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How to Prune a Garden Path by Nipping It in the Bud: Fast Priming of Verb Argument Structure

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The syntactic preferences of briefly displayed prime words were found to affect readers' ability to resolve temporary syntactic ambiguities. In two self-paced reading experiments, participants read target sentences containing ambiguous sentence complements (e.g., ''The photographer accepted the fire could not be put out.''), in which ''the fire'' could be the direct object of the main verb ''accepted,'' or the subject of a sentence complement. A briefly displayed prime verb (duration of 39 ms) appeared immediately prior to reading the main verb, and had a significant impact on syntactic misanalysis effects for the ambiguous sentence complement. Priming the matrix verb with a verb that tends to be used with a direct object (e.g., ''obtained'') resulted in increased processing difficulty in the disambiguating region of the sentence complement (e.g., ''could''). Priming the matrix verb with a verb that tends to be used with a sentence complement (e.g., ''realized'') resulted in significantly less processing difficulty in the disambiguating region. The results are consistent with constraint-based theories of sentence processing that make immediate use of lexically specific information.

Key Words: syntactic ambiguity; parsing; sentence comprehension; fast priming; argument structure.

Recently, a new lexical priming technique has been developed, called ''fast priming,'' which can be used to study on-going lexical processes without disrupting the silent reading of text (Rayner, Sereno, Lesch, & Pollatsek, 1995; Sereno, 1995; Sereno & Rayner, 1992). As a reader encounters a critical target position in the text, a prime word is first presented for 30 to 40 ms, followed immediately by the target word. This display is perceived as a ''flicker,'' with readers typically being unable to identify the prime. Reading time data from these studies has revealed that the processing of a target word can be affected by a prime's orthographic, phonological, and semantic properties, indicating that these classes of information are rapidly activated during the silent reading of continuous text. This technique shows promise for studying purely automatic lexical processes, because the effects arise from a stimulus that readers are typically unable to identify or report (Sereno & Rayner, 1992).

In this paper, we demonstrate that fast priming can also be used to study how quickly lexical information affects the structural aspects of the language comprehension process. We provide evidence that the very early stages of sentence processing include the activation of rich and abstract information about the grammatical properties of words (lexical argument structure). This was accomplished by conducting experiments that embedded fast priming in a study of syntactic ambiguity resolution. The central question of these experiments was whether or not the syntactic proper-

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ties of a prime word could influence a reader's ability to resolve a temporary syntactic ambiguity. If primes influence these processes, the results would encourage the development of language processing theories that emphasize the detailed grammatical contributions of lexical items.

LEXICAL ARGUMENT STRUCTURE

The research presented below focuses on the role of lexical argument structure in sentence comprehension. Lexical argument structure is defined as information specifying how a word may combine syntactically and semantically with other words and phrases. Perhaps the best illustration of this kind of information comes from the lexical structure of verbs. Verb argument structure is assumed to include information about the possible syntactic complements of the verb (i.e., *subcategorization information*); the possible semantic or conceptual roles involved in the event denoted by the verb (i.e., *thematic role information*); and a mapping between thematic roles and syntactic complements (for one such account see Carlson & Tanenhaus, 1988). Consider a verb like ''accepted,'' which can appear in at least two different subcategorizations. The verb permits a direct object, as in Example 1a, in which ''the prize'' plays the role of ''Theme'' in the accepting event (i.e., it is being accepted). The verb also permits a sentence complement, as in Example 1b, in which ''the prize'' is not playing the role of Theme, but rather is the subject of a Proposition involved in the accepting event.

(1a). The man accepted the prize.

(1b). The man accepted that the prize was not going to him.

Several sentence processing studies have found that readers' preferences for a verb's different argument structures play an important role in the resolution of temporary syntactic ambiguities (e.g., Boland, Tanenhaus, Garnsey, & Carlson, 1995; Britt, 1994; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Holmes, Stowe, & Cupples, 1989; MacDonald, 1994; Trueswell, Tanenhaus, & Kello, 1993). Some of the best illustrations of these effects come from studies focusing on the Direct Object/Sentence complement (DO/S) ambiguity. Consider Example 2, in which the sentence complement is missing the optional complementizer ''that.''

(2). The man accepted the prize was not going to him.

Given the possible arguments for ''accepted,'' a temporary ambiguity arises regarding the relationship between the noun phrase ''the prize'' and the verb ''accepted.'' The noun phrase could be the direct object or the subject of a sentence complement. In sentences like this, readers show an initial preference for the direct object interpretation of the ambiguous noun phrase. In particular, readers show increases in reading times at the disambiguating region ''was not…,'' as compared to when the complementizer is present (e.g., Holmes et al., 1989; Ferreira & Henderson, 1990; Rayner & Frazier, 1987). This pattern suggests that readers experienced a ''garden-path'' because they initially considered ''the prize'' to be the direct object and had to revise this interpretation when they encountered the verb phrase ''was not.''

Further research has revealed that at least two aspects of lexical argument structure influence how readers and listeners resolve the DO/S ambiguity. First, a verb's subcategorization preference has been found to influence readers' parsing commitments (e.g., Holmes et al., 1989; Trueswell et al., 1993). For instance, Trueswell et al. monitored eye movements as people read sentences like Example 2. The study compared sentences that contained verbs that tend to use a direct object (e.g., ''accepted'') with sentences that contained verbs that tend to use a sentence complement (e.g., ''realized'' as in ''The man realized the prize was…''). Verbs that tend to use a direct object showed typical garden-path effects (i.e., long fixations and regressive eye movements in the disambiguating region ''was not going…''), suggesting that readers had incorrectly taken the noun as the direct object and were revising their commitment. Verbs that tend to use a sentence complement showed no signs of difficulty in this region.

The data suggested that subcategorization preferences of verbs were made available quite rapidly and that they were used to inform initial parsing commitments.

A second factor that has been found to influence syntactic commitments is the plausibility of the noun phrase as the direct object of the verb. In a self-paced reading experiment and an eye-tracking experiment, Garnsey et al. (1997) compared nouns that were implausible Themes with nouns that were plausible Themes, as in Example 3.

(3). The photographer accepted (that) the money/fire could not be….

Garnsey et al. (1997) observed an interaction between noun plausibility and verb subcategorization preference. For verbs that tend to use direct objects (DO-bias verbs), participants spent a longer amount of time initially reading the implausible Theme (e.g., ''fire,'' as compared to the plausible Theme ''money''), suggesting they were considering the direct object analysis of the ambiguous noun phrase. In the verb phrase region (e.g., ''could not…''), readers showed clear signs of syntactic misanalysis for both plausible and implausible Themes, i.e., long initial reading times and more rereads. Thus, despite readers' sensitivity to the implausible direct object, they had difficulty recovering the verb's subordinate sentence complement alternative. For verbs that use the Direct Object and Sentence Complement with equal likelihood (Equi-biased verbs), no semantic anomaly effect was observed at the noun (e.g., ''money'' vs ''fire'') and only plausible Themes induced a garden-path effect in the verb-phrase region. This suggests that readers pursued both syntactic analyses in parallel, and information about semantic fit helped select between syntactic alternatives. Finally, for verbs that tend to use a sentence complement (S-bias verbs), little or no anomaly effect was seen at the noun, and neither noun induced a garden-path, suggesting that the sentence complement interpretation was initially pursued for both conditions. Taken together, this pattern suggests that verb-specific syntactic information is activated in parallel and constrained by the semantic fit of complements to corresponding thematic roles.

Trueswell et al. (1993) and Garnsey et al. (1997) interpreted their findings as support for the constraint-based lexicalist theory of sentence processing, which proposes that the recognition of a verb includes the parallel activation of lexical argument structure and that this information determines initial parsing commitments (MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). For the DO/S ambiguity, the recognition of the main verb (e.g., ''accepted'') includes the parallel activation of both the direct object and sentence complement subcategorization frames, with the relative activation of alternatives depending upon the probability the verb uses these structures (e.g., Garnsey et al., 1997; Trueswell et al., 1993). The extent to which a verb activates a frame helps determine initial parsing preferences for the ambiguous noun phrase.

Although the constraint-based lexicalist account is consistent with the findings, several researchers have argued that this position is too strong, in that the current results do not require parsing preferences to stem from the automatic activation of argument structure during word recognition (Frazier & Clifton, 1996; Mitchell, 1989; Mitchell, Cuetos, Corley, & Brysbaert, 1995). One part of this argument has been that the DO/S results only require that lexical preferences be computed and used some time between encountering the verb ''accepted'' and encountering the head of the ambiguous noun phrase ''prize.'' It has also been noted that prior research focusing on lexical processing has found inconsistent data regarding the presence of subcategorization and thematic role information during word recognition. In particular, several researchers have examined the relationship between the complexity of verb argument structure and processing load (e.g., Schmauder, 1991; Schmauder, Kennison, & Clifton, 1991; Shapiro, Brookins, Gordon, & Nagel, 1991; Shapiro & Levine, 1990; Shapiro, Zurif, & Grimshaw, 1987, 1989). The experiments employed a dual-task interference technique in

which participants listened to continuous speech while they performed a secondary task of lexical decision or naming to an unrelated word. Response time to the secondary task was used as a measure of local processing load during the perception of the sentence. On critical trials, presentation of the visual target coincided with hearing a verb of a particular lexical complexity. In general, these studies have revealed no effects of subcategorization complexity and have found conflicting results regarding thematic role complexity. It is possible that some of the variability between experiments has been due to how difficult the secondary task was for participants, because easier secondary tasks tend to be less sensitive to differences in processing load (Schmauder et al., 1991; Shapiro et al., 1991). However, Schmauder (1991) has also found no effects of verb complexity in reading time studies, which do not rely upon a secondary interference task. In the experiments, fixation durations on verbs showed no relation to their thematic or subcategorization complexity. Although the eye-tracking and dual-task results raise questions about the presence of argument structure during word recognition, the results are not definitive. This is because the studies tended not to adequately control for factors that could affect the availability of possible argument structures, such as the frequency of use of particular structures and the presence of semantically constraining contexts. Thus, it is unclear whether complexity effects are expected, given that words with multiple syntactic frames may have been biased toward a single structural and thematic alternative.

Still others have found positive results of verb argument structure preferences during reading and listening (McElree, 1993; McElree & Griffith, 1995). In particular, McElree and colleagues have developed a task of speeded grammaticality and/or plausibility judgment, in which speed-accuracy trade-off (SAT) curves can be used to assess the sensitivity to lexical information over time. Readers' sensitivity to violations of subcategory and thematic role information were examined and compared (McElree & Griffith, 1995). The results revealed that both subcategorization and thematic role violations can be detected quite rapidly over the course of encountering a word, with subcategorization violations having a slightly faster time course of detection than thematic violations. Moreover, McElree (1993) found that preferred subcategorization frames had a higher probability of retrieval than less preferred subcategorization frames, with the data suggesting parallel activation of possible frames. Although these findings are consistent with rapid activation of lexical argument structure, we believe the results should be taken with some caution. This is because the SAT paradigm requires participants to read a large number of similar sentences. Thus, although the SAT functions revealed the time course with which information was used to perform the task, the repetition of similar stimuli with similar structures may have allowed participants to attend to particular aspects of the input, such as lexically specific preferences that they may not otherwise focus on when processing highly variable text.

In sum, although several studies of syntactic ambiguity resolution have found relatively rapid effects of lexical argument structure, word recognition research has found inconsistent evidence that argument structure is activated during the recognition of a verb. Indeed, some researchers have used the findings from the word recognition literature to argue that initial syntactic commitments do not involve argument structure, and that effects of lexical preference in syntactic ambiguity resolution stem from the rapid revision of an otherwise lexically-blind parser (the ''lexical filtering'' hypothesis, e.g., Ferreira & Henderson, 1991; Frazier, 1989; Frazier & Clifton, 1996; Mitchell, 1989; Mitchell et al., 1995). Thus, two important questions remain about effects of lexical preference on syntactic ambiguity resolution. First, does the recognition of a verb include the automatic activation of information pertaining to argument structure? And second, does the word recognition process have a direct impact on the commitments readers make to temporary syntactic ambiguity?

FAST PRIMING AND ARGUMENT STRUCTURE

The present research used the fast priming technique to examine the issues outlined above. We embedded the fast priming technique in a study of the DO/S ambiguity. Participants read sentential complement constructions whose main verbs were able to take a direct object or a sentence complement, as illustrated below.

(4) The talented photographer *accepted* (that) the fire could not have been prevented.

obtained DO-Prime

realized SC-Prime

The main verb of each target sentence (e.g., ''accepted'') was a verb that strongly prefers a direct object as its argument (DO-biased verbs). The noun phrase (e.g., ''the fire'') was always a poor Theme of the verb. Recall that for sentences of this type, Garnsey et al. (1997) found that without the optional complementizer ''that,'' readers were surprised by the poor object ''fire,'' resulting in long reading times. Long reading times were also observed in the verb-phrase region ''could not,'' suggesting that readers had difficulty retrieving the subordinate sentence complement argument structure.

In the present study, the main verb was fast primed by a structurally biased prime verb: a DO-Prime or a SC-Prime. DO-Primes (e.g., ''obtained'') were verbs that strongly prefer a direct object and do not permit a sentence complement. SC-Primes (e.g., ''realized'') were verbs that strongly prefer a sentence complement and rarely use a direct object. If argument structure is activated early in lexical recognition, brief exposure to a prime verb should be able to prime the argument structure activation pattern of the target word. This in turn should affect parsing commitments. Thus, we expect that sentences primed with DO-Prime verbs should show large garden-path effects for ambiguous sentence complements, whereas sentences primed with SC-Primes should show substantially fewer signs of garden-pathing.

In previous studies of fast priming, eye movements were monitored as participants read text (e.g., Sereno & Rayner, 1992). The present experiments used a self-paced reading version of the fast priming technique. Prior to reading a sentence, all letters were initially masked. Words were revealed in a one word moving window, at a rate determined by the participants' button presses. At critical word positions, the button press initiated the presentation of the prime word, which lasted exactly 3 screen cycles (39 ms) and was replaced immediately by the target verb. Pretesting revealed that this sequence appeared as a flicker to the reader, with primes being rarely identifiable.

If lexically specific structural preferences were present during the earliest stages of encountering a word, we would expect the structural preferences of the ''flicker'' to affect readers' parsing commitments for ambiguous sentence complements. If priming effects are found, they place strong constraints on the time course of lexical influences in processing and help guide refinements to lexicalist accounts of sentence processing.

EXPERIMENT 1

Method

Participants

Thirty-two participants from the University of Pennsylvania volunteered for the experiment. They received extra course credit or were paid for their participation. All participants were native speakers of English.

Procedure

Each trial consisted of participants silently reading a pair of sentences and answering a yes/no comprehension question with feedback. At the beginning of each trial, the participant saw groups of equal signs ''='' replacing each character in the sentences. The participant pressed a button marked SCROLL on a button box to present and read the first word. With each press of the SCROLL button, the next word was revealed and the previous word was replaced by equal signs until the participant reached the end of the second sentence

(moving-window self-paced reading; Just, Carpenter, & Woolley, 1982).

Each trial contained a prime-target sequence. When the participant pressed the SCROLL button to read the word in the critical position, the following events occurred. The equal sign mask for the word position was replaced by a prime word of the same number of characters. The prime word remained on the screen for exactly 3 screen cycles (39 ms). The prime word was then replaced by the intended target word, which remained on the screen until the next press of the SCROLL button. This priming event was typically perceived as a flicker on the screen.

Before beginning the experiment, participants were told to read the sentences as quickly as they could comfortably go, while still being able to answer the comprehension questions correctly. Participants were told that, from time to time, they might see letters flicker as a word appeared on the screen. They were told not to worry about the flicker and to pay attention to what they were reading.

A postexperiment interview was also conducted, in which participants were asked the following questions in the order listed. ''(1) Did you see words flickering or changing? If so, on what percentage of the trials did you notice a word change/flicker/flash? (2) When you did see flashing words, what percentage of the time would you say that you were aware of what the flashed word was?'' These questions were asked by the experimenter, and care was taken to make sure that the participant understood the questions. Because a prime was presented on every trial, the percentage of trials on which a prime word was identified can be estimated by taking the fraction reported in response to question 1 and multiplying it by the fraction reported in response to question 2.

Display Characteristics

An Apple 16-inch color monitor was used. The contrast was set to its maximum setting, and intensity was set to a middle setting. All stimuli appeared as white text on a black background. The luminance intensity of each lower case letter of the alphabet was measured using a photometer, yielding an average luminance of 0.58 cd/m^2. The black background had a luminance of 0.31 cd/m^2. Participants viewed the monitor in a dimly lit room at an approximate distance of 45 cm. Each block character, which was in Courier 14 pt. font, was 0.29 cm wide, subtending a visual angle of approximately 0.37°, resulting in 2.7 characters per degree.

The prime duration had been confirmed by placing a photo-diode on the computer screen. Oscilloscope measurements revealed that the primes were displayed for exactly three screen cycles (39 ms) and that the target word replaced the prime word on the next (fourth) screen cycle.

Materials

The first sentence of every target trial contained a main verb in the past tense followed by a sentence complement, as illustrated in Example 4 above. Target sentences were a subset of the target sentences reported in Garnsey et al. (1997, the DO-bias target items). Unambiguous sentence complements began with the optional complementizer ''that.'' Ambiguous sentence complements did not contain the complementizer, making the noun phrase ''the fire'' a potential direct object of the verb. The main verb (e.g., ''accepted'') was always a verb that permits a sentence complement, but strongly prefers to appear with a direct object, as determined by a sentence completion study reported in Garnsey et al. (1997). In addition, the noun phrase (e.g., ''the fire'') was always a semantically implausible Theme of the verb, as determined by a rating study in Garnsey et al. (1997). All words of the sentence, up to and including the first three words of the verb phrase of the sentence complement, appeared on the first line of text.

Each main verb was matched with two prime words: a DO-Prime and an SC-Prime. DO-Primes (e.g., ''obtained'') were verbs that strongly prefer a direct object and do not permit a sentence complement. SC-Primes were verbs that strongly prefer a sentence complement and rarely use a direct object. DO-Primes were selected from the Brandeis Verb

Lexicon (Grimshaw & Jackendoff, 1981) or experimenter intuitions. SC-Primes were selected from the sentence completion norms of Trueswell et al. (1993) and Garnsey et al. (1997). All primes contained the same number of characters as the target verb that they were associated with. Each DO-Prime and SC-Prime pair were matched for overall frequency. Finally, each DO-Prime and SC-Prime pair were matched for letter overlap with the target verb of the sentence. All target sentences and primes appear in Appendix 1.

Four presentation lists were constructed by randomly combining the 16 target sentence pairs with 54 distractor sentence pairs. Distractor trials contained a variety of sentence types including main clauses with direct objects. Each distractor trial contained a prime word, with the position of the prime ranging from the second word in the first sentence to words late in the second sentence. The majority of primes appeared in the first sentence. All prime and target words were content words and shared the same syntactic category (e.g., nouns were primed with nouns, verbs with verbs). Within a presentation list, eight target items were primed with a DO-Prime and eight target items were primed with a SC-Prime. For each of these types of primes, four items were ambiguous sentence complements and four were unambiguous sentence complements. Each target item was then rotated though these four conditions, generating four different presentation lists. Target items were initially constructed and assigned to a condition such that average word length in characters of the ambiguous NP (e.g., ''the fire'') and the first two words of the disambiguating VP (e.g., ''could not'') were approximately equal across conditions. Each test sentence was followed by at least two distractor trials. Each participant was presented with 10 practice trials and one of the four presentation lists. The experiment, including instructions and practice, lasted about 40 min.

Corpus Analysis

A corpus analysis was also conducted on all prime and target verbs from the parsed text files of the Penn Treebank (Marcus, Santorini, & Marcinkiewicz, 1993). Two corpora were used. First, we used a one million word corpus of Wall Street Journal Text, which was specially annotated for distinguishing arguments from adjuncts. All forms of each verb (past tense, present, infinitive, etc.) were extracted and analyzed automatically for argument structure. A subset of the corpus was hand checked for accuracy and found to have no errors with respect to assigning DO and S complements. Second, the one million word parsed Brown Corpus was also used. Because this corpus is not annotated for arguments vs adjuncts, we limited this analysis to the past tense forms of the verbs.

From these two sources, we located 5453 tokens of the verbs, with an average hit rate of 114 tokens per verb. We estimated the probability that each verb appeared with either a Direct Object, a Sentence Complement, or some other argument structure. As can be seen in Table 1, the probabilities confirm the various classifications of verbs. It is important to note that sentence complement arguments are slightly lower than one might expect. However, when a verb appears in a non-main clause position, it is much less likely to contain a sentence complement argument. Appendix 2 contains the syntactic complement probabilities for each verb.

TABLE 1

Probability of the Direct Object (DO), Sentence Complement (S) Structures

	Type of complement		
Type of verb	Direct object	Sentence	Other
DO-biased Target	0.55	0.23	0.22
SC-Prime	0.12	0.41	0.47
DO-Prime	0.84	0.00	0.16

Results

All subjects scored better than 90% correct on the comprehension questions. On the basis of the postexperiment questionnaire, 4 of the

TABLE 2

Experiment 1: Mean Reading Times in Milliseconds for Each Word Position

		Word position						
Prime-Type	Ambiguity	accepted	(that)	the	fire	could	not	have
DO-Prime	No-that	443		396	447	515	411	384
	That	459	422	375	370	371	364	376
	difference	−16		+21	+77	+144	+47	+8
SC-Prime	No-that	429		397	394	457	385	365
	That	414	431	366	388	391	354	381
	difference	+15		+31	+6	+66	+31	−16

32 participants were excluded from reaction time analyses because they claimed to identify the prime word on 50% or more of the trials. These 4 subjects were analyzed separately and are reported at the end of the results section.

The remaining 28 participants reported identifying the prime words on an average of 4.8% of the trials (range of 0 to 25%). Table 2 presents their mean self-paced reading times for each of the word positions, beginning with the main verb, for each of the four conditions. Within each word position, reading times beyond 2.5 *SD* of the mean for each subject were adjusted to 2.5 *SD*, affecting less than 3% of the data. For convenience, the ambiguity effect for each word position (ambiguous minus unambiguous reading times) is graphically illustrated in Fig. 1. As can be seen in the figure, the magnitude of the ambiguity effects was much greater for DO-Primes as compared to SC-Primes in the sentence complement region. Thus, the ambiguity effect associated with ambiguous sentence complements was substantially reduced when the matrix verb was primed with a verb that prefers a sentence complement.

Analyses by Word Position

For each word position, subject and item means were entered into separate analyses of variance (ANOVAs) with three factors: Prime Type (DO-Prime, SC-Prime); Ambiguity (No-that, That); and the presentation List or item Grouping factor (4 lists in the subject analysis and 4 item groups in the item analysis). All analyses of variance of reading time data in this paper were conducted on reading times adjusted for string length. Reading times for each subject were entered into a separate regression analysis with reading time as the dependent variable and string length as the independent variable (see Ferreira & Clifton, 1986; Trueswell, Tanenhaus, & Garnsey, 1994). Residual reading times were computed and used in the ANOVA. The results of these ANOVAs are presented below. Because string length was controlled, the statistical patterns reported below as significant were also statistically significant in analyses of unadjusted reading times.

The main verb. There were no significant differences at the main verb (e.g., ''accepted''). Reading times for verbs primed with DO-Primes were on average 30 ms longer than verbs primed with SC-Primes, but this difference was only marginally significant in the item analysis, $F1(1,24) = 1.18$; $F2(1,12) = 3.84$, $p < .08$.

The complementizer. The optional complementizer ''that'' appeared in only the Unambiguous materials. There was little difference between DO-Prime and SC-Prime conditions, resulting in no significant effect of Prime Type, Fs < 1.

The determiner. At the determiner ''the,'' reading times for the ambiguous (No-that) condition were on average 26 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity in the subject analysis and a marginally significant effect of

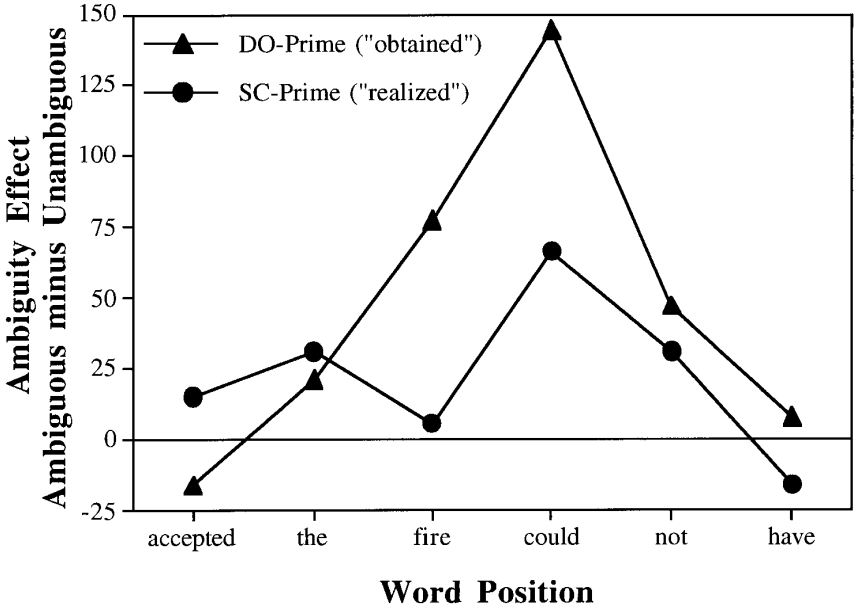

FIG. 1. Mean ambiguity effects in milliseconds (reading times for ambiguous sentence complements minus reading times for unambiguous sentence complements) for each word position (Experiment 1).

ambiguity in the item analysis, $F1(1,24) = 4.95$, $p < .05$; $F2(1,12) = 4.47$, $p < .06$.

The noun. At the noun (e.g., ''fire''), reading times for the ambiguous (No-that) condition were on average 42 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,24) = 9.98$, $p < .01$; $F2(1,12) = 10.88$, $p < .01$. As seen in Table 2, this effect of Ambiguity was carried by the DO-Primes, resulting in a significant interaction between Prime-Type and Ambiguity, $F1(1,24) = 7.07$, $p < .05$; $F2(1,12) = 4.82$, $p < .05$. Simple effects revealed that the +77 ms effect of ambiguity for DO-Primes was significant, $F1(1,24) = 11.51$, $p < .01$; $F2(1,12) = 9.48$, $p < .05$, and the +6 ms effect of ambiguity for SC-Primes was not significant, Fs < 1. In addition, effects of priming were found only in the Ambiguous (No-that) conditions, resulting in a significant effect of Prime-Type for Ambiguous sentence complements, $F1(1,24) = 9.34$, $p < .01$; $F2(1,12) = 6.83$, $p < .05$, and no effect of Prime-Type for Unambiguous (That) sentence complements, Fs < 1.

The disambiguating verb (DV). At the DV (e.g., ''could''), reading times for the ambiguous (No-that) condition were on average 105 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,24) = 18.91$, $p < .01$; $F2(1,12) = 13.40$, $p < .01$. As seen in Table 2, this effect of Ambiguity was largely carried by the DO-Primes, resulting in an interaction between Prime-Type and Ambiguity that was significant in the item analysis and marginally significant in the subject analysis, $F1(1,24) = 3.15$, $p < .09$; $F2(1,12) = 5.91$, $p < .05$. Thus, the large ambiguity effect was reduced when the main verb was primed with a SC-Prime. Simple effects revealed that the +144 ms effect of ambiguity for DO-Primes was significant, $F1(1,24) = 16.74$, $p < .01$; $F2(1,12) = 15.22$, $p < .01$, and the +66 ms effect of ambiguity for SC-Primes was also significant, $F1(1,24) = 4.60$, $p < .05$; $F2(1,12) = 5.27$, $p < .05$. In addition, effects of priming were found only in the Ambiguous (No-that) conditions, resulting in a marginal effect of Prime-Type for Ambiguous sentence complements in the item analysis, $F1(1,24) = 2.34$; $F2(1,12) = 4.17$, $p < .07$, and no effect of

Prime-Type for Unambiguous (That) sentence complements, $F1(1,24) = 2.21$; $F2(1,12) = 1.92$.

DV + 1. At the next word (e.g., ''not''), reading times for the ambiguous (No-that) condition were on average 39 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,24) = 10.11$, $p < .01$; $F2(1,12) = 5.99$, $p < .05$.

DV + 2. There were no significant differences at the next word position (e.g., ''have'').

Participants Who Identified Primes

In postexperiment interviews, four participants reported identifying the primes on 50% or more of the trials. Two factors are likely to explain this phenomenon. First, it is well known that there are individual differences in the perceptual identification of briefly displayed material (e.g., Brown & Hagoort, 1993). Although we did not directly measure perceptual sensitivity in our participants, it is likely that these four participants had higher sensitivity to brief displays. Second, it is very likely that these four subjects attempted to ''search'' for primed words in the text. Indeed, one of the four participants admitted that he went against the experimenter's instructions and hunted for primes in the material, pausing on primed words. This conclusion is supported by the reading time pattern for these four participants. Mean reading time on the main verb (the primed word) was 557 ms, which is substantially longer than the grand mean of 459 ms for these four participants and the 436 ms mean reading time on the verb for the remaining 28 participants.

It is interesting to note that these four participants instead showed inhibitory effects of subcategorization preferences on parsing. Table 3 presents the mean reading times at the DV region. As can be seen in the table, SC-Primes showed a much larger Ambiguity effect than DO-Primes. This is consistent with some prior priming experiments which suggest that primes slightly above the threshold of identification may eliminate facilitation effects and could possibly induce effects of inhibition (Carr & Dagenbach, 1990; Dagenbach, Carr, & Wilhelmsen, 1989; see also Sereno & Rayner, 1992 for a similar account of fast primes with longer durations). The results presented here however are at best suggestive, because they come from such a small subset of participants.

TABLE 3

Experiment 1: Mean Reading Times in Milliseconds at the Disambiguating Verb, for the Four Participants Who Identified Primes

	Ambiguity		
Prime-Type	No-That	That	Difference
DO-Prime	479	435	+44
SC-Prime	561	461	+100

Discussion

The subcategorization preferences of a briefly flashed prime word had an impact on the processing difficulty associated with ambiguous sentence complements. DO-Primes showed much larger garden-path effects than SC-Primes, suggesting that readers' parsing preferences were affected by information that was retrieved during the earliest stages of recognizing the matrix verb. Moreover, all of these results were obtained from readers who reported that they rarely, and in many cases never, identified the primes. Thus, the differences in processing difficulty stemmed from experimental conditions that were otherwise perceptually identical to the readers.

There are certain aspects of these findings that are worth highlighting. First, all effects of priming appeared in the ambiguous and not the unambiguous items. The descriptive statistics and ANOVAs support this observation. Thus, it is reasonable to conclude that the primes affected processes having to do with syntactic ambiguity resolution. For instance, one cannot argue that the effects were due to the prime word fitting into the sentence as a whole—compare ''The photographer obtained the fire could not have been prevented'' to ''The photographer realized the fire could

not have been prevented.'' If this were the case, one would expect similar priming effects for unambiguous sentences—compare ''The photographer obtained that the fire could not have been prevented'' to ''The photographer realized that the fire could not have been prevented.'' The fact that the effects of priming occurred in only the ambiguous conditions strongly supports the conclusion that the primes affected processes having to do with syntactic ambiguity resolution and that the earliest stages of recognizing a verb included activating information pertaining to lexical argument structure.

There are, of course, some basic questions left unanswered by this result. For instance, given the design of the present experiment, it is unclear whether effects of priming were due to DO-Primes increasing the garden-path effect, SC-Primes reducing the garden-path effect, or both of these possibilities. This issue was addressed in Experiment 2 by including a condition in which the matrix verb was not preceded by a verb, but was instead preceded by a string of letters that was not an acceptable word of English. Differences between these three conditions were then used to assess the relative contribution of DO-Primes and SC-Primes.

EXPERIMENT 2

There were two major differences between this experiment and Experiment 1. First, this experiment included a baseline priming condition in which nonword primes were used. Second, an additional set of target sentences were constructed and included in the design. The nonword priming condition was added to reveal how processing proceeds for primes that are not strongly associated with any particular verb argument structure. The additional target sentences were constructed to provide more power to the experimental design, which included six conditions (a 3×2 design), as compared to four conditions (a 2×2 design) in the previous experiment.

The results of this experiment were expected to replicate those of the previous experiment. In particular, the reading time data were expected to reveal a larger ambiguity effect for DO-Primes than for SC-Primes. The size of the ambiguity effect for sentences with nonword primes (NW-Primes) should tell us whether DO-Primes increased processing difficulty or SC-Primes decreased processing difficulty, or whether both of these possibilities were at work. An inspection of corpus results suggests the expected pattern (see Table 1). DO-Prime verbs have a stronger preference for the direct object alternative than do the target verbs, whereas SC-Primes have a stronger preference for the sentence complement alternative than do target verbs. Thus, if NW-Primes make little or no contribution to determining parsing preferences, we ought to expect ambiguous NW-Prime sentences to fall in between DO-Prime and SC-Primes sentences. DO-Primes should increase the garden-path effect, and SC-Primes should decrease the garden-path effect, relative to the NW-Prime baseline.

Method

Participants

Forty-two participants from the University of Pennsylvania volunteered for the experiment. They received extra course credit or were paid for their participation. All participants were native speakers of English.

Procedure

The procedure, equipment, and display characteristics of the stimuli were the same as those reported in Experiment 1.

Materials

The materials were the same as those used in Experiment 1, with the following exceptions. First, two additional target-prime verb pairs were added, resulting in a total of 18 target-prime pairs. Second, two sets of target sentences were created for each new target verb, and a second target sentence was created for each old target verb, resulting in 36 items total. Thus, 16 target sentences were the same as those used in Experiment 1. The new items were modified from a set developed by Susan

Garnsey for other experimentation (Garnsey, personal communication). Third, each target item was paired with a Nonword prime consisting of a random letter string of the same length as the matrix verb (e.g., target verb ''accepted,'' DO-Prime ''obtained,'' SC-Prime ''realized,'' and NW-Prime ''lxodoged''). All primes contained the same amount of letter overlap with the target.

Six presentation lists were constructed by randomly combining the 36 target trials with 90 distractor trials. Within a presentation list, 12 target items were primed with a DO-Prime, 12 target items were primed with a SC-Prime, and 12 target items were primed with a NW-Prime. For each of these types of primes, 6 items were ambiguous sentence complements and 6 were unambiguous sentence complements. Each target item was then rotated through these six conditions, generating six different presentation lists. As in the first experiment, the string length of the ambiguous NP and disambiguating VP were counterbalanced across conditions. All distractor trials contained a primed word. Primes and prime positions on distractor trials had properties similar to Experiment 1, except that 20% of primes were nonwords. Each target trial was followed by at least one distractor trial. Each participant was presented with 10 practice trials and one of the six presentation lists and given a break in the middle of the experiment. The entire experiment, including instructions and practice, lasted about one hour.

Results

All subjects scored better than 90% correct on the comprehension questions.[1] All subjects reported identifying primes on less than 15% of the trials, with a mean of 1%, and a range of 0 to 12%.

Table 4 presents mean reading times for each of the word positions, beginning with the main verb, for each of the four conditions. Within each word position, reading times beyond 2.5 *SD* of the mean for each subject were adjusted to 2.5 *SD*, affecting less than 3% of the data. For convenience, the ambiguity effect for each word position (ambiguous minus unambiguous reading times) is graphically illustrated in Fig. 2. As can be seen in the figure, the Ambiguity effect in the disambiguating verb region was larger for DO-Primes as compared to SC-Primes. The Ambiguity effect for NW-Primes was in between those found DO-Primes and SC-Primes.

Analyses by Word Position

For each word position, subject and item means for residual reading times were entered into separate analyses of variance (ANOVAs) with three factors: Prime Type (DO-Prime, SC-Prime, NW-Prime); Ambiguity (No-that, That); and the presentation List or item Grouping factor (6 lists in the subject analysis and 6 item groups in the item analysis). The results of these ANOVAs are presented below.[2] Because string length was controlled, the statistical patterns reported below as significant were also significant in analyses of unadjusted reading times.

The main verb. At the main verb (e.g., ''accepted''), the mean reading time for the DO-Prime condition (456 ms) was longer than the NW-Prime (442 ms) which was longer than the SC-Prime (424 ms), resulting in a significant effect of Prime Type, $F1(2,72) = 5.46$, $p < .01$; $F2(2,60) = 3.62$, $p < .05$. Two-tailed *t* tests were conducted on both the subject and item means, comparing these conditions. The 32 ms difference between DO-primes and SC-Primes was significant, $t_1(41) = 3.51$, $p < .01$; $t_2(35) = 3.00$, $p < .01$. The 18 ms difference between SC-Primes and NW-Primes was significant in subject analysis only, $t_1(41) = 2.10$, $p < .05$; $t_2(35) = 1.42$. And, the 14 ms difference between DO-Primes and NW-Primes was not significant, $t_1(41) = -1.07$; $t_2(35) = 1.22$.

[1] Four subjects (not reported here) did poorly on comprehension questions and were not included in the experiment.

[2] Due to a labeling error, item 16b was presented in the incorrect condition in the sixth presentation list (unambiguous instead of ambiguous). The missing item cell was therefore replaced with the subject's grand mean. No other errors appeared in the lists.

TABLE 4

Experiment 2: Mean Reading Times in Milliseconds for Each Word Position

Prime-Type	Ambiguity	Word position						
		accepted	(that)	the	fire	could	not	have
DO-Prime	No-that	460		388	391	463	380	380
	That	452	412	365	390	386	359	387
	difference	+8		+23	+1	+77	+21	−7
SC-Prime	No-that	411		380	388	423	373	379
	That	436	395	362	381	394	359	383
	difference	−25		+18	+7	+29	+14	−4
NW-Prime	No-that	440		373	387	439	373	375
	That	444	397	353	375	385	351	371
	difference	−4		+20	+12	+54	+22	+4

The complementizer. The optional complementizer ''that'' appeared in only the Unambiguous materials. Reading times for the DO-Prime condition were slightly longer than reading times for the SC-Prime and NW-Prime conditions. However, there was no significant effect of Prime Type, $F1(1,24) = 1.09$; $F2(1,12) = 1.11$.

The determiner. At the determiner (''the''), reading times for the ambiguous (No-that) condition were on average 20 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,36) = 10.86$, $p < .01$; $F2(1,30) = 9.70$, $p < .01$. There was also a small effect of Prime Type, which was marginally significant only in the

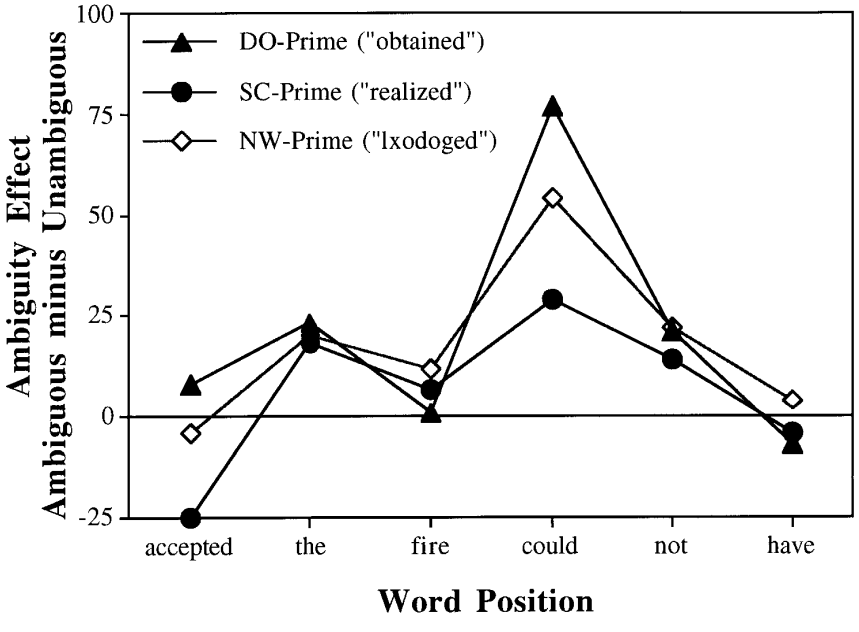

FIG. 2. Mean ambiguity effects in milliseconds (reading times for ambiguous sentence complements minus reading times for unambiguous sentence complements) for each word position (Experiment 2).

subject analysis, $F1(2,72) = 2.62$, $p < .09$; $F2(2,60) = 2.10$.

The noun. At the noun (e.g., ''fire'') there were no significant effects or interactions.

The disambiguating verb (DV). At the DV (e.g., ''could''), reading times for the ambiguous (No-that) condition were on average 54 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,36) = 26.04$, $p < .01$; $F2(1,30) = 19.77$, $p < .01$. As seen in Fig. 2, this effect of Ambiguity was largest for DO-Primes and smallest for SC-Primes with NW-Primes in the middle, resulting in an interaction between Prime-Type and Ambiguity, which was significant in the item analysis and marginally significant in the subject analysis $F1(2,72) = 2.68$, $p < .08$; $F2(2,60) = 3.19$, $p < .05$. In addition, a reliable interaction between Prime-Type and Ambiguity was observed for the two word prime conditions, DO- and SC-Prime, $F1(1,36) = 6.43$, $p < .05$; $F2(1,30) = 5.73$, $p < .05$, replicating the pattern observed in the first experiment.

Simple effects revealed that the effect of Ambiguity was reliable within DO-Prime and NW-prime conditions (DO-Prime: $F1(1,36) = 18.57$, $p < .01$, $F2(1,30) = 19.34$, $p < .01$; NW-Prime: $F1(1,36) = 9.43$, $p < .01$; $F2(1,30) = 12.58$, $p < .01$), but was significant only in the subject analysis for SC-Primes ($F1(1,36) = 5.50$, $p < .05$; $F2(1,30) = 3.09$, $p < .09$). Finally, as can be seen in the table, differences between priming conditions showed up only in the Ambiguous (No-That) materials. Two-tailed t tests comparing the priming conditions of the Ambiguous materials revealed that the +40 ms difference between the DO-Prime and SC-Prime conditions was significant, ($t_1(41) = 2.31$, $p < .03$; $t_2(35) = 2.57$, $p < .02$), but that the +25 ms difference between the DO-Prime and NW-Prime, and the −20 ms difference between the NW-Prime and SC-Prime, were not significant (DO- vs NW-Prime: $t_1(41) = 1.58$, $t_2(35) = 1.59$; NW- vs SC-Prime: $t_1(41) = 0.80$; $t_2(35) = 1.06$). Mean reading times for the Unambiguous materials were all within 9 ms of each other, resulting in no significant differences between primes.

DV + 1. At the next word (e.g., ''not''), reading times for the ambiguous (No-that) condition were on average 19 ms longer than the unambiguous (That) condition, resulting in a significant effect of Ambiguity, $F1(1,36) = 16.71$, $p < .01$; $F2(1,30) = 7.56$, $p < .05$.

DV + 2. There were no significant differences at the next word position (e.g., ''have'').

Discussion

The subcategorization preferences of primes were found to influence the parsing preferences of readers. DO-Prime sentences showed evidence of processing difficulty in the ambiguous sentence complement, whereas SC-Prime sentences showed significantly less signs of processing difficulty. The results of the baseline priming condition (NW-Primes) suggested that both DO-Primes and SC-Primes were contributing to the processing differences for the ambiguous sentence complements. At the disambiguating verb, DO-Primes showed the largest effect of ambiguity (+77 ms), NW-Primes showed the second largest effect (+54 ms) and SC-Primes showed the smallest effect (+29 ms), resulting in an interaction between Ambiguity and type of Prime. Priming effects resided in the ambiguous sentences, showing a reliable difference between the DO-Prime and SC-Prime conditions in this position. Similar comparisons with NW-primes were suggestive but statistically unreliable. Such a pattern might be expected, given that NW-Primes fell in between DO-Primes and SC-Primes.

Thus, the general pattern of priming found in Experiment 1 was replicated in Experiment 2. However, there were also some important differences between the results of the two experiments. In particular, Experiment 1 found an ambiguity effect at the noun position for DO-Primes, which was greatly reduced for SC-Primes. Experiment 2 found no ambiguity effect at the noun for any of the priming conditions, including NW-Primes. There are a few possible explanations for this difference between the experiments. First, Experiment 2

included additional target sentences not tested in Experiment 1. It is therefore possible that these new items masked an effect at this position. Perhaps the new sentences contained nouns that were slightly more plausible direct objects. However, no reliable effects or interactions are found at the noun even when using just the 16 items that had been repeated from Experiment 1. Thus, differences in the materials cannot explain the lack of an effect at the noun.

One revealing aspect of this data is that NW-Primes also showed no ambiguity effect at the noun. This suggests that any transience of effects at the noun does not have to do with lexical priming, but rather is a general difference in how readers in this experiment reacted to the ambiguous noun. The NW-Prime condition ought to map best onto the self-paced reading findings of Garnsey et al. (1997) who did not use any lexical priming. However, Garnsey et al. found a reliable increase in reading times at the noun for implausible objects in the ambiguous condition. We therefore suspect that the lack of an immediate effect at the noun in the present experiment is an artifact of self-paced reading, which is known to sometimes show effects one word later than expected. The reason for the difference between the two experiments may be that participants in Experiment 2 were asked to read approximately twice as many trials as compared to participants in Experiment 1. Thus, participants may have become somewhat ''numb'' to the self-paced reading task, causing some delay in reacting to unexpected words.

It is also important to note that reading times at the matrix verb in Experiment 2 showed reliable signs of facilitation when it was primed with a SC-Prime as compared to when it was primed with a DO-Prime. This difference was also present in Experiment 1, but it was not statistically significant. This pattern might suggest a semantic component to the priming effects. Although we will postpone a full discussion of this issue until the general discussion, we note here that there exist close ties between the kinds of syntactic complements that a verb takes and the semantic properties describing the event or action (e.g., see Fisher, Gleitman, & Gleitman, 1991; Levin, 1993; Pinker, 1989). Thus, SC-Primes are expected to overlap semantically with target verbs more than DO-Primes; e.g., both SC-Primes and target verbs tend to be verbs of communication or propositional attitude, because both permit sentence complements. It is difficult however to take the position that semantic priming alone explains the effects on syntactic ambiguity resolution. For instance, one may wish to take the position that increased semantic overlap made the sentence complements of SC-Prime sentences easier to process. However, such an account would predict similar facilitation for unambiguous sentence complements, which did not occur. Thus, as explained further in the discussion, the data pattern suggests a more sophisticated notion of semantic overlap, in which the information pertains to both semantic and syntactic aspects of argument structure preferences.

In sum, Experiment 2 replicated the general findings of Experiment 1 regarding effects of primes on syntactic ambiguity resolution. DO-Primes showed larger garden-path effects than SC-Primes. The inclusion of nonword primes suggested that both DO-Primes and SC-Primes were affecting ambiguity resolution. Moreover, this replication used a large set of new target sentences, suggesting that the priming effects are fairly stable under this prime duration.

GENERAL DISCUSSION

The current findings indicate that the fast priming technique holds promise as a tool for studying how lexical information is structured for use in on-line sentence interpretation. In previous studies, fast priming was used to study a prime's impact on on-going lexical processes (e.g., Sereno & Rayner, 1992). The current research suggests that the same technique can be used to study automatic lexical contributions to on-going syntactic and interpretive processes.

The experiments revealed that the argument preferences of a briefly displayed prime

can affect syntactic ambiguity resolution. This finding is consistent with prior research that has found rapid effects of lexical preference on both syntactic ambiguity resolution and speeded sentence judgments (Boland et al., 1995; Garnsey et al., 1997; McElree, 1993; McElree & Griffith, 1995; Trueswell et al., 1993; Trueswell, 1996). In addition to supporting these results, the fast priming data allow us to address some important issues raised in the introduction about the time course of processing. The brief duration of the prime allows us to infer that fast priming effects arise from processes occurring during the earliest stages of recognizing a verb (the first 39 ms). This strongly supports the hypothesis that information pertaining to argument structure is activated very early in word recognition. It also suggests that this lexical information influences the earliest stages of sentence parsing. This second inference is not conclusive—lexical argument structure could conceivably be active early but used later—but we eschew a delayed-use explanation and discuss it in more detail later in this section. Finally, the data indicate that effects of argument preference are due to automatic lexical processes and are unlikely to be due to possible experiment-specific strategies developed by the reader. Readers reported that they rarely identified prime words, yet systematic effects of these primes were revealed in how easily readers resolved the temporary syntactic ambiguity. A strategic account of lexical preferences is therefore placed in the difficult position of explaining how the grammatical information of a brief stimulus, which was typically perceived as a flicker, determined readers' commitments to interpretation (see also Sereno & Rayner, 1992).

Implications for Theories of Sentence Processing

The current results clearly encourage the development of sentence processing theories that emphasize the lexicalization of grammatical information (e.g., Ford, Bresnan, & Kaplan, 1982; Gorrell, 1991; MacDonald et al., 1994; Trueswell & Tanenhaus, 1994). For instance, the findings are compatible with the constraint-based lexicalist theory outlined in the introduction. Under this view, the recognition of a verb activates combinatory syntactic and semantic information that allows the processing system to make partial commitments to interpretation (see MacDonald et al., 1994; Trueswell et al., 1993; Trueswell & Tanenhaus, 1994). This theory provides a natural framework for explaining the results, in which priming effects are the result of overlapping grammatical properties of prime and target verbs. In particular, we assume that word recognition includes the activation of invariant syntactic features capable of representing any word's combinatory syntactic properties (see also MacDonald et al., 1993; Kim, Srinivas, & Trueswell, 1997). Similarly, a semantic combinatory system is proposed, in which thematic roles are characterized as clusters of event properties (see Dowty, 1989; Tabossi, Spivey-Knowlton, McRae, & Tanenhaus, 1996). Given that both of these classes of information are highly relevant for processing a word in a sentence, this information should be computed as quickly as possible to help readers converge on the most likely interpretation of the phrase or sentence. Previous findings only required that these classes of information be activated rapidly enough to affect syntactic ambiguity resolution. The current findings suggest that lexical argument structure is a central component of lexical processes, in that this information is activated during the very early stages of encountering a word.

The priming results are, on the other hand, problematic for the family of theories that propose a lexically blind stage of initial syntactic processing (i.e., the ''lexical-filtering theories''; Frazier, 1989; Frazier & Clifton, 1996; Mitchell, 1989; Mitchell et al., 1995). Such theories predict that for the DO/S ambiguity, the direct object alternative is pursued initially for all verbs, because the parser is unable to use lexically specific preferences to inform initial commitments. Lexical preferences can only be used to evaluate and revise initial pars-

ing commitments. Under this account, there are two potential explanations for why the parser does not initially use lexical information. One possibility is that argument structure is not activated during word recognition and therefore not available to the parser. This explanation is clearly inconsistent with the current findings, which show that this information is activated immediately. Another possibility is that syntactic processes are encapsulated from on-going lexical processes and cannot use lexical information to determine initial commitments (e.g., Frazier, 1987). Thus, even though argument structure information is activated during word recognition, it is unavailable to guide parsing commitments and is not consulted until a revision stage can occur. This second account is in principle consistent with the current findings, because SC-primes did not completely eliminate processing difficulty for ambiguous complements. However, this account faces serious experimental and theoretical challenges. In particular, prior evidence of rapid effects of lexical preference (e.g., Garnsey et al., 1997; Trueswell et al., 1994; Trueswell, 1996) requires that parsing revisions happen so quickly that in some cases they are undetectable by any available measure of reading time (Frazier & Clifton, 1996). Even on this position, lexical filtering does not easily account for the fast priming results. On an account in which the processing of detailed lexical information is independent from parsing processes until some delayed stage, one would expect that by the time the parser consults lexical information, it would receive a stable and accurate representation of the target verb. The transient presentation of a prime seems an unlikely candidate for affecting a delayed stage of processing. The lexical filtering approach must therefore assume a very close temporal link between lexical and syntactic processes, raising serious doubts about the existence of an initial stage of lexically blind syntactic processing.

Implications for Lexical Representation

In addition to addressing issues related to the time course of processing, the current findings raise certain questions about the nature of lexical representations and their use in sentence interpretation. One question that arises from our results is whether the representations being primed are syntactic or semantic in nature. Our treatment of the lexical preferences has been essentially a syntactic one, in that we have classified verbs in terms of the frequency that they appear with certain syntactic complements. However, an account of the data could be provided that relies on the priming of thematic roles rather than subcategorization frames. In particular, DO-Primes could facilitate an expectation for a Theme role, and SC-Primes could facilitate an expectation for the Proposition role. These expectations could explain the preferences in interpretation observed in the present experiments, because the Theme and Proposition roles tend to correspond to the noun phrase complement and sentence complement, respectively. An exclusively thematic proposal of this sort would be consistent with the findings of Shapiro and colleagues that thematic role information and not subcategorization information is activated during word recognition (e.g., Shapiro et al., 1989), but would be inconsistent with the McElree findings of earlier activation of subcategorization information (McElree & Griffith, 1995).

Similarly, many researchers have noted the close ties between the kinds of syntactic complements that a verb takes and the semantic properties describing the event or action (e.g., see Fisher, Gleitman, & Gleitman, 1991; Levin, 1993; Pinker, 1989)—e.g., verbs that denote events involving ''transfer'' typically appear with two syntactic complements. Thus, one may wish to propose an account of the current findings that focuses on the semantic properties of events, so long as the properties being primed implicitly encode possible argument structures. Crucially, such an account would also need to explain how these semantic properties map onto each verb's particular preferences for certain syntactic complements over others. To do this, a processing theory

would need to be developed that parallels the linguistic literature on the relationship between event structure and syntactic structure (e.g., Levin, 1993; Pinker, 1989). Verbs could be ambiguous with respect to certain semantic features (e.g., ''transfer,'' ''impact,'' and ''perception''), and the relative availability of these features could translate into preferences for certain syntactic and thematic relationships.

We believe, however, that prior experimental results indicating that syntactic ambiguity resolution can be affected by thematic role preferences (e.g., Tabossi et al., 1994; Trueswell et al., 1994), subcategorization preferences (e.g., Holmes et al., 1989, Trueswell et al., 1993), and the interaction between the two (e.g., Garnsey et al., 1997; Trueswell, 1996), make it reasonable to propose that both syntactic and semantic combinatory information are activated in parallel during word recognition and that the current priming effects are the result of both of these processes. Although this position cannot be verified by the current results, it is possible to test this hypothesis experimentally. In particular, the semantic properties of fast primes could be manipulated to examine their impact on syntactic ambiguity resolution. For instance, prime verbs can be used that have exceptional dissociations between their semantic/thematic preferences and their syntactic/subcategory preferences. Moreover, syntactic accounts can be tested by examining what contribution the argument-taking properties of nouns have on the processing verbs. For instance, how would the noun prime ''idea,'' which can take a sentential complement, affect the processing of verbs that also take sentence complements?

Again, we suspect that both thematic and syntactic properties of lexical items are activated quite rapidly and both contribute to the fast priming effects. One important caveat is that the rate at which lexical properties are computed should depend upon the strength of the association between input stimulus and information of interest. Moreover, as previous studies of syntactic ambiguity resolution have found, it is important to consider the relevance of these sources of information for resolving the particular ambiguity (e.g., Trueswell et al., 1994). Thus, the extent to which a briefly displayed prime word affects syntactic ambiguity resolution should depend upon three factors: the rate at which the priming stimulus activates argument structure features; the degree to which these features overlap with the target; and the extent to which these features are relevant for resolving the syntactic ambiguity. In this context, we note that McElree and Griffith (1995) have provided evidence from the speed-accuracy trade-off paradigm that detection of subcategorization violations have a slightly faster time course than do thematic role violations. One is likely to find a corresponding effect using fast-priming—stronger effects of a prime's subcategory preferences as compared to a prime's thematic preferences. However, such effects are expected only if the prime's subcategorization preferences are more informative to syntactic ambiguity resolution than the prime's thematic preferences. Conditions in which thematic preferences are more informative should yield the opposite result, in which thematic preferences are the main contributor to priming effects.

Closing Remarks

In sum, we have provided evidence that effects of lexical preference on syntactic ambiguity resolution stem from processes occurring during the early stages of encountering a verb. The effects encourage the development of language processing theories that place great emphasis on the detailed grammatical contributions of lexical items. The presence of a lexical intervention technique for silent reading opens up several avenues for research in the field of sentence processing. Further manipulation of the structural and semantic properties of fast primes within syntactically ambiguous phrases is likely to yield a more detailed understanding of exactly how lexical information is organized and used to inform

syntactic processes. Finally, it will be important to conduct similar fast priming studies using techniques that are more sensitive to subtle differences in reading times, such as the use of eye-tracking. We are currently exploring this (Kim, Garnsey, & Trueswell, in progress). Such an approach could be used to examine in more detail how processes occurring at the primed verb relate to processes occurring at the point of syntactic disambiguation. We suspect that such results would be quite useful for developing a better understanding of the relationships between the levels at which language is represented and processed.

APPENDIX 1: TARGET SENTENCES AND PRIMES FOR EXPERIMENTS 1 AND 2.

All target sentences are given in the unambiguous form (i.e., with a ''that''). For Experiment 2, two target sentences were generated for each main verb. The target sentences from Experiment 1 are indicated with ''E1.'' The three different primes are listed after each sentence pair, in the order of DO-Prime, SC-Prime, and NW-Prime. Experiment 1 did not use the NW-Primes.

1a. The talented photographer accepted that the fire could not have been prevented. (E1)

1b. The basketball star accepted that the managers would have to be strict. (obtained, realized, lxodoged)

2a. The experienced lawyer advised that the contract would need some changes. (E1)

2b. The local veterinarian advised that the horse should be prevented from running. (handled, worried, acmdged)

3a. The newspaper editor advocated that the town needed to be cleaned up. (E1)

3b. The new mayor advocated that the disaster could be avoided by a financial austerity plan. (possessed, responded, wljjbened)

4a. The concerned priest asserted that the morning would be the best time for making the decision about the sick child. (E1)

4b. The angry customer asserted that the salesman should be fired for lying about products. (prepared, supposed, kmzdfyed)

5a. The CIA director confirmed that the money should have been managed better. (E1)

5b. The coast guard confirmed that the sailor could not have been rescued. (witnessed, pretended, rtygyzued)

6a. The scuba diver discovered that the headache was caused by lack of oxygen. (E1)

6b. The French explorers discovered that the thunder had caused a mountain avalanche. (influenced, complained, hdwtfdhhed)

7a. The young campers forgot that the mountains could be very cold at night. (E1)

7b. The substitute forecaster forgot that the sky would be cloudy and gray. (killed, wished, kldled)

8a. The new owners insured that the river would never flood their basement. (E1)

8b. The cautious driver insured that the police would not find his car suspicious. (changed, decided, ywwrted)

9a. The alert detective learned that the witness was planning to leave town. (E1) precise.

9b. The chemistry student learned that the invention could have made measurement much more. (dropped, assumed, tjmnced)

10a. The confident engineer maintained that the debate would be easy to win.

10b. The devoted caretaker maintained that the season was causing his chronic allergies. (fascinated, postulated, hhrhokhled)

11a. The journal editor printed that the media had been irresponsible and cruel. (E1)

11b. The local publisher printed that the singer had not been accurately quoted. (touched, replied, ojomeed)

12a. The lab technician proposed that the water might be contaminated with sewage. (E1)

12b. The city planners proposed that the residents did not want another shopping mall. (replaced, insisted, yaitgped)

13a. The surgical nurses protested that the patients were not being treated well. (E1)

13b. The political group protested that the ocean had been polluted beyond legally allowed levels. (delivered, concluded, ugifhhxed)

14a. The French teacher repeated that the class should be finished by Friday.

14b. The armed gunman repeated that the wallet was not enough for him. (confused, promised, pqdgzaed)

15a. The attorney general revealed that the state was planning to crack down on drunken driving. (E1)

15b. The oil company revealed that the river had been contaminated by a highly toxic chemical. (employed, admitted, lsczoted)

16a. The frustrated tourists understood that the snow would mean a late start. (E1)

16b. The wise consumer understood that the lake was a very popular destination. (penetrated, speculated, osfzylwxed)

17a. The trained referees warned that the game would probably be canceled. (E1)

17b. The angry residents warned that the noise had disturbed every single weekend. (picked, proved, vdqied)

18a. The art critic wrote that the painting had been a clever forgery. (E1)

18b. The popular novelist wrote that the ring would change the structure of the story. (faced, hoped, chhed)

APPENDIX 2

Probability of Taking a Direct Object, Sentence Complement, or Other Complement, as Estimated from Corpus Counts

Verb	Direct object	Sentence complement	Other
DO-bias Target verbs			
accepted	.94	.03	.03
advised	.44	.09	.47
advocated	.80	.07	.13
asserted	.25	.58	.17
confirmed	.58	.36	.06
discovered	.46	.40	.14
forgot	.42	.16	.42
insured	.88	.05	.07
learned	.32	.39	.28
maintained	.71	.26	.03
printed	.94	.00	.06
proposed	.62	.11	.27
protested	.50	.12	.38
repeated	.83	.04	.12
revealed	.58	.35	.08
understood	.48	.37	.16
warned	.10	.51	.39
wrote	.46	.09	.44
DO-Prime verbs			
changed	.62	.00	.38
confused	.88	.00	.12
delivered	.91	.00	.09
dropped	.31	.00	.69
employed	.94	.00	.06
faced	.96	.00	.04
fascinated	1.00	.00	.00
handled	.97	.00	.03
influenced	.93	.00	.07
killed	.90	.00	.10
obtained	.97	.00	.03
penetrated	.92	.00	.08
picked	.76	.01	.23
possessed	.90	.00	.10
prepared	.42	.00	.58
replaced	.98	.00	.02
touched	.85	.00	.15
witnessed	1.00	.00	.00
SC-Prime verbs			
admitted	.29	.44	.28
assumed	.57	.39	.04
complained	.00	.46	.54
concluded	.22	.56	.23
decided	.07	.34	.59
hoped	.00	.44	.56
insisted	.00	.66	.34
postulated[a]	—	—	—
pretended	.00	.67	.33
promised	.32	.07	.61
proved	.19	.19	.62
realized	.30	.61	.08
replied	.04	.19	.77
responded	.00	.11	.89
speculated	.00	.68	.32
supposed	.00	.12	.88
wished	.06	.39	.55
worried	.18	.34	.48

Note. DO-Bias Targets and SC-Primes were originally selected based on sentence completion norms of Garnsey et al. (1997) and Trueswell et al. (1993). This is why there are some mismatches between experiment categorization and corpus counts (i.e., asserted, learned, warned, assumed, promised, and proved).

[a] ''Postulate'' never appeared in the corpus.

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