Harrington, Michael; Dennis, Simon John Structural Priming in Sentence Comprehension
The 25th Annual Meeting of the American Cognitive Science Society / R. Alterman and D. Kirsh (eds.): pp.510-515

Structural Priming in Sentence Comprehension

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Abstract

Structural priming in sentence production has long been observed, but the nature of the information that mediates priming and the conditions under which it occurs remain open questions. This study presents a data driven account of structural priming that addresses both issues in sentence comprehension. Evidence from an on-line English reading task by first and second language readers showed priming for the latter, suggesting that priming may occur where there are insufficient sentence traces in memory to support sentence interpretation. The empirical results are simulated using the Syntagmatic Paradigmatic (SP) model, a distributed, instance-based account of sentence comprehension.

Introduction

Structural priming is the tendency to unconsciously generalize recently spoken or heard syntactic structures to subsequent sentences (Bock & Loebell, 1990; Pickering & Branigan, 1999). Priming arises even in cases where the following sentence shares neither lexical nor thematic content with the previous one e.g. *The 747 was landing by the airport's control tower* will prime *The man is being stung by the bee*, despite the *by* phrase in the first sentence being an adjunct prepositional phrase and the *by* phrase in the second heading a passive (Bock & Loebell, 1990).

Structural priming is generally assumed to involve the persistent activation of structural information previously employed in processing. However, significant questions remain concerning the nature of this information and the conditions under which it is used. The consensus view is that priming is mediated by information regarding surface form configurations (Bock & Loebell, 1990; Pickering, Branigan, Cleland & Stewart, 2000; Chang, Dell, Bock, & Griffin, 2000). Pickering and colleagues maintain that priming results from lasting activation of verb subcategorization information (Pickering & Branigan, 1998; Pickering, et al., 2000). This information is represented as a distinct level of lexical representation that is independent of specific lexico-syntactic processes like thematic relations and tense (see Chang, et al., 2000 for a similar approach using alternative formalisms).

In this paper we consider a more parsimonious alternative; namely, that structural priming occurs because the prime and target structures occur within the same context. The part of the trace stored when processing the prime in a particular context facilitates subsequent processing in similar contexts. Pickering and others (Pickering & Branigan, 1999) have argued against a data-driven approach to structural priming on the grounds that the prime and target sentences can be very different and in particular need not have substantial lexical overlap. In this paper we present and test the *Syntagmatic-Paradigmatic Model* (Dennis, submitted), a distributed instance-based model of processing that captures structural priming effects without recourse to abstract structural information.

Another important question concerns the conditions that give rise to structural priming. Pickering & Branigan (1999) have suggested limited resource availability as a determinant of priming, with priming more likely when resources are limited. The distributed instance-based model proposed here makes similar predictions. An individual with fewer linguistic resources may be more likely to make use of available primed structures in subsequent production. Alternatively, experienced individuals may have stored more instances of sentences of the appropriate structural form prior to the priming trial. These previous instances may serve to reduce the impact of the prime sentence as a consequence of the retrieval based processing assumed in the model.

In this study we examine both representation and condition issues by examining structural priming in an on-line reading task that compares reading performance by first and second language readers of English. If priming is sensitive to resource availability then second language (L2) individuals reading in the target L2 should show more priming than first language (L1) individuals on the same comprehension task. The empirical results will then be simulated using the Syntagmatic-Paradigmatic Model in order to test the assumptions of the data-driven approach to structural priming. Although recent work argues for a unitary system underlying comprehension and production, theory and research has focused on production (Pickering et al., 2000; Potter & Lombardi, 1998). The present study also extends our understanding of priming in comprehension.

Overview of the Syntagmatic Paradigmatic Model

The Syntagmatic Paradigmatic Model (SP; Dennis submitted) is a distributed, instance-based model of verbal cognition. depicts the SP model as it would appear when exposed to the following mini corpus:

1. John loves Mary
2. Bert loves Ellen
3. Steve loves Jody
4. Who does Bert love ? Ellen
5. Who does Steve love? Jody
6. When the loud music started John left
7. When the race started Dave left
8. When the lecture started Michael left

The SP model consists of three long-term memory systems, lexical, sequential and relational, each of which is defined in terms of syntagmatic and paradigmatic associations. Syntagmatic associations are thought to exist between words that often occur together, as in “run” and “fast¨. By contrast, paradigmatic associations exist between words that may not appear together but can appear in similar sentential contexts, such as “run” and “walk” (Ervin-Tripp 1970).

Lexical memory consists of a trace for each word comprised of the paradigmatic associates of that word across the corpus. In the example, the lexical trace for John is {Bert, Steve, Dave, Michael} because each of these words substitutes for “John” in a sentential context. For “Bert” and “Steve” the paradigmatic associations derive from the simple active constructions in sentences two and three, while for “Dave” and “Michael” the associations derive from the more complicated clause initial constructions in sentences seven and eight. In the lexical trace, however, these associations are accumulated regardless of their origin. Sequential memory consists of a trace for each sentence comprised of the syntagmatic associations embodied by that sentence. In the example, the sequential trace for the sentence “John loves Mary” is the string of words, “John”, “loves”, and “Mary”, in order.

Relational memory consists of a trace for each sentence. It is comprised of the paradigmatic associations embodied by that sentence. In the example, the relational trace for “John loves Mary” would be {John: Bert, Steve; Mary: Ellen, Jody}. Note that although the lexical and relational traces both contain paradigmatic associations, the lexical trace is accumulated over the entire corpus for an individual word (e.g. in this corpus *John* is bound to the distributed pattern containing *Bert*, *Steve*, *Dave* and *Michael*), while the relational trace is a binding of the paradigmatic associations of each of the words in a given sentence, so that within the relational trace for “John loves Mary”, *John* is bound only to *Bert* and *Steve* (not *Dave* or *Michael*). Note that as suggested above the set containing *Mary*, *Ellen*, and *Jody* can be thought of as a representation of the “lovee” role and the set containing *John*, *Bert* and *Steve* as the “lover” role, so the trace is an extraction of the relational information contained in the sentence. That is, the relational trace captures a form of deep structure.

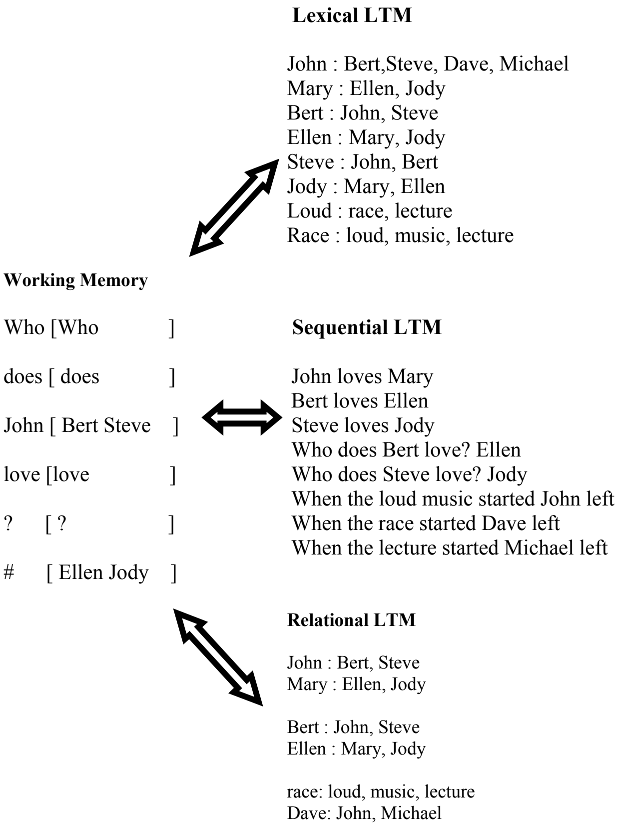

Figure 1: The SP Model architecture.

In the SP model, sentence processing is characterized as the retrieval of associative constraints from long-term memory followed by the resolution of these constraints in working memory. Creating an interpretation of a sentence/utterance involves the following steps:

Sequential Retrieval: The current sequence of input words is used to probe sequential memory for traces containing similar sequences of words. In the example, traces four and five; “Who does Bert love? Ellen” and “Who does Steve love? Jody”; are the closest matches to the target sentence “Who does John love? #” and are assigned high probabilities:

0.499	who does bert love ? ellen
0.499	who does steve love ? jody
0.001	john loves mary …

In this simple example, the retrieved traces contain many of the same words in the same order and consequently are the best retrieval candidates. In general, however, lexical traces are used to establish structural similarity even in the absence of lexical overlap.

Sequential Resolution: The retrieved sequences are then aligned with the target sentence to determine the appropriate set of paradigmatic associates for each word. At this stage, sentential context will affect the trace words that are aligned with each of the input words:
who: who (0.997) /does: does (0.997) /john: steve (0.478)/ bert (0.478) / love: love (0.998) /?: ? (0.998) /#: jody (0.460) /ellen (0.460)
The "#" symbol indicates an empty slot. Ultimately, it will contain the answer to the question. The numbers in brackets are probabilities associated with the words immediately preceding them. Space precludes a description of how these probabilities are calculated but a full exposition is available in Dennis (submitted). Note that the slot adjacent to the "#" symbol contains the pattern {Jody, Ellen}. This pattern represents the role that the answer to the question must fill (i.e. the answer is the lovee).

Relational Retrieval: The bindings of input words to the corresponding sets of paradigmatic associates (the relational representation of the target sentence) are then used to probe relational long-term memory. In this case, trace one is favoured as it involves the same role filler bindings as the target sentence. That is, it contains a binding of John onto the {Steve, Bert} pattern and it also contains the {Jody, Ellen} pattern.

0.687 john: bert (0.298) steve (0.298)
mary: ellen (0.307) jody (0.307)
0.089 bert: steve (0.319) john (0.226)
ellen: jody (0.320) mary (0.235)
0.089 steve: bert (0.319) john (0.226)
jody: ellen (0.320) mary (0.235) …

Despite the fact that "John loves Mary" has a different surface form than "Who does John love ? #" it contains similar relational information and consequently has a high retrieval probability.

Relational Resolution: Finally, the paradigmatic associations in the retrieved relational traces are used to update working memory:

who: who (0.997) / does: does (0.997) / john: john (0.500)/ steve (0.488) bert (0.488) /love: love (0.998)/ loves (0.153) / ?: ? (0.998) /#: mary (0.558) ellen (0.523) jody (0.523)

In the relational trace for "John loves Mary", "Mary" is bound to the {Ellen, Jody} pattern. Consequently, there is a strong probability that "Mary" should align with the "#" symbol which as a consequence of sequential retrieval is also aligned with the {Ellen, Jody} pattern. Note that the model has now answered the question - it was Mary who was loved by John.

To summarize, the model hypothesizes four basic steps. Firstly, the series of words in the target sentence is used to retrieve traces that are similar from sequential long term memory. Then, the retrieved sequential traces are aligned with the input sentence to create a relational interpretation of the sentence based on the word order. This interpretation is then used to retrieve similar traces from relational long term memory. Finally, working memory is updated to reflect the paradigmatic constraints retrieved in the previous step.

In a number of circumstances, it is necessary for the model to be able to distinguish between traces that were stored in the current context from those that are part of the background memory of the system. Rather than propose a separate memory system to store the recent traces, the SP model assumes that these traces are more available because they contain a representation of the current context. Rather than try to provide explicit context processing mechanisms, the model simply uses a symbol (CC, C1, C2, …) to represent the appropriate context and otherwise treats these symbols as if they were words. When a given retrieval probe shares context with traces in memory the same context symbol is used in each. In this paper, the contextual mechanism will be used to capture the fact that the prime and the target appear on the same trial and hence share context. This treatment of context is somewhat arbitrary, but is used here in lieu of a more comprehensive mechanism.

The Study

The study compares performance by English L1 and English L2 readers on a self-paced, reading task. Subjects read sentence pairs that were either matched or mismatched for syntactic structure, but that always differed in lexical content. Faster reading times in the critical region of the second sentence in the congruent Matched pair (same structures, different lexis) over the incongruent Mismatched pair (different structures, different lexis) would represent evidence for structural priming in comprehension. Evidence is sought for priming for the Matched versus Mismatched pairs across groups, and for greater priming evident in L2 participants. The findings are then simulated in the Syntagmatic-Paradigmatic model.

Method

Participants Forty-two native English speakers (henceforth L1) and 24 fluent speakers/readers of English as a second language (L2) participated in the experiment. Both groups were recruited from an introductory Linguistics course at an Australian university and participated for course credit. The L2 speakers were matriculated students at the university, having a minimum of 6.5 on the IELTS test (550 TOEFL) and most had been in the country for at least five months at the time of the test. They were from different L1s.

Materials The stimuli set contained two kinds of syntactic structures, questions involving Object Extraction (OE) and Subject Extraction (SE) (Juffs & Harrington, 1995). Each sentence was presented in either a Match condition, in which both sentences were the same structure, or Mismatched condition were one of each structure was presented. Examples of the match and mismatch condition are presented below.

Subject extraction sentences
Prime: Who did Ann believe likes Mary at the club?
Match: Who did Joe THINK saw Irene in the class?
Mismatch: Who did Joe THINK Irene saw in the class?

Object extraction sentences
Prime: Who did Ann believe Mary likes at the club?
Match: Who did Joe THINK Irene saw at the club?
Mismatch: Who did Joe THINK saw Irene at the club?

The critical comparison is between the reading times in the underlined regions in the Match and MisMatch sentences. The region immediately following the first verb, where the reader either encounters a proper noun (in the OE structure) or another verb (in the SE structure) represents a point where on-line processing decisions must be made, and where structural priming may be evident. The 16 pairs consisted of 32 sentences made up of different first verbs and a following proper noun (OE) or 2nd verb (SE) that were matched for frequency. The 32 sentences were randomly assigned across structure and matching conditions for each subject. The need to match for frequency meant that particular verbs always appeared with a specific following proper noun (in the OE sentences) or second verb (in the SE sentences). Each subject saw 16 subject and 16 object extraction sentences. Half the target sentences were presented first and half presented second. Likewise, half the pairs matched for syntactic structure and half did not. Each subject saw the 16 test sentence pairs and 24 filler pairs in a randomly ordered, 40-item set. The filler pairs consisted of grammatical structures that differed from the test items.

Procedure Participants were tested in groups of 10-18 in a computer lab. The sentences were presented on computer using the standard self-paced moving window technique in which a sentence was read by hitting a key to progress to each subsequent word. After the first sentence was read it disappeared from the screen and the second sentence read using the same procedure. In order to focus attention on global comprehension, subjects were then asked to give a rating of relatedness for the pair. Each subject did five practice sets of sentence structures, which were different from those used in the experiment.

Results

For the L1 participants: L1 First sentence, $M = 411$ msec, $SD = 139$ msec; L1 Second Sentence, $M = 373$ msec, $SD = 110$ msec, L1 Overall $M = 392$ msec, $SD = 101$ msec. For the L2 participants: L2 First Sentence, $M = 573$ msec, $SD = 233$ msec; L2 Second Sentence, $M = 459$ msec, $SD = 145$ msec, L2 Overall $M = 522$ msec, $SD = 156$ msec. In general the L1 participants read the sentences faster than their L2 counterparts. The 130 msec advantage in Overall M reading time for the L1s was significant, $t = 13.56$, $p < .001$. In addition, the second sentence was read significantly faster across structure and match conditions for the L1 participants, $t = 5.59$, $p < .001$ and for the L2 participants, $t = 8.09$, $p < .001$.

The key comparison is between reading times on the second sentences as a function of the type of preceding sentence. Reading time (in milliseconds) is the difference between the first verb and the words in the following critical region. In the moving window technique reading time per word tends to increase as the reader moves from left to right. The smaller the difference between the critical region and the first verb, the greater the facilitation, or priming. Three region values were calculated: Region 1 (First critical word – 1st verb); Region 2 (average of first and second critical words – 1st verb); and Region 3 (average of first, second and third critical words – 1st verb). The averages are used because the moving window is a fairly noisy procedure in which the locus of processing effects is difficult to identify precisely. Table 1 presents reading time differences between first verb and the three region values.

Table 1.
Reading time differences between first verb and the three region values by Language (L1 versus L2), Structure (Object Extraction versus Subject Extraction), and Condition (Match versus Mismatch).

* Difference in milliseconds

Structure x Match	1st region		2nd region		3rd region	
	M	*SD*	*M*	*SD*	*M*	*SD*
L1 OE Match	13	49	16	49	32	55
L1 OE Mismatch	22	46	31	39	44	43
L1 SE Match	24	52	32	49	39	44
L1 SE Mismatch	11	49	21	53	38	54
L2 OE Match	33	130	47	138	70	148
L2 OE Mismatch	69	283	73	177	89	175
L2 SE Match	16	117	48	142	79	139
L2 SE Mismatch	58	151	80	165	90	155

The key contrast is between the Match and Mismatch cells in the respective structures and language. Lower difference times in the Match cells are evidence for priming. For the L1 subjects this pattern is evident in the OE sentences for all three Regions, but the opposite pattern holds for the SE sentences, though the differences are small in both cases. For the L2 subjects the predicted pattern is evident for both structures. Differences for the L2 subjects range from 42 msec between Matched and Mismatched SE sentences in Region 1 to an 11 msec difference the same sentences in Region 3.

The mean results by language and region were analyzed in a two-way ANOVA with Structure (OE vs SE) and Condition (Match vs. Mismatch) as within-subject factors. Because of the difference in sample sizes ($N = 42$ L1 versus $N = 24$ L2), language was not included as a between subjects variable in the statistical analysis. Due to space limits only results that were significant or approaching significance will be presented. For the L1 subjects, there were no significant main effects in either the Subject or the Item analyses. The L1 subjects were not sensitive to differences in Structure or

Condition. This was not the case for the L2 subjects. Although there was no main effect evident for Structure, the effects for Condition were significant or approaching significance across all three regions. There was no interaction of Structure and Condition in any of the regions. In Region 1 there was a main effect for Matching on the subject analysis F_1 (1,23) = 7.07, $p < .05$, MSE = 5015, but not for the Item Analysis F_2 1,31)= .67, *n. sg*. MSE = 6012. In Region 2 there was a reliable difference for both subject and item analyses F_1 (1,23)= 5.54, $p < .05$, MSE = 4281, F_2 (1,31)= 7.19, $p < .05$ MSE = 5995. Both subject and item analyses approached significance in Region 3: F_1 (1,23)= 3.40, $p = .078$, MSE = 3216, F_2 (1,31)= 3.34, $p = .077$, MSE = 7113. There was a large amount of variability in the L2 data, as is evident in the standard deviation values in the Table 1 and the MSE values in the ANOVA. This variability may come from the somewhat heterogenous nature of the L2 sample. The L2 subjects represent a number of L1s and, although in full-time academic study in an Australian university, they may still differ in English proficiency. Although the first verbs were randomly assigned across structure and matching conditions, the need to match for frequency meant that particular verbs always appeared with a specific following proper noun (in the OE sentences) or second verb (in the SE sentences). A finer-grained analysis is needed to examine these specific combinations.

In summary, the L1 subjects showed no significant differences in reading times across Structure or more importantly Condition. In contrast the L2 subjects did show a reliable effect for Condition, with reading times on the Matched sentences significantly faster than those on the Mismatched sentences. In the next section we use the Syntagmatic-Paradigmatic model to model these findings.

Modeling Structural Priming

The empirical findings can be interpreted as a consequence of the retrieval based processing assumed in the model. An individual with fewer linguistic resources may be more likely to make use of available primed structures in subsequent production. Alternatively, experienced individuals may have stored more instances of sentences of the appropriate structural form prior to the priming trial. These previous instances then serve to reduce the impact of the prime sentence. To model these effects, the SP model was exposed to the following corpus:

1. Joe saw Ellen .
2. Bill hurt Sarah .
3. Bert helped Kirsten .
4. What do you believe ?
5. What do you know ?
6. What do you feel ?
7. C1 Who did Ellen believe saw Bert ?
8. C2 Who did Sarah know Joe hurt ?

Traces one to six were added to allow the induction of background knowledge on the substitution probabilities of words. As a consequence of lexical training the model learns the following substitution sets:

Joe, Bill and Bert
saw, hurt and helped
Ellen, Sarah and Kirsten
believe, know, feel

Note that lexical learning occurred only over the first six traces and was conducted on the change probabilities only.

Traces seven and eight represent two different prime situations. In context C1, the model has been given the subject extraction prime "Who did Ellen believe saw Bert?". In context, C2 the model has been given object extraction prime "Who did Sarah know Joe hurt?" Now can investigate the response of the model as a consequence of presenting the target subject extraction sentence "Who did Kirsten feel helped Bill?" either in the congruent context C1 (see Figure 2A) or in the conflict context C2 (see Figure 2B).

A) Congruent Context for L2
c1: c1 (1.00) / who: who (1.00) / did: did (1.00)/ kirsten: ellen (1.00) / feel: believe (1.00)/ helped: saw (1.00) /
bill: bert (1.00) / ?: ? (1.00)

B) Conflict Context for L2
c2: c2 (1.00) / who: who (1.00) / did: did (1.00)/Kirsten: Sarah (1.00) feel: know (1.00) / helped: hurt (.48) Joe (.02) / bill: Joe (.49)/ ?: ? (1.00)

Figure 2: Working memory following syntactic resolution of the subject extraction sentence "Who did Kirsten feel helped Bill?" in either the congruent (A) or conflict (B) contexts.

Note that in the positions post the critical verb (i.e. the helped and Bill positions) the substitution probabilities are much lower in the conflict case than in the congruent case. These lower substitution probabilities correspond to longer reading times in the equivalent conditions and are also seen when the object extraction version of the sentence is presented (i.e. "Who did Kirsten feel Bill helped?"). To understand why the SP model is producing these results it is instructive to look at the traces that are returned during sequential retrieval in each case. When the subject extraction sentence is used as a probe in context C1, trace seven "C1 Who did Ellen believe saw Bert?" is retrieved. As this matches the structure of the probe there is no ambiguity in the alignment. However, when the same probe is used in context C2 it is trace eight that is retrieved. Against trace eight there are two dominant alignments:

```
C1 Who did Kirsten feel helped Bill  --  ?
C2 Who did Sarah   know   --   Joe  hurt ?
and
C1 Who did Kirsten feel  -  helped Bill  ?
C2 Who did Sarah   know Joe hurt    --   ?
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These two possible alignments share probability mass and hence create ambiguity in the critical region.

To simulate the L1 subjects, additional traces were added to capture in a purely qualitative fashion their additional language experience:

1. Joe saw Ellen .
2. Bill hurt Sarah .
3. Bert helped Kirsten.
4. Simon loves Alison.
5. Paul knew Nina.
6. What do you believe?
7. What do you know?
8. What do you feel?
9. What do you say?
10. What do you think?
11. CC Who did Nina say loves Simon?
12. CC Who did Alison think Paul knew?
13. C1 Who did Ellen believe saw Bert?
14. C2 Who did Sarah know Joe hurt?

Four additional traces (4, 5, 9 & 10) have been added to simulate additional general language experience necessary for lexical training and two additional traces (11 & 12) have been added to simulate past experience with the subject and object extraction sentences specifically. Note that these additional SE and OE questions have a neutral context representation (CC). Figure 3 shows the response of the model when presented with the subject extraction sentence "Who did Kirsten feel helped Bill" in context C1 the congruent context (see Figure 3A) and in context C2 the conflict context (see Figure 3B).

A) Congruent Case for L1
c1: c1 (.65) cc (.35) / who: who (1.00) / did: did (1.00) / Kirsten: Ellen (.65) Nina (.30) Alison (.05) / feel: believe (.65) say (.30) think (.05) / helped: saw (.65) loves (.30) Paul (.04) / Bill: Bert (.65) Simon (.30) knew (.04) / ?: ? (1.00)

B) Conflict Case for L1
c2: cc (.80) c2 (.20) / who: who (1.00) / did: did (1.00) / Kirsten: Nina (.69) Sarah (.20) Alison (.11) / feel: say (.69) know (.20) think (.11) / helped: loves (.69) Paul (.10) hurt (.10) / Bill: Simon (.69) knew (.10) Joe (.10) / ?: ? (1.00)

Figure 3: Working memory following syntactic resolution of the subject extraction sentence "Who did Kirsten feel helped Bill?" in either the congruent (A) or conflict (B) contexts.

While there is still some priming in the L1 Conflict simulation, it much reduced because now the background traces representing the correct structure are retrieved and participate in syntactic resolution.

Conclusions

Structural priming in comprehension was evident only for the L2 participants, a finding consistent with a contextually dependent retrieval explanation for why priming might occur. The simulations showed that the distributed instance-based model of sentence processing presented here provides a promising tool for modeling these effects. The findings here also yield insight into structural priming in comprehension, an area that has received comparatively little attention in priming research.

Acknowledgments

This research was supported by Australian Research Council grant A00106012, US National Science Foundation grant EIA-0121201 and US Department of Education grant R305G020027.

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