for "yes" responses; means in the associate- and topic-priming condition are for "no" responses.

targets in the propositional-, associate-, and topic-priming pairs.[2] Priming (same vs. different or appropriate vs. inappropriate) and VF (LVF vs. RVF) were within-participants factors; response hand (yes as a right-hand vs. yes as a left-hand response) was a between-participants factor. Only correct responses were included in the analyses of the reaction-time data. All latencies three standard deviations from a participant's mean were treated as missing data. All effects were tested at a significance level of $p < .05$ unless otherwise indicated. Mean accuracy rates and response times to targets in the six priming conditions appear in Table 3 and in Figures 1 and 2 (response times and accuracy, respectively).

Propositional-Priming Pairs

Our analysis of reaction times to targets in the same- and different-proposition conditions revealed reliable effects of priming and VF, $F(1,59) = 6.63$, $MSe = 14{,}829$ and $F(1,59) = 13.76$, $MSe = 17{,}209$, respectively. These effects were modified by a reliable Priming × VF interaction, $F(1,59) = 4.47$, $MSe = 71{,}788$. Participants showed a priming effect, faster responses to targets in the same- than in the different-proposition condition, but only when targets appeared in the RVF/LH, $F(1,59) = 5.39$. They showed no priming effect when targets appeared in the LVF/RH, $F < 1$.

Our analysis of the accuracy data mirrored the pattern described above. We found reliable effects of priming and VF, $F(1,59) = 21.50$, $MSe = 3.03$ and $F(1,59) = 53.04$, $MSe = 2.46$, respectively. These effects were modified by a reliable Priming × VF interaction, $F(1,59) = 7.57$, $MSe = 7.28$. Participants showed a propositional-priming effect, greater accuracy to targets in the same- than in the different-proposition condition. This occurred when targets appeared in the RVF/LH, $F(1,59) = 16.48$, but not when targets appeared in the LVF/RH, $F < 1$.

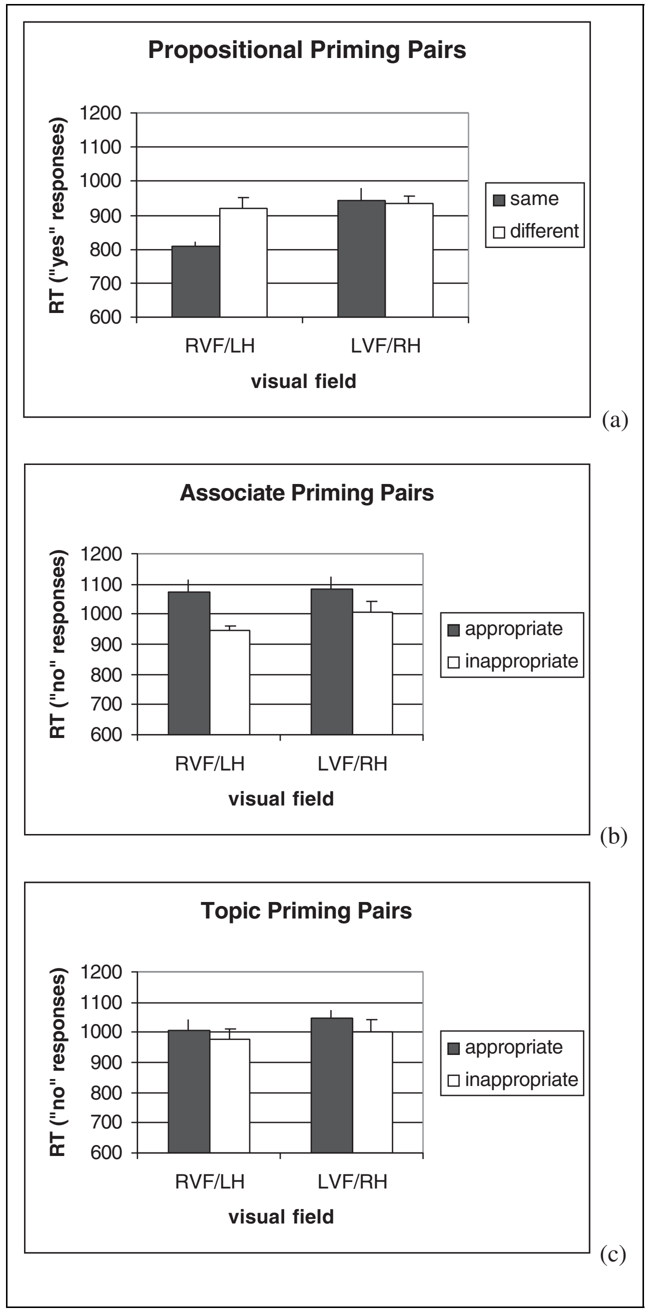

Figure 1. Mean response times (in msec) to targets in Experiment 1 as a function of visual field: (a) "yes" responses to targets in propositional priming pairs; (b) "no" responses to targets in associate priming pairs; and (c) "no" responses to targets in topic priming pairs. Error bars depict standard errors.

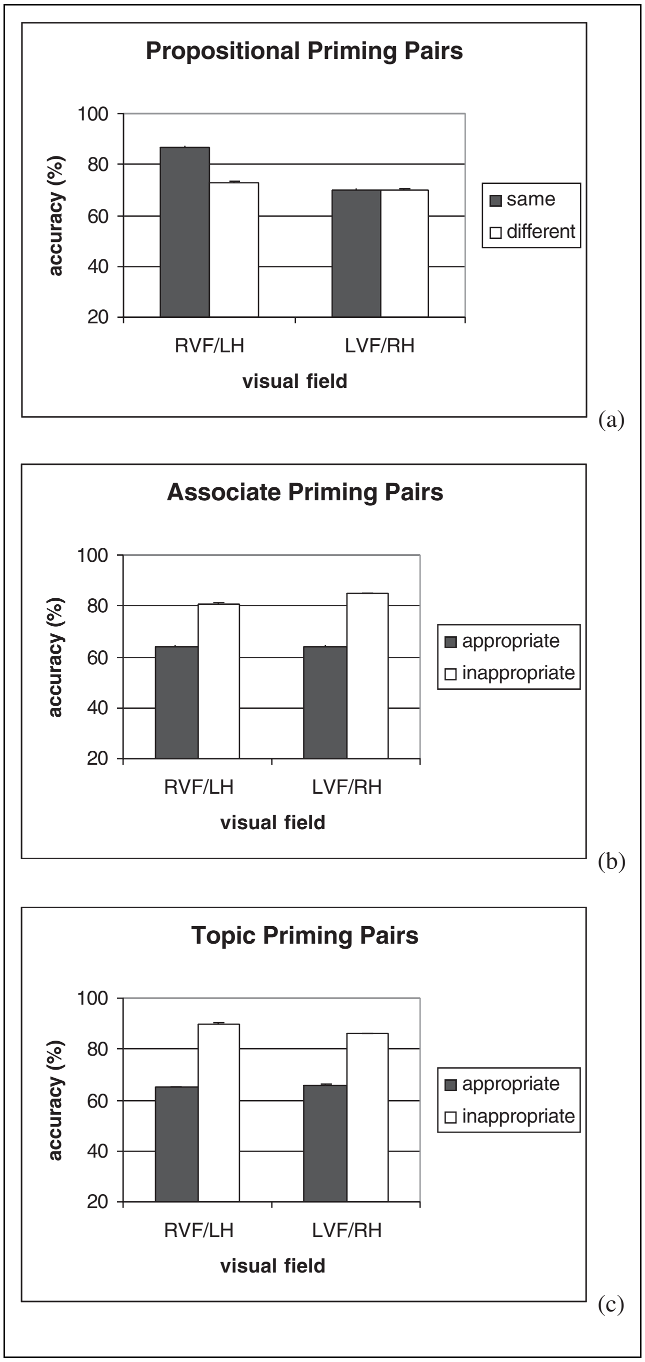

Figure 2. Mean accuracy rates (in percentages) to targets in Experiment 1 as a function of visual field: (a) ''yes'' responses to targets in propositional priming pairs; (b) ''no'' responses to targets in associate priming pairs; and (c) ''no'' responses to targets in topic priming pairs. Error bars depict standard errors.

Associate-Priming Pairs

Our analysis of the reaction-time data revealed reliable effects of priming and VF, $F(1,59) = 47.32$, $MSe = 22{,}128$ and $F(1,59) = 11.23$, $MSe = 21{,}466$, respectively. These effects were modified by a marginal Priming × VF interaction, $F(1,59) = 2.75$, $MSe = 132{,}101$, $p = .10$. When targets appeared in the RVF/LH, participants showed a large priming effect, slower responses to appropriate than to inappropriate associates of the homograph, $F(1,59) = 17.36$; participants showed a somewhat smaller, but still reliable, priming effect when targets appeared in the LVF/RH, $F(1,59) = 7.99$. Our analysis of the accuracy data revealed a reliable priming effect. Participants were less accurate to appropriate than to inappropriate associates of the homographs, $F(1,59) = 133.10$, $MSe = 3.13$. This effect did not depend on VF.

Topic-Priming Pairs

Our analysis of reaction times to the topic words revealed a reliable effect of priming and a marginal effect of VF, $F(1,59) = 4.19$, $MSe = 14{,}263$ and $F(1,59) = 3.85$, $MSe = 11{,}462$, $p = .06$, respectively. We found no Priming × VF interaction, $F < 1$. Participants were slower to respond to appropriate than to inappropriate topics in both the LVF/RH and the RVF/LH. Our analysis of the accuracy data revealed a large priming effect, $F(1,59) = 216.29$, $MSe = 2.74$. Participants were less accurate to appropriate- than to inappropriate-topic words.

The priming patterns in this experiment suggest both differences and similarities in how discourse is represented in the two hemispheres. Only the left hemisphere showed evidence for a representation that was structured in terms of propositional relations. We found the typical propositional-priming effect when targets were presented to the RVF/LH, but not when they were presented to the LVF/RH. This suggests that concepts in the same proposition were ''closer'' in the left hemisphere's representation of a sentence than were concepts in different propositions.

The priming patterns in the two hemispheres were similar, however, with respect to the representation of context-appropriate semantic information. Participants had considerable difficulty rejecting both appropriate associates and topics when they were presented in either the RVF/LH or the LVF/RH. This suggests that information about the contextually appropriate senses of ambiguous words and information about the topics of the passages were incorporated into readers' representations in both hemispheres. Participants had difficulty rejecting the targets because these items resonated with information contained in their memory representation.

It is important to note that the priming effects in this experiment were obtained several seconds after participants read the sentences. This suggests that the representations in each hemisphere do not decay rapidly. Priming effects that hold across intervals as long as these are generally thought to be relatively stable and would probably be found at even longer intervals (Ratcliff & McKoon, 1978).

We began this experiment by asking whether discourse is represented differently in the two hemispheres. Our results suggest that a propositionally structured representation resides in the left hemisphere, whereas information relevant to the discourse model (e.g., thematic information about the passages) resides in both hemispheres. This experiment, however, provides no information about how the right hemisphere may have contributed to the construction of these representations. We investigated this issue in Experiment 2.

EXPERIMENT 2

On the basis of our findings in Experiment 1, we might conclude that the discourse representation in the right hemisphere was an incomplete reflection of the representation in the left hemisphere. The right hemisphere contained the same semantic information as did the left, but the information was not structured in the same way. A corollary to this conclusion might be that the right hemisphere played no unique role in constructing the discourse representation; it mirrored some, but not all, of the activities in the left hemisphere. One problem with this conclusion, however, is that it ignores the fact that the two hemispheres undoubtedly interacted in the construction of the discourse representation. The two cerebral hemispheres may ultimately store similar representations, but the right hemisphere may play a unique and important role in constructing them.

Our goal in this experiment was to determine whether input from the right hemisphere was necessary to the development of the discourse representation in the left hemisphere. Previous research on right hemisphere language comprehension suggests that the right hemisphere plays an important role in the ability to identify main ideas and themes. Individuals with a right hemisphere damage exhibit a range of comprehension difficulties. In particular, they appear to have difficulty making many of the inferences that are necessary to construct a coherent discourse model (Meyers, 1994; Beeman, 1993; Brownell et al., 1986). Thus, the priming that we found for topic-related words in both the hemispheres may have depended on comprehension activities that occurred in the right hemisphere. Alternatively, the hemispheres may have represented the topic-related information redundantly and in parallel.

We investigated this issue in a group of callosotomy participants. We used the same materials and priming paradigm as those described in Experiment 1, but we chose not to manipulate VF. The VF manipulation in Experiment 1 required four material sets to implement. Unfortunately, we had too few callosotomy participants in this experiment to counterbalance material sets across participants. We considered two alternative design changes to overcome this constraint. First, we considered presenting all four material sets to each participant. We were concerned, however, about the effect that this might have on accuracy rates, a concern that turned out to be well justified. Second, we considered creating additional passages and recognition items. With enough items, we could be justified in relaxing our counterbalancing requirements. We were unable, however, to find a large enough pool of balanced homographs around which we could construct additional materials. Thus, we eliminated the VF manipulation and counterbalanced our materials across two material sets. The participants received both material sets. All test items were presented centrally, and each item remained on the screen until the participant responded to it. Participants responded with their right hands only.

We made two important assumptions in this experiment. First, we assumed that participants' responses under these conditions would reflect the nature of the discourse representations stored in their left hemispheres. Participants responded to test items with their right hands, so even though the passages and test items were presented centrally and presumably processed in both hemispheres, their response output should primarily reflect information in their left hemisphere. Although both hemispheres do have limited ipsilateral motor control (Trope, Fishman, Sussman, & Gur, 1987; Brinkman & Kuypers, 1973), right-hand responses to LVF/RH stimuli are invariably slower and less accurate than right-hand responses to RVF/LH stimuli (Baynes, Tramo, & Gazzaniga, 1992). Hence, the presence of responses controlled by different hemispheres should increase the variability of response time. Our response times were quite homogeneous. Second, we assumed that the discourse representation in the left hemisphere was constructed in the absence of substantial right hemisphere input. Research in a variety of paradigms has shown that higher-order semantic information does not transfer between the hemispheres in the absence of intact callosal fibers (Baynes, Wessinger, Fendrich, & Gazzaniga, 1995; Kingstone & Gazzaniga, 1995; Sidtis, Volpe, Holtzman, Wilson, & Gazzaniga, 1981). All of the patients in this experiment have MRI-verified complete callosal section (Eliassen, Baynes, Lutsep, & Gazzaniga, in preparation; Gazzaniga, Holtzman, Deck, & Lee, 1985). Thus, priming for context-appropriate topic words in this experiment would suggest that right hemisphere processing was highly unlikely to contribute to the representation of topic-related information in the left hemisphere, at least not for the passages that we used in this study.

Results and Discussion

We performed item analyses on the reaction-time and accuracy data for each participant. This involved a repeated-measures ANOVA on responses to targets in the propositional-, associate-, and topic-priming pairs. Priming (same vs. different or appropriate vs. inappro-

Table 4. Mean Reaction Times (RT, in Milliseconds) and Accuracy Rates (AR, in Percentages) for Each Participant (Standard Errors are in Parentheses)

	V.J.		*J.W.*		*D.R.*	
Priming Condition	*RT*	*AR*	*RT*	*AR*	*RT*	*AR*
Propositional						
Same	1387 (81)	84 (0.24)	1186 (34)	93 (0.14)	1511 (68)	77 (0.22)
Different	1644 (83)	77 (0.18)	1315 (41)	84 (0.22)	1925 (132)	75 (0.22)
Associate						
Appropriate	1624 (102)	39 (0.26)	1575 (109)	30 (0.30)	2475 (143)	63 (0.18)
Inappropriate	1585 (95)	64 (0.25)	1522 (96)	46 (0.18)	2167 (100)	82 (0.26)
Topic						
Appropriate	1687 (130)	50 (0.23)	1672 (137)	24 (0.28)	2749 (165)	63 (0.28)
Inappropriate	1580 (63)	73 (0.24)	1519 (92)	55 (0.22)	2615 (151)	83 (0.22)

Means in the propositional-priming condition are for "yes" responses; means in the associate- and topic-priming condition are for "no" responses.

priate) was a within-items factor. Only correct responses were included in our analyses of the reaction-time data. All latencies three standard deviations from a participant's mean were treated as missing data. Effects were tested at a significance level of $p < .05$ unless otherwise indicated. Mean response times and accuracy appear in Table 4 and in Figures 3 and 4 (response times and accuracy, respectively).

Propositional-Priming Pairs

Our analyses of reaction times to targets in the same- and different-proposition conditions revealed reliable effects of priming. All participants responded faster to targets in the same- than in the different-proposition condition, $F(1,28) = 4.80$, $MSe = 212,938$, $F(1,28) = 7.64$, $MSe = 216,933$, and $F(1,28) = 5.71$, $MSe = 41,855$, V.J., D.R., and J.W., respectively. Participants were also more accurate to targets in the same- than in the different-proposition condition; however, this effect was not reliable, $F < 1$.

Associate-Priming Pairs

All participants responded slower to appropriate than to inappropriate associates of the homographs, although these differences were not reliable, $F(1,28) = 2.30$, $F(1,28) = 2.51$, and $F < 1$, V.J., D.R., and J.W., respectively. In addition, all participants were less accurate to appropriate than to inappropriate associates. The priming effects were reliable in our analyses of V.J.'s and D.R.'s errors, $F(1,28) = 9.95$, $MSe = 0.35$ and $F(1,28) = 4.37$, $MSe = 0.49$, respectively. The effect was marginal in our analysis of J.W.'s data, $F(1,28) = 2.99$, $MSe = 0.48$, $p = .09$.

Topic-Priming Pairs

Participants responded more slowly to appropriate than to inappropriate topic words; however, the priming effect was not reliable in any analysis, all F's < 1. Our analysis of the accuracy data revealed reliable priming effects. All participants were less accurate to appropriate than to inappropriate topics, $F(1,28) = 7.10$, $MSe = 0.43$, $F(1,28) = 5.14$, $MSe = 0.42$, and $F(1,28) = 15.29$, $MSe = 0.38$, V.J., D.R., and J.W., respectively.

The pattern of priming that we found in this experiment is similar in most respects to the pattern that we observed in Experiment 1. We found that participants responded faster to a target when it was preceded by a prime from the same proposition than when it was preceded by a prime from a different proposition. We also found that participants were less accurate to appropriate associates and topics than to inappropriate associates and topics. We did, however, fail to replicate some of the effects that we observed in Experiment 1. In particular, we found no reliable effects of priming in our analyses of reaction times to the associate and topic words. One explanation for our failure to observe reliable priming in the reaction-time data is that participants had poor accuracy rates in these conditions. The mean accuracy rate across participants was 54% for associate words and 58% for topic words. Thus, almost half of the response times in these conditions was treated as missing data, making it difficult to obtain reliable effects.

We examined our data to determine why accuracy rates to associate and topic words were so much lower in this experiment than in Experiment 1. One possibility is that the callosotomy participants found the task more difficult than did the normal participants. This explan-

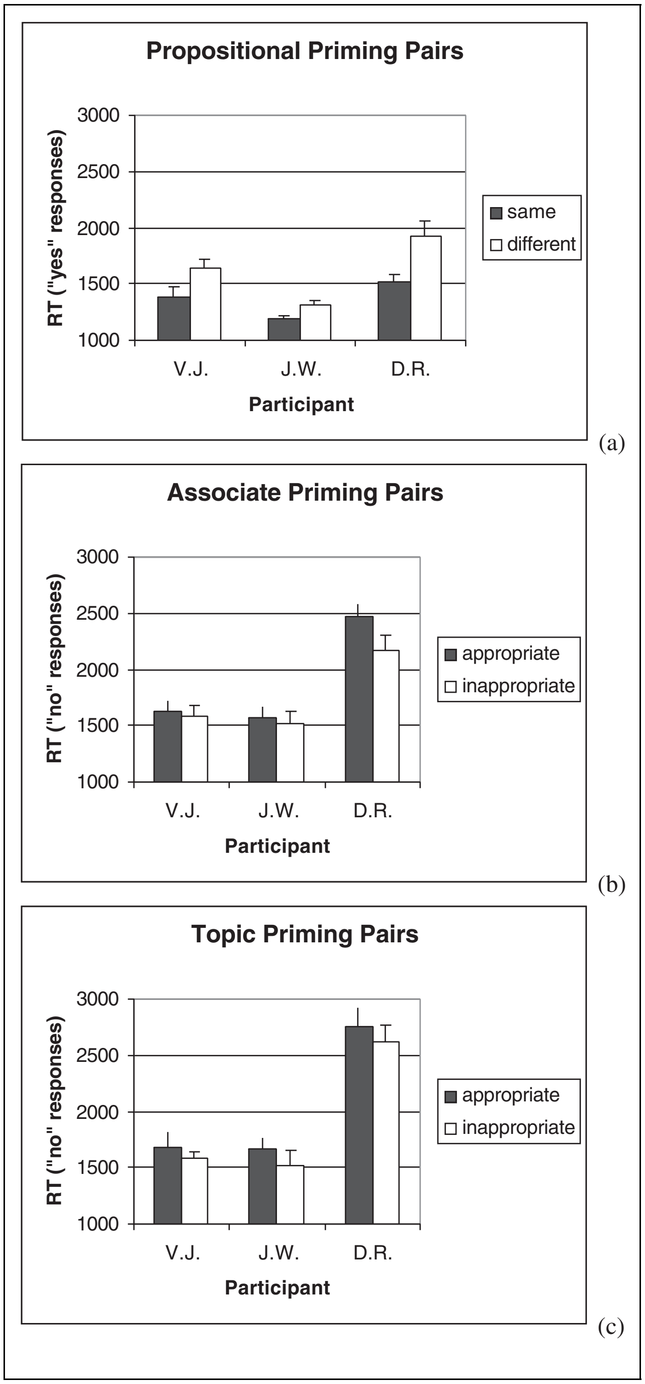

Figure 3. Mean response times (in msec) to targets in Experiment 2 for each participant: (a) ''yes'' responses to targets in propositional priming pairs; (b) ''no'' responses to targets in associate priming pairs; and (c) ''no'' responses to targets in topic priming pairs. Error bars depict standard errors.

ation would also predict, however, that callosotomy participants should have been less accurate than normal participants to targets in the propositional-priming condition. This was not the case, however. The mean accuracy rate was 82% for the callosotomy participants and 75% for normal participants. Another possibility is that accuracy to associate and topic words was lower in this experiment than in Experiment 1 because the callosotomy participants received two material sets. That is, unlike other participants, they read each passage twice, once when it was associated with a context-appropriate test item and once when it was associated with a context-inappropriate item. In order to investigate this possibility, we compared accuracy rates on the

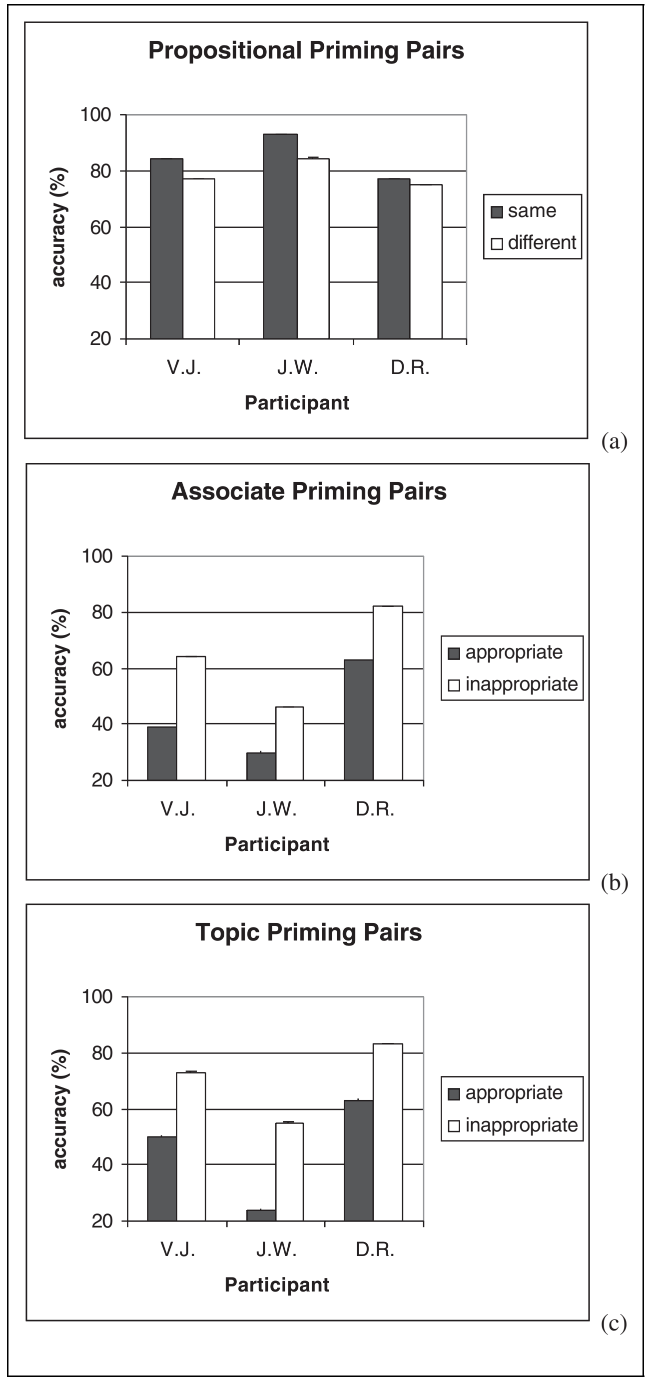

Figure 4. Mean accuracy rates (in percentages) to targets in Experiment 2 for each participant: (a) ''yes'' responses to targets in propositional priming pairs; (b) ''no'' responses to targets in associate priming pairs; and (c) ''no'' responses to targets in topic priming pairs. Error bars depict standard errors.

Table 5. Mean Reaction Times (RT, in msec) and Accuracy Rates (AR, in Percentages) for Each Participant as a Function of Material Set

	V.J.				*J.W.*				*D.R.*			
	Set 1		*Set 2*		*Set 1*		*Set 2*		*Set 1*		*Set 2*	
Priming Condition	*RT*	*AR*	*RT*	*AR*	*RT*	*AR*	*RT*	*AR*	*RT*	*AR*	*RT*	*AR*
Propositional												
Same	1437	79	1324	88	1211	89	1130	96	1597	64	1472	89
Different	1736	71	1551	82	1415	86	1210	82	2127	61	1750	85
Associate												
Appropriate	1577	68	1648	11	1504	43	1650	18	2349	61	2636	57
Inappropriate	1528	79	1598	50	1430	63	1638	29	2136	89	2185	75
Topic												
Appropriate	1658	68	1727	32	1632	36	1689	11	2566	75	2942	54
Inappropriate	1575	79	1556	67	1446	79	1568	29	2421	86	2799	78

Means in the propositional-priming condition are for "yes" responses; means in the associate- and topic-priming condition are for "no" responses.

two material sets. Mean response times for each material set appear in Table 5.

As can be seen in Table 5, accuracy to associate words in the first material set was not much different from that observed in Experiment 1. In contrast, accuracy to associate words in the second set was much lower. The differences in accuracy between the two sets were all reliable, $F(1,27) = 7.00$, $MSe = 0.50$, $F(1,27) = 3.97$, $MSe = 0.59$, and $F(1,27) = 4.00$, $MSe = 0.47$ (V.J., J.W., and D.R., respectively). The same pattern was found for the topic words. Accuracy in the first set was much higher than was accuracy in the second set, $F(1,27) = 4.01$, $MSe = 0.46$, $F(1,27) = 3.99$, $MSe = 0.45$, and $F(1,27) = 4.74$, $MSe = 0.32$ (V.J., J.W., and D.R., respectively). These data suggest that participants represented the associate and topic concepts more strongly after reading the passages for the second time; this made it more difficult to reject the recognition items at test (see Table 2). The high error rate for associate and topic items in the second material set resulted in a substantial amount missing response time data. Thus, even though participant reaction time patterns were in the predicted direction, our ability to detect reliable effects was likely impaired by a significant loss of power.

In summary, the callosotomy participants showed evidence for a discourse representation that had propositional structure and contained context-appropriate semantic information. Moreover, the discourse representation appeared to be constructed in the absence of substantial right hemisphere input. We should be cautious about this latter conclusion, however. It is based on the assumption that right-hand responses should reflect comprehension activities in the left hemisphere. Although this technique emphasizes the left hemisphere's contribution, it does not rule out some contribution from the right hemisphere. For example, Kingstone and Gazzaniga (1995) showed that both hemispheres could collaborate to combine literal information with a manual output, but were unable to combine higher-order information. Hence, we cannot rule out some right hemisphere contribution to the acceptance or rejection of stimuli when both hemispheres have access to the stimulus materials.

GENERAL DISCUSSION

Current theories of discourse processing make an important distinction between the reader's representation of the text itself (the propositional representation) and the reader's representation of what the text is about (the discourse model). Our findings suggest that this distinction is also important with respect to how discourse is represented in the brain. The results of Experiment 1 clearly suggest that the left hemisphere contains a discourse representation that reflects the distance among concepts in the propositional structure of sentences. Participants showed the standard propositional-priming effect, faster responses to targets in same- than in different-proposition pairs. We found this effect, however, only when targets were presented in the RVF/LH. We found no propositional priming for targets presented in the LVF/RH.

Although we found that the right hemisphere's representation lacked a propositional structure, we found that it did contain important semantic information about the passages. Participants showed associate and topic priming, faster responses to context-appropriate associates and topics than to inappropriate ones. We found this effect both when targets were presented in the LVF/RH and RVF/LH. This pattern suggests that the right hemisphere, like the left, contains aspects of the discourse model; most importantly, it contains information about the topics or themes of passages.

Our results are consistent with recent research by Faust et al. suggesting qualitative differences in how the two cerebral hemispheres encode the meanings of sentences (Faust, Babkoff, & Kravetz, 1995; Faust, 1998; Faust & Kravetz, 1998). They argue that the left hemisphere has integrative syntactic and semantic mechanisms that encode a ''message-level'' representation, that is a semantically integrated representation of the whole sentence meaning. The right hemisphere, in contrast, constructs an associative network representation consisting of the individual words in a sentence and the semantic relations among them. Our results extend this view by suggesting that the message-level representation in the left hemisphere has propositional structure. Concepts that are close in the propositional structure of a sentence are strongly linked in the left, but not in the right, hemisphere's internal representation. Moreover, our results suggest that the associative network in the right hemisphere contains links, not only among individual lexical items in sentence, but also among related semantic concepts, such as the context-appropriate senses of ambiguous words and the topics of sentences.

The results that we obtained in Experiment 1 raise an interesting question about how the right hemisphere acquires information relevant to the discourse model when the propositional representation on which the discourse model is based resides in the left hemisphere. One answer to this question can be found in models that attribute the right hemisphere's role in discourse comprehension to the nature of its lexical–semantic system (Burgess & Lund, 1998; Beeman, 1993, 1998; Chiarello, 1991, 1998). For example, Beeman (1993) has suggested that representational differences in the two hemispheres may underlie the right hemisphere's role in discourse processing. He argues that the hemispheres have qualitatively distinct semantic networks. The left hemisphere has a finely coded network that supports the rapid selection of a single contextually appropriate meaning, whereas the right hemisphere has a coarsely coded network that weakly activates multiple meanings and distantly related features. Thus, the right hemisphere maintains activation for concepts that are distantly related to words and phrases in an incoming sentence. These activated concepts can provide information that is essential for elaborating a discourse representation with context-appropriate inferences or for reinterpreting a word or phrase when the left hemisphere has selected an inappropriate meaning. Alternatively, the right hemisphere's role in discourse processing may arise from processing differences in the two hemispheres. Chiarello (1991) has suggested that rapid selection of a single meaning might be crucial to left hemisphere structure-building processes, whereas the slow activation and decay of information in the right hemisphere might be crucial to elaboration or revision of meaning.

The challenge for models of right hemisphere comprehension such as those described above is to specify the circumstances in which the right hemisphere will play a unique role in constructing a coherent discourse representation. Our results suggest that the conditions used in this study did not promote a special role for the right hemisphere. Both the left and right hemispheres represented contextually appropriate semantic information about the sentences (see Experiment 1). Moreover, the representation of such information may not require right hemisphere input (see Experiment 2). One explanation for our findings is that the semantic relations that were represented in both hemispheres resulted from similar processing mechanisms. The associate and topic words that we used in our experiments were strongly related to individual words in the passages; thus, the integration of this information into the discourse representation may have been supported by lexical priming that occurred similarly in both hemispheres. A stronger test of the unique role of the right hemisphere in discourse comprehension may require the use of materials in which inference concepts are not supported by strong lexical associations with individual words in the preceding context.

We began this study asking how discourse is represented in the two cerebral hemispheres. Our results suggest that the right hemisphere represents many of the same relations as does the left hemisphere, but its representation lacks propositional structure. The absence of propositional structure in the right hemisphere places important constraints on how it is likely to contribute to language comprehension. For example, it is unlikely to play much of a role in processes that depend on access to a structured representation, such as anaphor resolution or certain types of inference. Nonetheless, the right hemisphere may make an important contribution to discourse comprehension by means of processes, such as lexical priming, that are less constrained by propositional structure.

METHODS

Experiment 1

Participants

Participants were 60 undergraduate psychology students who received course credit for their participation (38 women and 22 men). All participants spoke English as their first language, and none had a diagnosed reading or learning disability. In addition, all were right-handed and had normal or corrected-to-normal vision.

Materials

The study materials consisted of 56 two-sentence passages used previously by Long et al. (1997) and Till, Mross, and Kintsch (1988). The passages were constructed in pairs such that each passage contained the same ambiguous noun (see the pair of passages in Table 1). The homograph appeared at the end of either the first or the second sentence of the passage, and its meaning was unambiguously specified by the context. The homographs had approximately equally strong associates to each of their senses (i.e., they were "balanced" homographs). These associates were used as the set of associate test items and were appropriate or inappropriate depending on the sentence context. The topic test items were the modal responses made by a group of pilot participants in Till et al.'s study. Participants were asked to "write down a word reflecting their understanding of what the paragraph was about" (p. 286). The appropriate-topic word for one passage of a pair served as the inappropriate-topic word for the other passage in the pair. The characteristics of the associate and topic words (e.g., number of syllables, word frequency) can be found in Till et al. (p. 286).

Each of the 56 passages was analyzed to determine its underlying propositional structure. A proposition was defined as a relation (verb or modifier) and its arguments (see Kintsch, 1974). Each passage contained a sentence that had at least two propositions with a noun–verb–noun structure (e.g., While the maid folded the laundry, the baby grabbed the iron.). Strictly speaking, each of these sentences also contained a third proposition that was a conjunction of the other two and several sentences contained propositions in which an adjective modified a noun in the sentence. We also constructed an additional four passages in the manner described above. These passages were used as practice to familiarize participants with the procedure. The total set of 60 passages was divided into 15 lists: 14 experimental and 1 practice. The lists were constructed such that two passages containing the same ambiguous noun were placed in different lists. Each list contained four passages.

A recognition test followed each study list. The test consisted of 12 prime–target pairs (three prime–target pairs of each type) interleaved among 24 filler items. One prime–target pair of each type (i.e., propositional, associate, and topic) was associated with each passage in the study list. The prime–target types were defined as follows (see Table 2): (1) The propositional-priming pairs consisted of a noun preceded by another noun from the same proposition (same-proposition priming condition) or by another noun from a different proposition in the same sentence (different-proposition priming condition). We controlled for the proximity between the prime and target words; primes and targets in the same-proposition and different-proposition conditions were separated by the same numbers of intervening words. In addition, we controlled for linear order of prime and target. Some primes had preceded targets in the passages; others had followed the targets. (2) The associate-priming pairs consisted of the appropriate or the inappropriate associate of the homograph preceded by a noun from the same sentence as the homograph (appropriate-associate and inappropriate-associate priming conditions, respectively). (3) The topic-priming pairs consisted of the appropriate or the inappropriate topic word for the passage preceded by a noun from the final sentence of the passage (appropriate-topic and inappropriate-topic priming conditions, respectively). The homograph never appeared in the list of test words. The various priming conditions and VF presentation (i.e., target in the LVF or RVF) were counterbalanced within and across material sets. A passage that was associated with a same-propositional priming pair in one set was associated with the different-propositional priming pair in another set. In addition, a target in the same-proposition condition that was presented in the LVF in one set was presented in the RVF in another set. The same was true for the associate- and topic-priming pairs.

Procedure

Participants were seated 57 cm from a computer screen. Each passage in the study list was presented individually in the center of the screen for 14 sec. Each study list was followed by a recognition test. The recognition test consisted of 48 single words, including 12 priming pairs (three priming pairs associated with each passage: one propositional-priming, one associate-priming, and one topic-priming pair). The priming pairs were interleaved among 24 filler items (8 true and 16 false). Each test list was preceded by a fixation point in the middle of the screen. The fixation point remained on the screen until all recognition items had been presented. Participants were told to keep their eyes on the fixation point throughout the test. Test items were presented for 150 msec each and appeared in one of three positions: (1) in the center of the screen, immediately above the fixation point; (2) in the LVF, such that the end of the word was 2.5° of visual angle to the left of fixation; or (3) in the RVF, such that the beginning of the word was 2.5° of visual angle to the right of fixation. The test list began with three filler items. The priming pairs were presented randomly in the remainder of the list, separated by intervening filler items. A filler item followed the last priming pair in the list. Primes were always presented centrally; targets appeared equally often to the left and right of center. Filler items were presented randomly in one of the three positions on the screen.

Participants pressed a key labeled "yes" if a test word had appeared in one of the preceding sentences and a key labeled "no" if it had not appeared. Participants were told to keep their index fingers on the yes and no keys at all times. Response hand was counterbalanced across participants. We recorded their responses and response latencies to each item. Latencies were recorded from the onset of the test item. Participants received the 14 study-test trials in random order. These trials were preceded by a practice trial.

Experiment 2

Participants

Three complete callosotomy patients participated in this experiment. All had normal developmental and educational histories and were at least high school graduates.

V.J. is a left-handed female whose first seizure occurred at the age of 16.5 years. Her seizures increased in frequency and severity, becoming intractable, but she was resistant to the idea of surgery. She elected to undergo resection of the corpus callosum after suffering a severe burn during a drop-attack at age 41. In 1994, she underwent a two-stage callosotomy with the anterior two-thirds of the callosum sectioned first, followed by the posterior section about 9 months later. V.J. has demonstrated anomalous language lateralization. After the second stage of callosotomy, she became agraphic and was subsequently demonstrated to have motor control of writing in her isolated right hemisphere (Baynes, Eliassen, Lutsep, & Gazzaniga, 1998). However, spoken language production and comprehension of both written and spoken language appear to be carried out independently by her left hemisphere, although with some reduction in output. Like most left hemisphere dominant callosotomy patients, she has had no loss of verbal IQ on the WAIS-R following surgery; thus, we believe her left hemisphere to be competent in all aspects of language processing necessary for this task (Eliassen et al., in preparation). At the time of this experiment, V.J. was 46 and approximately 4 years postcallosotomy.

J.W. is a right-handed male with a history of staring spells since grade school. He had his first grand mal seizure at 18. His seizures increased in severity and frequency, becoming intractable. In 1979, a two-stage callosotomy was performed, beginning with the posterior half of the callosum, including the splenium. The anterior portion was sectioned 10 weeks later. At the time of this experiment, J.W. was 45 years old and almost 20 years postcallosotomy.

D.R. is a right-handed female who began to experience brief episodes of altered consciousness at about age 18 and was diagnosed with a seizure disorder. She was able to complete a BS degree in accounting and worked as an accountant until her mid 30s when worsening seizures interfered with her capacity to work and precluded driving. Her seizures persisted despite trials of multiple anticonvulsants. In 1983, she underwent single-stage callosotomy. At the time of this experiment, D.R. was 53 years old and approximately 15 years postcallosotomy.

Materials and Procedure

The passages and test items were the same as those used in Experiment 1. The priming pairs were counterbalanced across two material sets; a passage that was associated with a same-proposition priming pair in one set was associated with the different-proposition priming pair in the other set. The same was true for the associate and topic-priming pairs; a passage that was associated with an appropriate associate or topic word in one set was associated with the inappropriate associate or topic word in the other set. An equal number of priming pairs of each type (i.e., 28) appeared in each material set.

The passages and test items were presented in study-test trials as described in Experiment 1, with one exception. All test items were presented in the center of the computer screen and remained on the screen until participants made a response. All responses were made with the right hand. Participants used their index and middle fingers to make yes and no responses, respectively. Given, the small number of participants in this experiment, we were unable to counterbalance material sets across participants. Thus, each participant received one material set and then the other set. Participants had a 10-min break between material sets.

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Notes

1. We do not know whether the prime words from the sentences did indeed facilitate readers' access to the passage representations. This does not affect our conclusions, however. We were interested in the priming effect that arises from the relation between the target and the passage representation and not in any effect that arises from the relation between the prime word and target.
2. Our initial analyses were conducted including response hand and sex. We found no reliable effects nor any interactions involving these two factors. Thus, we do not include them in our presentation of the results.

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