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 mantic 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 activa-

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 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

(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

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., ''ac-

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

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

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

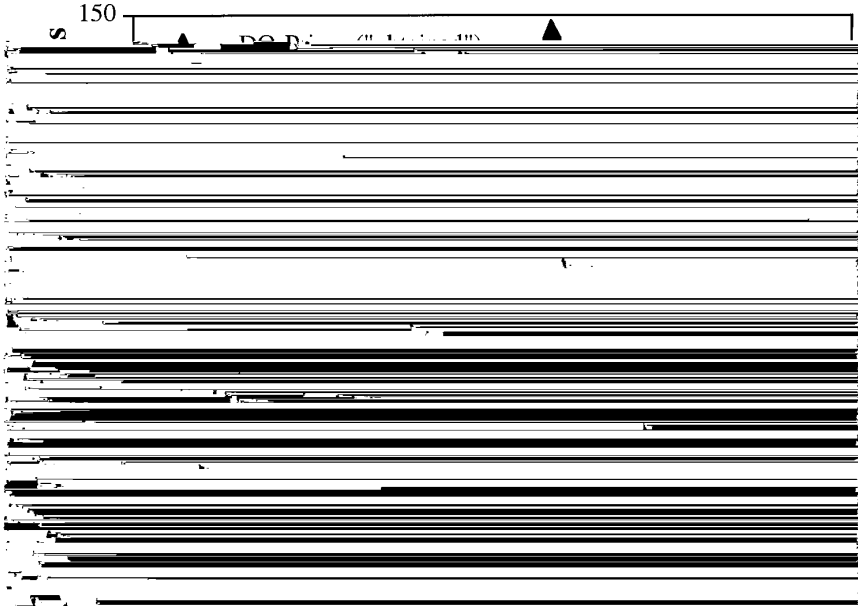

FIG. 1. Mean ambiguity effects in milliseconds (reading times for ambiguous sentence complements minus reading times for unambiguous sentence complements) for each word position (Experiment 1).

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 (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

not have been prevented.'' If this were the case, one would expect similar priming effects were expected to reveal a larger ambiguity effect for DO-Primes than for SC-Primes. The

TABLE 4

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

subject analysis, *F1*

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 hy-

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

ing commitments. Under this account, there findings raise certain questions about the na-

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 ambig ty 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 senten-

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)

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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