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The representation of discourse in the two hemispheres: An individual differences investigation ☆

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Abstract

Two experiments were conducted to investigate discourse representation in the two cerebral hemispheres as a function of reading skill. We used a lateralized visual-field procedure to compare left hemisphere (LH) and right hemisphere (RH) sensitivity to different discourse relations in readers with varying skill levels. In Experiment 1, we investigated two levels of discourse representation in memory: (a) the propositional representation and (b) the discourse model. We found that all readers were sensitive to propositional relations in the LH. In contrast, sensitivity to propositional relations in the RH increased as a function of reading skill. In addition, reading skill was positively related to topic relations in the LH, whereas it was negatively in the RH. In Experiment 2, we investigated propositional relations of different distances and again found that all readers were sensitive to propositional relations in the LH, whereas sensitivity to propositional relations in the RH was negatively related to reading skill. In general, reading skill appears to be associated with left-lateralized discourse representations.

Keywords: Individual differences; Discourse processes; Discourse representation; Right hemisphere; Language; Memory; Laterality; Reading skill

1. Introduction

Reading comprehension is a complex skill consisting of multiple subcomponent processes. The ability to learn and execute these processes is variable. Individual differences in reading comprehension are large, even among college students. Good and poor readers differ in their ability to execute processes at all levels—word, sentence, and discourse. At the word level, poor readers have less efficient word-recognition processes than do good readers. They are particularly impaired at recognizing infrequent and irregular words. At the sentence level, poor readers have difficulty processing complex sentences, particularly those with atypical syntactic structures. Good and poor readers show the largest differences, however, at the discourse level. Poor readers often fail to integrate ideas across sentences, to identify main ideas and themes, and to make inferences necessary to construct a coherent and referential discourse representation.

Our goal in this study was to determine whether individual differences in comprehension skill are related to hemispheric differences in discourse representation. In the next section, we describe current views of discourse representation in memory. We then describe recent research documenting hemispheric differences in memory for discourse. Finally, we discuss the relation between comprehension ability and lateralization.

1.1. Representation and memory for discourse

Psycholinguists have developed relatively detailed descriptions of the mental representations that readers

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create when they understand a text. They generally agree that readers construct at least two inter-related representations during comprehension: a propositional representation (also called a textbase) and a discourse model (also called a situation model) (Gernsbacher, 1990; Graesser et al., 1994: Greene et al., 1992; Kintsch, 1988; Kintsch and van Dijk, 1978; McKoon and Ratcliff, 1990, 1992, 1998). The propositional representation is organized as a network of the explicit ideas or "propositions" derived from the text and the relations among them (Kintsch, 1974). This representation is "locally" coherent, in that incoming propositions are integrated with those propositions that are active in working memory. The relations among propositions are primarily referential (Kintsch, 1974; McKoon & Ratcliff, 1980; Ratcliff & McKoon, 1978).

The propositional representation serves as a foundation for the discourse model (Graesser et al., 1994; Greene et al., 1992; McKoon and Ratcliff, 1990, 1992, 1998). The discourse model is a representation of what a text is about. Explicit text information is integrated with relevant world knowledge to reflect the important features of the real or imaginary situation depicted in the text. To construct a discourse model, readers must engage in active inferential processing to interpret and to organize text information in light of their prior understanding of the knowledge domain. The discourse model is "globally" coherent; that is, ideas in the text are connected by means of some overarching theme. The theoretical distinction between a reader's propositional representation and the reader's discourse model can be used as a framework for understanding how the processes involved in comprehension might be distributed across the two cerebral hemispheres.

1.2. Hemispheric differences in discourse processing and memory

Most research on hemispheric differences at the discourse level has focused on the role of the right hemisphere in constructing a coherent discourse model. A number of studies have found that patients with RH brain damage have difficulty integrating ideas across sentences (Brownell, Potter, Bihrle, & Gardner, 1986) and identifying main ideas and themes. Moreover, some studies have found that RH-damaged patients exhibit inference problems in a variety of comprehension tasks (Beeman, 1993; Brownell et al., 1986; Cicone, Wapner, & Gardner, 1980; Hough, 1990; Tompkins & Mateer, 1985). It should be noted, however, that several studies have found no such deficits (McDonald & Wales, 1986; Tompkins, 1991), even when attempting to replicate previous findings. In addition, the few studies that have compared performance of RH-damaged patients to LH-damaged controls (rather than to non-brain-damaged controls) have shown no differences in discourse understanding between the two groups (Zaidel, Kasher, Soroker, & Batori, 2002).

Hemispheric differences in discourse processing have also been investigated in non-brain-damaged individuals using neuroimaging techniques. In an fMRI investigation, Robertson et al. (2000) manipulated discourse coherence by presenting sentences containing noun phrases that were introduced with either definite or indefinite articles. They found greater LH activation when participants comprehended unrelated sentences, those containing indefinite articles, and greater RH activation when participants comprehended sentences that included definite articles, cues that the sentences should be integrated. In contrast, Ferstl and von Cramon (2001) found no RH involvement in establishing a coherent discourse representation using an event-related fMRI paradigm. They investigated patterns of activation in participants reading coherent and incoherent passages. Participants had greater activation in the LH when reading coherent passages than when reading incoherent passages. The RH was not differentially activated as a function of text coherence. Their results suggest that only the LH is sensitive to conditions involving discourse-level processes.

Divided-visual-field paradigms have also been used to examine hemispheric differences in discourse processes in the intact brain. Beeman, Bowden, and Gernsbacher, 2000 used a divided-visual-field paradigm to investigate priming for predictive and coherence inferences across the two hemispheres. They found priming related to coherence inferences only in the LH, whereas priming related to predictive inferences was found only in the RH. Thus, Beeman and colleagues suggested that the RH plays a unique role in generating predictive inferences during discourse processing.

In the research described above, investigators have focused on how the RH may be involved in establishing coherence as discourse is processed. Studies have also examined how discourse is represented and retrieved from memory after comprehension. Long and her colleagues have used a lateralized item-priming-in-recognition paradigm to investigate how the propositional representation and the discourse model are distributed across the two hemispheres (Long & Baynes, 2002; Long, Baynes, & Prat, 2003; Long, Baynes, & Prat, 2005). In these studies, participants received a series of study-test trials composed of four short "to-be-remembered" passages and lateralized, single word recognition items. The logic behind the item-priming-in-recognition paradigm is that memory for an item will be facilitated to the extent that it is preceded by an item to which it is linked in memory. Words in the recognition list were related to each other either thematically (discourse model) or propositionally (propositional representation). They found that only the LH was sensitive to propositional relations, whereas the LH and RH were equally sensitive to discourse model relations.

In a subsequent study, Long et al. (2005) investigated the propositional representation more closely by testing prime–target pairs that varied with respect to distance in the propositional structure, including: (1) same proposition—the primes and targets were nouns from the same proposition, (2) different proposition—the primes and targets were nouns from different propositions in the same sentence, (3) different sentence—the primes and targets were nouns from different propositions in different sentences of the same passage, (4) different passage—the primes and targets were nouns from different passages in the same block of passages. They found that the LH was sensitive to propositional distance; facilitation was a linear function of distance in the propositional structure of the passage. In contrast, the RH was sensitive only to the difference between a within-passage prime and a between-passage prime. That is, memory was facilitated when a target was preceded by a prime from the same passage relative to one from a different passage; however, the RH was not sensitive to the structural relations among concepts within a passage.

Our review of the literature investigating discourse processing in the RH suggests that its role in discourse-level processing and representation is variable. Some studies have found that the RH plays a unique role in establishing and representing text ideas at the discourse level; some studies have found that the RH and the LH play similar roles; still other studies have found no significant RH involvement. Progress in understanding how the RH participates in constructing a coherent discourse representation will require investigating the factors that underlie this variability. In the current study, we investigate one factor that may affect the extent to which the RH is involved in discourse-level processes—individual differences in reading comprehension skill. We have chosen to focus on comprehension skill because it is strongly related to the ability to construct an accurate and coherent discourse model (Long, Oppy, & Seely, 1994, 1997). We hypothesized that variability in reading skill may also be related to hemispheric differences in the representation of discourse.

2. Experiment 1

Differences in skilled and less skilled readers' memory for discourse is well established (e.g., Berger & Perfetti, 1977; Bisanz, Das, Varnhagen, & Henderson, 1992; Gernsbacher, Varner, & Faust, 1990; Perfetti and Goldman, 1976; Perfetti & Lesgold, 1977; Petros, Bentz, Hammes, & Zehr, 1990). Skilled readers recall more information from texts than do less-skilled readers and the information that they recall is more accurate. Moreover, skilled readers construct stronger connections among text ideas in memory than do less-skilled readers (Long et al., 1994, Long, Oppy, & Seely, 1997) and this leads to greater priming effects in recognition memory. We are unaware of any research, however, that has examined the distribution of skilled and less-skilled readers' memory representations across the two hemispheres.

Experiment 1 was an extension of an earlier experiment by Long and Baynes (2002, Experiment 1). The materials and procedure were the same; participants received a series of study-test trials in which a block of passages was presented for study, followed by a recognition test consisting of single words. Embedded in the recognition list were sets of prime–target pairs. Sample passages and prime–target pairs appear in Table 1.

Reading skill was measured by performance on the Nelson–Denny Reading Test, a standardized test with vocabulary and comprehension subsections. The vocabulary subsection involves selecting synonyms for 80 vocabulary

Table 1
Sample passages and example prime–target pairs (from Long and Baynes, 2002)

Priming relation	Prime	Target	Correct response
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			
Topic priming pairs			
Appropriate-topic	Architect	Earthquake	No
Inappropriate-topic	Architect	Breath	No
Associate priming pairs			
Appropriate-associate	Townspeople	Money	No
Inappropriate associate	Townspeople	Candy	No
Propositional priming pairs			
Same-proposition	Disaster	Structure	Yes
Different-proposition	Danger	Structure	Yes
The guest ate garlic in his dinner, so the waiter brought a mint. The worried guest soon felt comfortable socializing with his friends			
Topic priming pairs			
Appropriate-topic	Friends	Breath	No
Inappropriate-topic	Friends	Earthquake	No
Associate priming pairs			
Appropriate-associate	Dinner	Candy	No
Inappropriate associate	Dinner	Money	No
Propositional priming pairs			
Same-proposition	Guest	Garlic	No
Different-proposition	Waiter	Garlic	No

words of increasing difficulty. The comprehension subsection involves answering comprehension questions about several short narrative and expository passages. Performance on the test is highly correlated with measures of reading exposure and general world knowledge (Stanovich & Cunningham, 1993) and is strongly related to the likelihood that readers construct and represent discourse-level relations (Long et al., 1994, 1997). We compared patterns of discourse representation in individuals as a function of their performance on the reading test.

We predicted that item priming would be more consistent in the RVF/LH than in the LVF/RH and that comprehension ability would be related to priming only in the RH. These predictions were founded on previous research showing that the LH is sensitive to more discourse relations than is the RH and to research showing that discourse processing in the RH is more variable across materials and individuals than is processing in the LH.

2.1. Method

2.1.1. Participants

Participants were 92 undergraduate students at the University of California, Davis. The data from 8 participants were excluded because their recognition accuracy was less than 70%. The 84 remaining participants were all right-handed, native English speakers, with normal or corrected-to-normal vision and no diagnosed reading disability. All participants received course credit for their participation.

2.1.2. Materials

The study materials consisted of 56 two-sentence passages used previously by Long and Baynes (2002), modified from a set of passages used by Till, Mross and Kintsch (1988). The passages were constructed in pairs such that each contained the same ambiguous noun (see 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 sentence context. Till, Mross, and Kintsch (1988) selected homographs using Cramer's (1970) association norms. Homographs that had equally strong associates to both senses of the word were selected for the study (e.g., iron's top two associates are "steel," response probability = .128 and "clothes," response probability = .119). These associates were used as the set of associate test items and were appropriate or inappropriate depending on context. The topic test items were the modal responses made by a group of pilot participants (see Till et al., 1988). The appropriate topic for one passage of a pair served as the inappropriate topic for the other passage in the pair.

Each of the 56 passages was analyzed to determine its underlying propositional structure. A proposition was defined as a relation and its associated argument(s). 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.). Four additional passages were constructed in the manner to serve as a practice block. The total set of 60 passages was divided into 15 blocks of 4 passages each: 14 experimental blocks and 1 practice block. The blocks were constructed such that two passages containing the same ambiguous noun never appeared in the same block.

Each block of passages was followed by a recognition test with embedded prime–target pairs. The prime–target pairs (see Table 1) were defined as follows. Propositional-priming pairs were composed of targets preceded by primes from either the same proposition (same-proposition condition) or different propositions (different-proposition condition). Nouns in the same-proposition and the different-proposition conditions were separated by the same mean number of words to control for proximity effects. The linear order of prime target pairs was also counterbalanced such that primes appeared both before and after targets in the passages. The associate-priming pairs consisted of targets that were contextually related (appropriate associate) or unrelated (inappropriate associate) to the homograph and were preceded by a noun from the same sentence. The topic-priming pairs consisted of targets that were either the topic of a passage (appropriate topic) or an unrelated word (inappropriate topic) and were preceded by a noun from the final sentence of the passage. The homograph never appeared in the list of test words.

The recognition tests were constructed such that each block of passages was followed by a recognition list consisting of 12 prime–target pairs: four proposition pairs (one for each passage in the block), four associate pairs (one for each passage in the block), and four topic pairs (one for each passage in the block). The test also included 8 filler items. The resulting recognition test had 32 items, with equal numbers of "yes" and "no" items.

The priming conditions and VF presentation (i.e., target in either LVF or RVF) were counterbalanced within and across material sets. A passage associated with the same-proposition priming pair in one set was associated with the different-proposition priming pair in another set. Similarly, a target in the same-proposition condition that was presented to the LVF in one set was presented to the RVF in another set.

2.1.3. Procedure

All participants received the Nelson–Denny Reading Test. They were given 15 min to complete the vocabulary section, and 20 min to complete the reading comprehension questions. Participants were then seated 57 cm from a computer screen. Each passage in the experiment was presented centrally for 14 s. Each block of four passages was followed by a recognition test. The priming pairs were interleaved with 8 filler items. A centrally presented fixation point preceded each item on the test list. The fixation point remained on the screen during the trial. Participants were instructed to keep their eyes on the fixation point throughout the test. Test items were presented for 150 ms each and appeared either in the center of the screen, at the fixation point in the LVF, such that the end of the word was 1.5° of visual angle to the left of fixation, or in the RVF, such that the beginning of the word was 1.5° of visual angle to the right of fixation. Inter-stimulus intervals varied as a function of response time. The next word in the test list appeared immediately after a response to the previous word.

Each test list began with three filler items. The priming pairs were presented randomly in the list, separated by intervening filler items. Primes were always presented centrally; targets appeared equally often in the LVF and in the RVF. Filler items were presented randomly at fixation, LVF, or RVF.

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

2.2. Results and discussion

Separate analyses were conducted for responses to topic, associate, and proposition targets. Priming in both the topic and associate conditions was reflected in increased time to reject associate and topic targets. These words did not appear in the passages, but were associated with it such that their representation in memory should lead to difficulty in rejecting the item. (i.e., these targets required "no" responses). Priming in the proposition condition was measured by facilitation in recognizing targets that were preceded by primes close to the target in the propositional structure (i.e., these targets required "yes" responses).

Response latencies and accuracy were analyzed by means of 2 (response hand) × 2(VF) × 2 (prime condition) ANOVAs with Nelson–Denny score as a covariate. The Nelson–Denny percentile scores ranged from 20 to 99, with a mean of 72 and a standard deviation of 20.77. Response hand was a between-participants variable. Prime condition (appropriate/inappropriate topic, appropriate/inappropriate associate, same/different proposition), and VF (LVF/RH and RVF/LH) were within-participant variables. We found no reliable effects involving response hand in any analysis. Thus, the results presented below are collapsed across this variable. All effects were tested at a significance level of $p < .05$ unless otherwise indicated.

2.2.1. Topic priming pairs

Our analyses of reaction times to targets in the appropriate and inappropriate conditions revealed reliable main effects of priming, $F(1,82) = 30.62$, $MSe = 879$, and Nelson–Denny score, $F(1,82) = 4.37$, $MSe = 75381$. We also found the following interactions: priming condition × Nelson–Denny, $F(1,82) = 7.02$, $MSe = 879$, priming condition × VF, $F(1,82) = 68.94$, $MSe = 1168$, and priming condition × VF × Nelson–Denny, $F(1,82) = 59.02$, $MSe = 1168$. Reaction times as a function of priming condition, VF, and Nelson–Denny score are depicted in Fig. 1.

When targets were presented in the RVF/LH, we found a priming condition × Nelson–Denny interaction, $F(1,82) = 32.91$, $MSe = 516$. Topic priming increased as a function of Nelson–Denny score. Participants who scored high on the test responded faster to targets in the inappropriate condition than in the appropriate condition suggesting that the appropriate topic words were difficult to reject because they resonated with information in readers' text representations. When targets were presented in the LVF/RH, priming condition also interacted with Nelson–Denny score, $F(1,82) = 38.04$, $MSe = 1532$, but in a different pattern than in the RVF/LH. Topic priming in the LVF/RH increased as Nelson–Denny scores decreased; that is, participants who scored low on the test showed priming, whereas high-scorers showed no response time differences as a function of priming condition.

We analyzed errors to targets in the topic-priming conditions. The overall error rate was 13.1%. We found no reliable effects, all Fs < 1.

2.2.2. Associate priming pairs

Our analysis of reaction times to targets in the associate conditions yielded reliable main effects of VF, $F(1,82) = 7.38$, $MSe = 4255$, and priming condition, $F = 39.28$, $MSe = 1305$. The relation between Nelson–Denny score and priming condition as a function of VF is depicted in Fig. 2. Reaction times were faster to targets in the RVF/LH than in the LVF/RH. Reaction times were also faster to targets in the inappropriate-associate than in the appropriate associate condition. This suggests that readers had difficulty rejecting a target when it was related to the meaning of a concept that had appeared in the passage. We found no effect of Nelson–Denny score nor any reliable interactions.

We analyzed errors to targets in the associate conditions. We found a reliable effect of priming condition, $F(1,82) = 4.99$, $MSe = .01$. Participants were more accurate in the inappropriate-associate condition than in the appropriate-associate condition, $M = 8.8$ and $M = 11.6$, respectively.

2.2.3. Proposition priming pairs

The analysis of reaction times to targets in the same and different proposition conditions yielded reliable main effects of priming condition, $F(1,82) = 18.36$, $MSe = 4670$ and Nelson–Denny score, $F(1,82) = 4.40$, $MSe = 78822$. We also found a reliable VF × priming condition interaction, $F(1,82) = 14.16$, $MSe = 3971$. These effects were modified by a VF × priming condition × Nelson–Denny interaction, $F(1,82) = 14.16$, $MSe = 3971$. The relation between Nelson–Denny score and priming condition as a function of VF is depicted in Fig. 3.

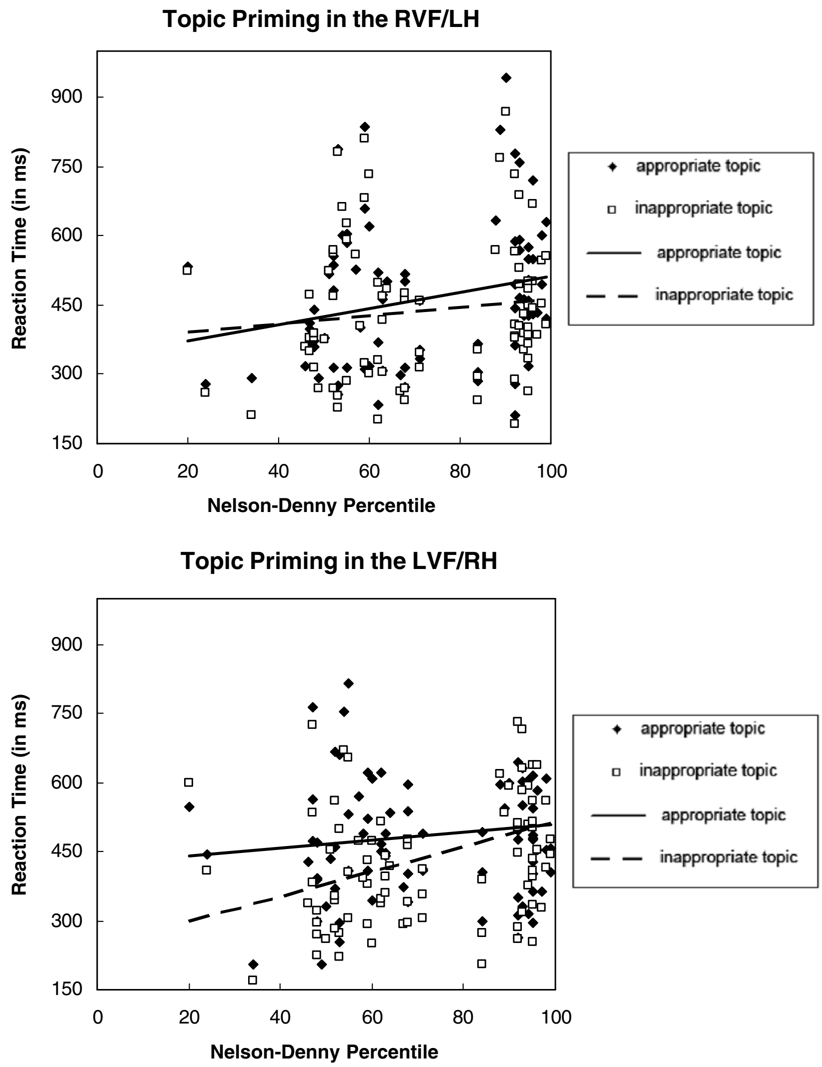

Fig. 1. Topic priming as a function of Nelson–Denny score and visual-field presentation.

When targets appeared in the RVF/LH, we found a reliable effect of priming condition, $F(1,82) = 4.40$, $MSe = 6749$, but no interaction between priming condition and Nelson–Denny score, $F(1,82) = 1.97$, $MSe = 6749$. As shown in Fig. 3, all participants responded faster in the same-proposition than in the different-proposition condition. When targets were presented in the LVF/RH, we found a reliable effect of proposition, $F(1,82) = 74.22$, $MSe = 1892$ and a reliable priming condition × Nelson–Denny interaction, $F(1,2) = 50.09$, $MSe = 1892$. Fig. 3 shows that reaction times to targets in the different-proposition condition did not vary as a function of Nelson–Denny score, whereas reaction times to targets in the same-proposition condition showed a negative relation with Nelson–Denny score. In other words, propositional priming in the LVF/RH increased as Nelson–Denny scores decreased.

We analyzed errors to targets in the proposition conditions. The total number of errors was low ($M = 2.7\%$) and we found no reliable effects, all Fs < 1.

In this experiment, discourse representation across the two hemispheres was modulated by comprehension skill. The effects of comprehension skill, however, depended on the type of relation that was examined. With respect to topic priming, both skilled and less-skilled readers were slower to respond to appropriate topics than inappropriate ones suggesting that they had difficulty rejecting a target word when its meaning overlapped with semantic information in their text representation. The particular pattern of priming, however, depended on VF presentation. Skilled readers showed priming in the RVF/LH, whereas less-skilled readers showed priming in the LVF/RH.

This finding extends previous research by Long and Baynes (2002). They used the same materials and procedures and found topic priming in both hemispheres. The results of the current experiment suggest that topic priming in the RVF/LH was based on the performance of the skilled comprehenders, whereas topic priming in the LVF/RH was based on the performance of the less-skilled comprehenders.

With respect to associate priming, readers were slow to reject a target that was a context-appropriate associate of an ambiguous word in the passage. Priming was unrelated

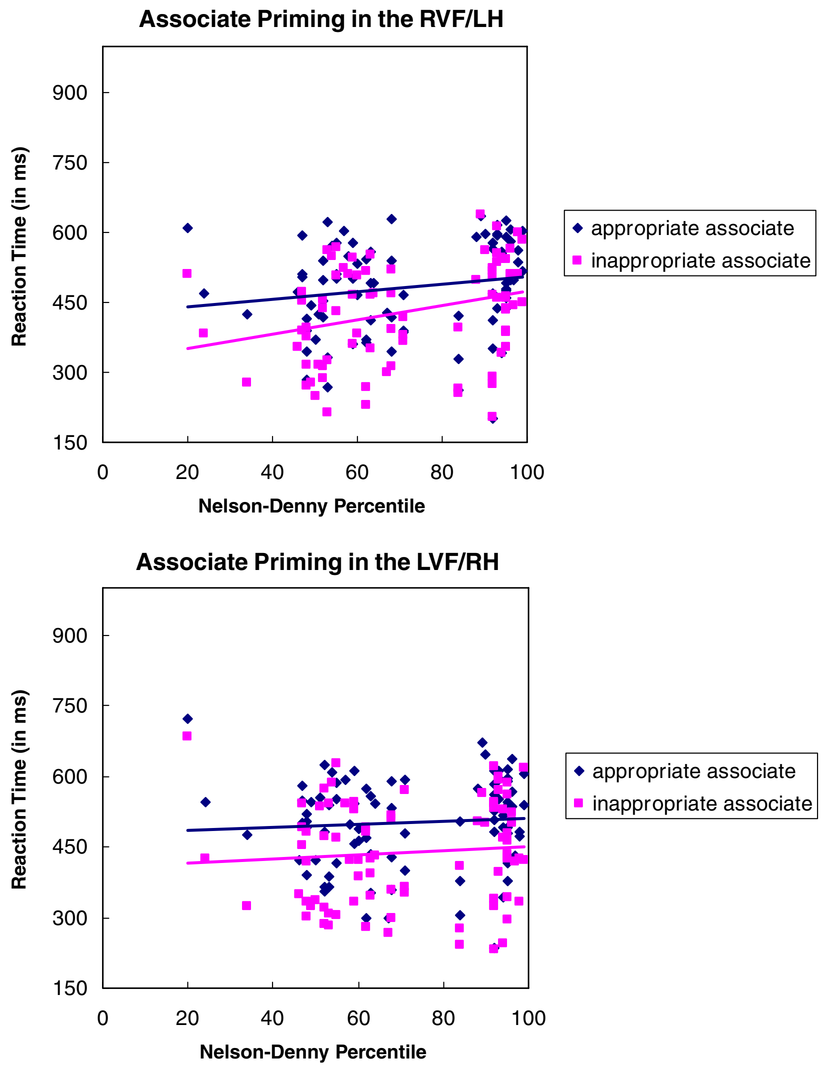

Fig. 2. Associate priming as a function of Nelson–Denny score and visual-field presentation.

to comprehension skill and was found in both hemispheres. These data are consistent with previous research showing accurate lexical ambiguity resolution in less-skilled readers (Long et al., 1994, 1997). These data are also consistent with previous research showing that both hemispheres have memory representations of passages that includes information about the appropriate senses of ambiguous words (Long & Baynes, 2002).

The most surprising effect in this experiment was the relation between propositional priming and reading skill. All readers were faster to recognize a target when it was preceded by an item from the same proposition in the sentence than when it was preceded by an item from a different proposition. Two nouns that were linked by a predicate were more closely connected in memory than were nouns that appeared in the same sentence, but not in the same proposition. Although all readers showed propositional priming, only less-skilled readers showed priming in the RH. This finding is surprising in light of Long and Baynes's (2002) interpretation of the propositional priming effect. They argued that the representation of propositional relations in memory is strongly related to the syntactic processing abilities of the LH. Syntactic processing is necessary to determine the structural relations among words in a text and is dominant in the LH. Thus, only the LH should show sensitivity to the propositional relations among explicit words in the text.

We decided to pursue the propositional priming effect in a second experiment. We had two goals. The first was to replicate our finding that less skilled readers are sensitive to propositional structure in both the LH and RH. Our second was to extend our findings by examining a greater range of propositional relations.

3. Experiment 2

Our results from Experiment 1 showed that less-skilled readers exhibited propositional priming in both the LH and RH, whereas skilled readers showed propositional priming only in the LH. Our results provide limited information about how propositional structure was represented among our less skilled readers because we examined only within-

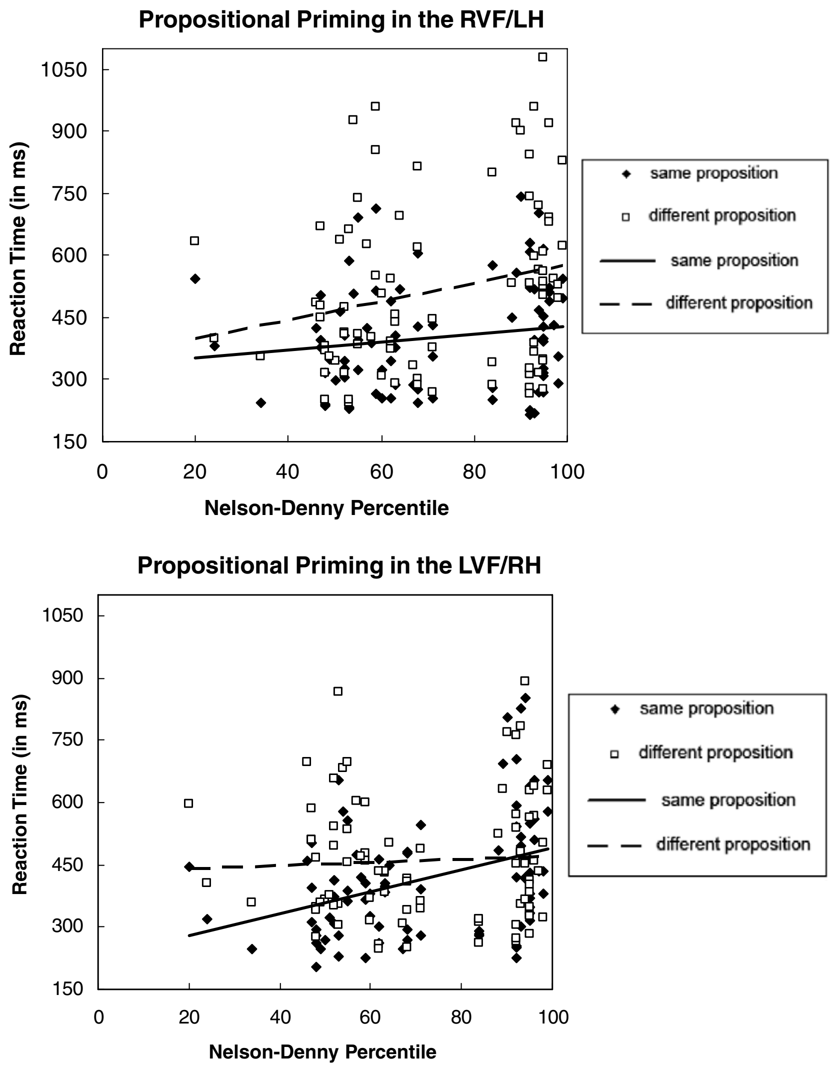

Fig. 3. Propositional priming as a function of Nelson–Denny score and visual-field presentation.

sentence propositional relations. In the current experiment, we investigated within-sentence, between-sentence, and between-passage relations. In addition, we investigated propositional relations in canonically structured sentences and in sentences with embedded clauses.

The materials and procedure were the same as those used by Long et al., 2005. They investigated the sensitivity of the RH and LH to four types of prime–target relations: (1) same proposition—the primes and targets were nouns from the same proposition, (2) different proposition—the primes and targets were nouns from different propositions in the same sentence, (3) different sentence—the primes and targets were nouns from different propositions in different sentences of the same passage, (4) different passage—the primes and targets were nouns from different passages in the same block of passages. Sample passages and prime–target pairs are depicted in Table 2.

The results from the Long et al. (2005) study showed facilitation that was linearly related to distance in the propositional structure of the passage. In contrast, the RH showed slower response times in the different-passage condition relative to the other conditions. Thus, the RH showed sensitivity to the overall semantic content of a passage, but not to its propositional structure.

The goal of the current experiment was to examine representation of propositional structure in readers of varying skill levels. We were particularly interested in the extent to which less skilled readers would show a propositional distance effect in the LVF/RH.

Table 2
Sample passages and example prime–target pairs for Experiment 2 (from Long et al., 2005)

Priming relation	Prime	Target
Everyone on the ranch was hustling to beat the first snow. While the cowboy (who had arrived at dawn) unloaded the hay, the tractor pulled a tree stump out of the way.		
Same proposition		
No intervening clause	Cowboy	Hay
Intervening clause	Cowboy	Hay
Different proposition	Tractor	Hay
Different sentence	Ranch	Hay
Different passage	Boat	Hay

3.1. Method

3.1.1. Participants

Participants were 153 right-handed, native English speakers, with normal or corrected-to-normal vision and no diagnosed reading disability. Participants were identified out of a pool of 240 recruited individuals, to ensure that they could recognize lateralized stimuli at brief presentation rates. The 153 selected participants had recognition accuracy levels above 70%. All participants received course credit for their participation.

3.1.2. Materials and procedure

The study materials consisted of 48 two-sentence passages. The passages were used previously by Long et al. (2005). Half of the passages included sentences with a canonical NVN structure; half of them included sentences with embedded clauses. Across material sets, every sentence appeared both with and without the embedded clause (see Table 2).The total set of 52 passages was divided into 13 blocks of four passages: 12 experimental blocks and 1 practice block. The order of passages within a block was randomized.

Each study block was followed by a recognition test. The test consisted of 4 prime–target pairs and 8 filler items. The prime–target pairs (see Table 2) were defined as follows: (1) same proposition—the primes and targets were nouns from the same proposition, (2) different proposition—the primes and targets were nouns from different propositions in the same sentence, (3) different sentence—the primes and targets were nouns from different propositions in different sentences of the same passage, (4) different passage—the primes and targets were nouns from different passages that appeared in the same study block. The nouns were selected to be primes and targets such that their linear order in the passages was counterbalanced. The passages were written such that nouns in the different-sentence and different-proposition priming pairs were equally or more highly associated than nouns in the same-proposition conditions, as measured by the Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998). Long et al. (2005) also used a lexical decision task to ensure that differences in semantic relatedness between prime and target pairs in the various conditions did not explain the observed priming effects.

The priming conditions and VF presentation (i.e., LVF versus RVF) were counterbalanced within and across material sets. A passage associated with the same-proposition priming pair in one set was associated with the different-proposition priming pair in another set. Similarly, a target in the same-proposition condition presented to the LVF in one set was presented to the RVF in another set. Each participant received all 48 passages and received one type of prime/target pair for each passage. Thus, participants received 48 target items, six of each priming type in each VF. The procedure was the same as that used in Experiment 1.

3.2. Results and discussion

Accuracy and response latencies were analyzed by means of 2 (response hand) × 2(clause) × 2(VF) ANOVA with Nelson–Denny score as a covariate. Response hand was a between-participants variable; clause (embedded clause present and embedded clause absent), prime condition (same-proposition, same-sentence, different-sentence, and different-passage), and VF (LVF/RH and RVF/LH) were within-participant variables. All effects were tested at a significance level of $p < .05$ unless otherwise indicated. Neither response hand nor clause was reliable in any analysis. Thus, the data are presented collapsed across these two variables.

All latencies more than three standard deviations from a participant's mean were treated as missing data. Only correct responses were included in the analyses of the reaction-time data. Errors and outliers together constituted approximately 20% of the data (19% and 1% errors and outliers, respectively). Two subjects were excluded from the analyses because they had cell "means" computed from only one reaction time after error and outlier exclusion. The remaining 151 subjects all had multiple reaction times per cell. The Nelson–Denny percentile scores ranged from 16 to 99, with a mean of 80 and a standard deviation of 19.6.

Analyses of reaction times to targets revealed a reliable effect of proposition, $F(3,147) = 17.66$, $MSe = 258815$. We also found a reliable Nelson–Denny × proposition interaction, $F(3,147) = 9.85$, $MSe = 144351$, and a reliable proposition × VF interaction, $F(3,147) = 3.43$, $MSe = 55268$. These effects were modified by a reliable Nelson–Denny × proposition × VF interaction, $F(3,147) = 4.18$, $MSe = 67488$. Propositional distance effects as a function of Nelson–Denny score and VF is depicted in Fig. 4.

The Bonferroni multiple comparisons adjustment was used for follow-up analyses. All of the results reported below are significant at $p < .01$ unless otherwise noted. Analyses of targets presented to the RVF/LH revealed no main effects or interactions with Nelson–Denny score. Reaction times were fastest in the same-proposition condition, followed by the different-proposition, different-sentence, and different-passage conditions, respectively. The following comparisons showed reliable main effects of proposition: (1) same-proposition and different-sentence conditions, $F(1,149) = 6.95$, $MSe = 91049$, $p = .009$, (2) same-proposition and different-passage conditions, $F(1,149) = 8.51$, $MSe = 156272$, and (3) different-proposition and different-passage conditions, $F(1,149) = 6.816$, $MSe = 74616$, $p = .01$.

Analyses of targets presented to the LVF/RH showed a different pattern of results. Reaction times were again fastest in the same-proposition condition, followed by the different-proposition, different-sentence, and different-passage conditions, respectively. The following comparisons showed reliable main effects of propositions: (1) same-proposition and different-passage conditions, $F(1,149) = 50.11$, $MSe = 679733$, (2) different-proposition

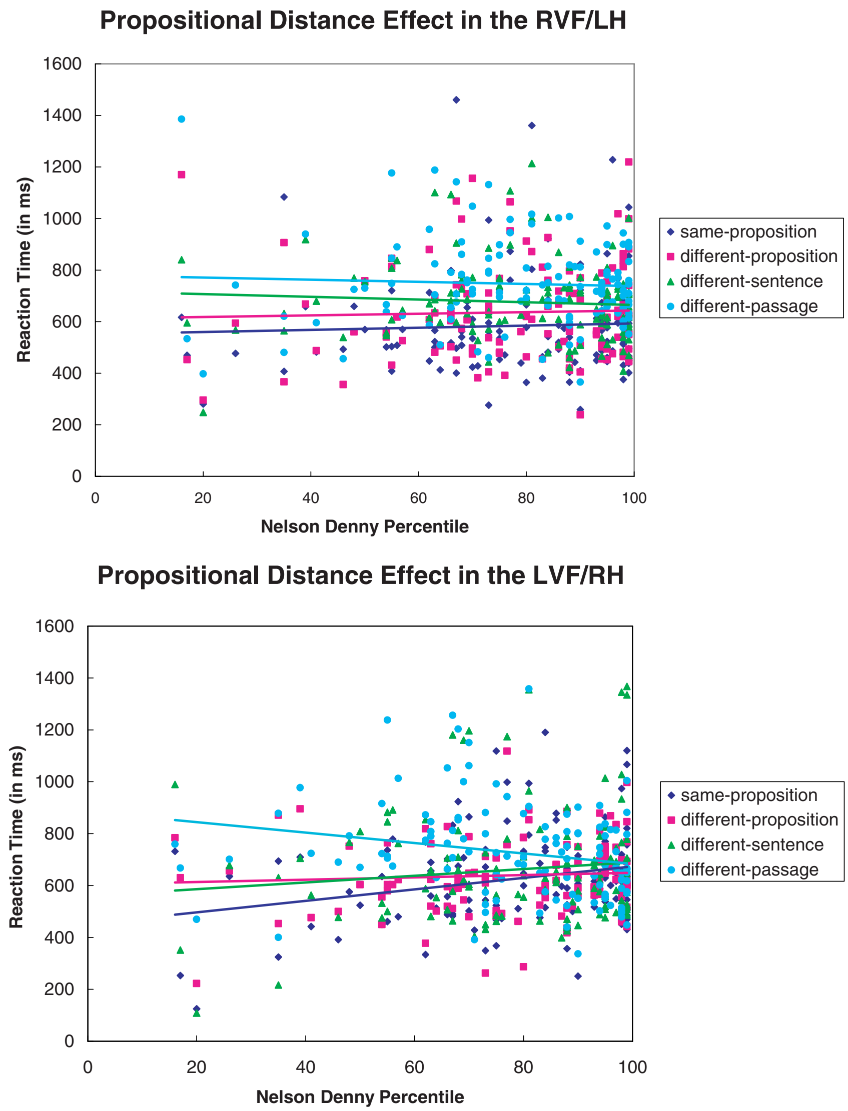

Fig. 4. Propositional distance effect as a function of Nelson–Denny score and visual-field presentation.

and different-passage conditions, $F(1,149) = 24.32$, $MSe = 306503$ and (3) different-sentence and different-passage conditions, $F(1,149) = 19.74$, $MSe = 400370$. Same-proposition and different-proposition conditions approached significance, $F(1,149) = 5.53$, $MSe = 76606$, $p = .02$. Each of these main effects of proposition, however, were modified by reliable interactions with Nelson–Denny score: (1) same-proposition and different-sentence conditions, $F(1,147) = 38.36$, $MSe = 520260$, (2) different-proposition and different-passage conditions, $F(1,149) = 17.56$, $MSe = 22171$ and (3) different-sentence and different-passage conditions, $F(1,149) = 15.88$, $MSe = 322060$. Nelson–Denny × proposition interaction approached significance in the same-proposition and different-proposition conditions, $F(1,149) = 4.75$, $MSe = 65726$, $p = .031$. Individuals with high Nelson–Denny scores showed little or no propositional priming, whereas individuals with low Nelson–Denny scores showed propositional priming comparable to that observed in the RVF/LH.

We analyzed errors to targets in the four propositional priming conditions. The overall error rate was 19.0%. We found no reliable effects, all Fs < 1.1.

These results replicate and extend the pattern of results that we observed in Experiment 1. All readers showed sensitivity to propositional structure when targets were presented in the RVF/LH. Moreover, the relation between priming and propositional distance was linear. In contrast, reading skill was negatively correlated with the propositional distance effect in the LVF/RH. Less-skilled readers showed large priming effects, whereas skilled readers showed no priming.

4. General discussion

This study is among the first to examine how discourse representation in the two hemispheres might be modulated by reading skill. The results of our experiments provide preliminary evidence that skilled and less-skilled readers represent discourse differently across the two hemispheres.

Skilled readers showed a more left-lateralized pattern of discourse representation than did less-skilled readers. We found LH sensitivity to propositional relations, associate relations, and topic relations among skilled readers. Moreover, they showed sensitivity to propositional and topic relations exclusively in the LH. In contrast, less-skilled readers showed a more mixed pattern of discourse representation than did skilled readers. Less-skilled readers showed sensitivity to propositional distance and to associate relations in both hemispheres, whereas they showed sensitivity to topic relations only in the LVF/RH.

When we compare our results to previous studies of discourse representation in the two hemispheres, we find both similarities and differences. Similarities arise when we examine performance to targets presented in the RVF/LH. We found LH sensitivity to propositional, associate, and topic relations as did Long and Baynes (2002). In addition, we found that the LH was sensitive to the distance among concepts in the propositional structure of the passages as did Long et al. (2005). Differences arise, however, when we examine performance to targets presented in the LVF/RH. Long and Baynes (2002) found topic priming in the RH, whereas we observed topic priming among skilled readers only in the LH. Moreover, previous studies have found propositional priming only in the LH (Long & Baynes, 2002; Long et al., 2005), whereas we observed propositional priming among less-skilled readers in both hemispheres. This pattern of similarities and differences is consistent with our hypothesis that RH linguistic capabilities are more variable across individuals than are LH capabilities. Our data suggest that reading skill should be included in the list of factors that are related to RH involvement in discourse processes.

Although our results suggest differences in how discourse is represented across the hemispheres in skilled and less-skilled readers, they tell us little about the processes that give rise to these differences. One straightforward explanation for why skilled readers showed more left-lateralized priming patterns than did less-skilled readers is that they have more lateralized language abilities. This explanation, however, is inconsistent with previous work on the relation between language skill and laterality. Annett and colleagues have found that bilateral organization, as indexed by neuroanatomical measures and handedness scales, is associated with better performance on linguistic tasks (e.g., Annett, 1992; Annett & Kilshaw, 1984; Annett & Manning, 1990). Similarly, Weems and Zaidel (2004) have found that RH linguistic performance is positively correlated with reading skill and vocabulary size. Other researchers looking at functional language lateralization have found no relation between laterality and task proficiency (Wood et al., 2004).

If differences in the laterality of language abilities do not explain our results, then what are the alternatives? One possibility concerns the role of task difficulty. Several studies have shown that increased neural activation, including increased bilateral activation, is associated with more difficult or complex processing of stimuli (for review see Just, Carpenter, & Miyake, 2003). Consider, for example, our finding that less-skilled readers represent propositional relations bilaterally, whereas skilled readers represent propositional relations only in the LH. Construction of the propositional representation relies heavily on lexical and syntactic processing. Although these processes are faster and more accurate in the LH, Just and colleagues have shown that the RH becomes increasingly involved in processing as sentences become more syntactically complex (Just et al., 2003). They argue that RH homologues of LH language areas are recruited when language tasks become more difficult. Thus, one explanation for our results is that less-skilled readers found the comprehension and/or memory demands of our task more difficult than did skilled readers and that this difficulty resulted in greater RH involvement in the task. Further research will be necessary in order to determine whether task difficulty can explain the individual variation that we found in our experiments and explain the variability of RH participation in language tasks that has been found in other studies.

In summary, the results described here document a relation between reading skill and the representation of discourse across the two hemispheres. Researchers have become increasingly aware that linguistic processes involve complex interactions among reader characteristics, text characteristics, and task demands. Our results provide evidence that these interactions are also important in understanding individual differences in reading comprehension skill and the hemispheric representation of discourse.

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