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Priming of Early Closure: Evidence for the Lexical Boost during Sentence Comprehension

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Abstract

Two self-paced reading experiments investigated priming in sentences containing “early” vs. “late closure” ambiguities. Early closure sentences impose relatively large processing costs at the point of syntactic disambiguation (Frazier & Rayner, 1982). The current study investigated a possible way to reduce processing costs. Target sentences were temporarily ambiguous and were disambiguated towards either the preferred “late” closure analysis or the dispreferred “early” closure analysis. Each target sentence was preceded by a prime that was either structurally identical or that required a different syntactic analysis. In Experiment 1, all of the prime sentences shared the same critical verb as the target (Arai et al., 2007; Carminati et al., 2008; Tooley et al., 2009, in press; Traxler et al., in press; Weber & Indefrey, 2009). In Experiment 2, verb repetition was eliminated by reorganizing the stimuli from Experiment 1. In Experiment 1, processing of the disambiguating verb was facilitated when an “early” closure target sentence followed an “early” closure prime. In Experiment 2, there were no significant priming effects, although an overall difference in processing time favored “late closure” targets. Combined analyses verified that the pattern of results in Experiment 1 differed significantly from Experiment 2. These experiments provide the first indication that “early” closure analyses can be primed and that such priming is more robust when a critical verb appears in both the prime and the target sentence. The results add to the body of data indicating a “lexical boost” for syntactic priming effects during comprehension. They have implications for theories of syntactic representation and processing (e.g., Boland & Blodgett, 2006; Vosse & Kempen, 2009; Sag et al., 2003).

Keywords

syntax; parsing; syntactic priming; syntactic ambiguity; unification grammar; usage-based grammar; head driven phrase structure grammar; lexical boost

Standard theories of language comprehension posit a key role for representations and processes at the level of the sentence (Chomsky, 1995; Frazier, 1979; Mitchell, 1987; Ford et al., 1982; Trueswell et al., 1993; Gibson & Warren, 2004; van Gompel, 2013). According to these accounts, syntactic processes mediate between word-level and sentence-level semantic representations. Contemporary studies have focused particularly on the nature of

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[V]The argument structure hypothesis predicts the lexical boost in double-object dative vs. prepositional-object dative priming. The evidence regarding comprehension priming for this type is mixed, as noted previously.

representations that underlie combinatory processing (Levelt, 1989; Branigan et al., 2005; Sag et al., 2003; Vosse & Kempen, 2009), the degree to which semantic interpretation depends on syntactic processing (e.g., Ferreira, 2003; Ferreira et al., 2002), and the nature and timing of interactions between prior knowledge and experience and processing based on "bottom-up" cues (MacDonald et al., 1994; Hale, 2011; Levy, 2008). Studies often emphasize the effects of contextual manipulations, because the degree to which a given stimulus evokes a particular syntactic configuration may depend on the likelihood of a given interpretation within a specific context (Altmann & Steedman, 1988; Tanenhaus et al., 1995).

Accounts that assign a role to contextual likelihood/conditional probability can be implemented in a number of ways, but however they are implemented, they must describe the mechanisms by which alternate syntactic analyses can rise and fall in prominence (otherwise a given syntactic analysis should always be preferred, given a specific collection of "bottom-up" syntactic cues). Some such accounts propose that combinatory syntactic information is associated with lexical items, that the strength of these associations can be modified by experience, and that contextual and lexical information are both consulted to determine the conditional probability of a syntactic analysis in a given instance (MacDonald et al., 1994; Spivey-Knowlton & Sedivy, 1998; Trueswell et al., 1994; van Gompel et al., 2001). Comprehenders may rely exclusively on lexically derived likelihood when a sentence is presented in isolation (within certain limits; Boland & Boehm-Jernigan, 1998; Boland & Blodgett, 2006). However, natural communication contexts provide a richer set of cues which may affect the way sentence-internal cues make contact with syntactic structure information.

Prior studies have identified a range of local (sentence-internal) and global (sentence-external) cues that influence processing of a range of syntactic structures. Some such studies have investigated sublexical frequency information (e.g., a verb may be more likely to appear with a sentence complement than a direct object; Trueswell et al., 1993), lexical semantics (e.g., that a particular noun may be a better or worse syntactic subject; Trueswell et al., 1994; Clifton et al., 2003), and contextual semantics (e.g., the degree to which a given syntactic analysis disambiguates reference; Altmann et al., 1992; Ni et al., 1996; Tanenhaus et al., 1995). Others have focused on the way syntactic knowledge develops (e.g., Tomasello, 2000; see Clark, 2009) and changes as the result of experience (Chang et al., 2000, 2012; Fitz et al., 2011).

Syntactic priming studies allow us to assess how one type of context affects sentence processing. Syntactic priming occurs when structural information from a prime sentence affects the way a subsequent target sentence is processed. *Syntactic priming* has been studied most extensively in production (Bock, 1986; Bock & Loebell, 1990; see Pickering & Ferreira, 2008). In production, comprehending or producing a target structure increases the likelihood that a participant will produce a matching structure in the near future (Bock, 1986; Bock & Loebell, 1990). In production, syntactic priming effects do not depend on prosodic, functional, or lexical repetition between prime and target expressions. However, the tendency to reproduce a target structure increases when a lexical item appears in both the prime and target expression (Pickering & Branigan, 1998). This *lexical boost* has been

interpreted as reflecting short-lived enhanced activity in pathways that connect lexical representations (*lemmas*) to representations that support combinatory operations (*combinatory nodes*). Currently, production priming is thought to respond to both short-term, lexically driven influences (Hartsuiker et al., 2008) and longer-term changes in the representational substrate driven by implicit learning processes (e.g., Chang et al., 2000, 2006).

Syntactic Priming in Comprehension

Classic studies of comprehension also purported to demonstrate the existence of syntactic priming (Carey, Mehler, & Bever, 1970). However, these early studies relied on mass repetition of particular syntactic structures, and did not necessarily demonstrate effects of syntactic repetition. They were vulnerable to alternative explanations, such as participant strategies and prosodic repetition (see also Noppeney & Price, 2004). More recent studies, however, also demonstrated effects of syntactic repetition during on-line comprehension and do not rely on mass repetition (Arai et al., 2007; Ledoux et al., 2007; Pickering & Traxler, 2004; Traxler, 2008b; Traxler & Pickering, 2005; Trueswell & Kim, 1998)[i]. In this kind of study, participants are typically exposed to a single prime sentence before responding to a target sentence.[ii] Responses have been gauged using eye-tracking (e.g., Tooley et al., 2009), the visual-world paradigm (e.g., Carminati et al., 2008), and event-related potentials (ERPs; e.g., Boudewyn et al., in press). These studies indicate that semantic repetition, by itself, is not sufficient for facilitated processing of syntactically challenging portions of sentences (Tooley et al., 2009).[iii] They indicate also that participant strategies are likewise not sufficient to facilitate processing of syntactically challenging portions of sentences (Traxler & Tooley, 2008; Traxler et al., in press).

To date, syntactic priming effects have been demonstrated for sentences containing reduced relatives (e.g., *The defendant examined by the lawyer was guilty*), double-object and prepositional-object datives (e.g., The pirate gave the princess the necklace; The pirate gave the necklace to the princess), “high-low” attachment ambiguities (e.g., The lumberjack chopped down the oak with the mushroom), and *modifier-goal* ambiguities (e.g., The girl dropped the blanket on the floor on the bed this morning) (Traxler et al., in press; Carminati et al., 2008; Thothathiri & Snedeker, 2008a, b; Boudewyn et al., in press; Traxler, 2008a). Some, but not all of these studies, also indicate that the lexical boost occurs in comprehension priming, as priming effects are sometimes larger when critical verbs are repeated across primes and targets. For example, Tooley and colleagues (2009) reported that both eye-tracking and ERP effects were larger when the initial verb in a reduced relative appeared in both a prime and a target sentence than when it did not (see also Traxler et al., in press). By contrast, the lexical boost has not been shown for modifier-goal ambiguities

[i]Recent studies have also demonstrated that exposure to a prime sentence that has a given structure can influence the final interpretation assigned to a subsequent globally ambiguous sentence (Branigan et al., 2005; Raffray & Pickering, 2010).
[ii]Trueswell & Kim’s study involved a fast priming manipulation, in which a subliminally presented verb either did or did not match the subcategory preference of a fully visible verb. Reading times were shorter when the two verbs had congruent subcategory preferences.
[iii]*Semantic repetition*, in this case, refers to the simple fact that when two adjacent sentences contain the same verb, they are referring to similar actions. It is possible that when two sentences refer to the same action (e.g., “examining”), the second could be easier to process than the first because the conceptual knowledge associated with the referenced event is already activated.

(Traxler, 2008a). Some studies involving double-object and prepositional-object datives have produced evidence for the lexical boost (Arai et al., 2007; Carminati et al., 2008), while others have not (Thothathiri & Snedeker, 2008a, 2008b; see also Sturt et al., 2010). The existence of the lexical boost in production studies has supported the idea that lexical items and syntactic structure representations are connected in long-term memory. If so, and if comprehension and production tap the same set of lexical and syntactic representations, one would expect to see the lexical boost in comprehension priming as well (within limits; see Boland & Blodgett, 2006; Boland & Boehm-Jernigan, 1998; Tooley & Traxler, 2010, 2012; Traxler & Tooley, 2007).

Because the nature of syntactic priming in comprehension, and in particular, the existence of the lexical boost, has potentially significant implications for syntactic representation and processing theory, it matters whether the lexical boost is a general phenomenon that occurs widely when syntactic priming occurs, or whether it is restricted to a small set of sentence types. Thus, the current study examined a sentence type which has not been previously shown to produce syntactic priming. This study tested readers' responses to sentences containing "early" vs. "late" closure syntactic ambiguities, see (1) below.[iv] The experiments serve a number of purposes, with the following two being the main ones. First, showing priming during comprehension for this sentence type would extend the range of sentence types for which priming has been demonstrated. Second, showing larger priming effects with lexical repetition for this sentence type would extend the range of sentence types for which we have evidence of the *lexical boost*.

Sentences such as (1) are temporarily ambiguous between an "early" and a "late" closure interpretation.

(1) While Mary was knitting the sock fell off her lap.

This ambiguity arises because the noun phrase *the sock* is a plausible object of the preceding verb *knitting*, but actually serves as the subject of the following main verb *fell*. For sentences like this, readers have a bias towards the late closure interpretation, whereby *the sock* is treated as the direct object of the preceding verb (Frazier & Rayner, 1982). This creates a processing problem when readers reach the main verb *fell*. If *the sock* has been assigned as object of the preceding verb, then *fell* is left without a syntactic subject, which is disallowed in English. To repair this problem, readers must undo their prior syntactic commitment (or rerank the structural possibilities). On the *early closure* interpretation, the initial clause is closed after the subordinate verb *knitting*. This leaves the noun phrase *the sock* free to be incorporated into the main clause as the subject (as in *the sock fell*).

Prior studies have indicated that sentence interpretation performance can be affected by the presentation of a prime sentence that matches the syntactic properties of the target sentence (e.g., Arai et al., 2007; Ledoux et al., 2007; Traxler & Tooley, 2008). To date, none of these experiments have addressed priming effects in sentences such as (1). The current study was designed to fill this gap in the literature and to test hypotheses that have emerged from

[iv]The terms "early" and "late" are not used here to imply or endorse any particular representation and processing theory. They are used because they are common terms for the kinds of sentences that were tested.

previous priming studies. One of these relates to the nature of syntactic representation and access to structural information during on-line sentence comprehension. Syntactic theories such as *unification grammar* (Vosse & Kempen, 2000, 2009) and head-driven phrase-structure grammar (HPSG; Sag et al., 2003) propose a close connection between lexical entries and syntactic structure representations (see also Ford et al., 1982; MacDonald et al., 1994). Related approaches call attention to the fact that, while there are a potentially infinite number of syntactic structures, people have finite attentional and memory resources that make it unlikely that every syntactic configuration that a person encounters is stored in long-term memory (Boland & Blodgett, 2006; Boland & Boehm-Jernigan, 1998; see also Tooley & Traxler, 2012; Traxler & Tooley, 2007). The *argument structure hypothesis* suggests that only syntactic relations that reflect arguments are stored in long-term memory. Other aspects of syntactic structure are computed as needed using general-purpose heuristics.

For sentences like (1), the main syntactic decision involves whether the second noun phrase (*the sock*) is to be treated as an argument (direct object) of the subordinate clause verb. According to syntactic representation theories like unification grammar and HPSG, the lexical representation of the verb *knitting* specifies that it can take an NP (direct object) argument or can appear (in a different form) with only a syntactic subject, as in the intransitive sentence *Mary was knitting*. If parsing entails activation of structural information via individual lexical entries (as opposed to application of processing principles that are blind to the specifics of a given lexical item), then syntactic priming for sentences like (1) should reflect this principle. More specifically, priming effects for sentences like (1) should be larger if the prime sentence shares a critical verb with the target. The two experiments reported here test whether this is the case by manipulating verb repetition between primes and targets.

The experiments also provide an index of strategic effects and semantic repetition effects. Because the type of target sentence was not predictable based on the type of prime sentence that appeared on a given trial, participants should not have been able to develop a strategy that relied on them predicting the imminent arrival of a particular kind of target sentence. As noted above, previous studies have demonstrated that semantic repetition, by itself, does not lead to facilitated processing of syntactically challenging parts of target sentences (Carminati et al., 2008; Tooley et al., 2009; Traxler & Tooley, 2008; Traxler et al., in press). The current experiments provide a further test of the semantic facilitation hypothesis. In Experiment 1, all of the prime sentences shared aspects of meaning with the target (in that the initial verb was always repeated). However, only half of the target sentences had the same syntactic structure as the prime. If semantics leads to facilitated target processing, then priming should occur for all target sentences, regardless of prime type (i.e., target sentences should be read faster than primes). If syntactic repetition is the cause of facilitated target processing, then priming should be observed only when there is syntactic overlap between primes and targets, regardless of semantic overlap.

Experiment 1

Experiment 1 tested whether syntactically disambiguating material would be read faster when a target sentence followed a prime sentence that had the same syntactic structure. The

test sentences included early closure versions (2a, 2c) and late closure versions (2b, 2d). The sentences were all temporarily syntactically ambiguous during processing of the second noun phrase (*the birds*/*the bell*), which could be treated as the object of the preceding subordinate clause verb or as the subject of an (as yet unseen) main verb. Generally, unless subcategory information or prosodic cues indicate otherwise, comprehenders have a bias to treat the second NP as an object of the preceding verb (Frazier & Rayner, 1982; Speer & Blodgett, 2006; Adams et al., 1987; cf. van Gompel & Pickering, 2001). All of the subordinate clause verbs were object-preferring and all of the post-verbal NPs were plausible objects of the subordinate clause verb. Hence, participants should be strongly "garden pathed" when they encounter the main verb (e.g., *came*, *struck* in 2a and 2c).

(2a) (Early Closure) As Jason watched the birds came closer and closer.

(2b) (Late Closure) As Jason watched the birds the fox came closer and closer.

(2c) (Early Closure) While Albert watched the bell struck midnight quite loudly.

(2d) (Late Closure) While Albert watched the bell the clock struck midnight quite loudly.

By crossing prime types (early vs. late closure) and target types (same), the experiment provides an estimate of the degree to which processing is facilitated when the prime and targets share aspects of syntactic form (early vs. late closure). The experiment also provides an estimate of semantic effects on target processing. If semantic overlap facilitates target processing, then critical regions in the target sentences should be read faster than primes, whether syntactic form is repeated or not.

Method

Participants—48 undergraduates from UC Davis participated in return for credit towards a course requirement. All were native speakers of English with normal or corrected vision and normal hearing.

Stimuli—Stimuli consisted of 96 test sentences resembling (2a-d), see Appendix. Half of the test sentences were disambiguated towards the late closure analysis by the inclusion of a second noun phrase following the initial verb. The other half of the test sentences were disambiguated towards the early closure analysis. Sentences were assigned pseudo-randomly to lists in pairs. Each pair consisted of a prime sentence and a target sentence. The prime and target sentences were presented immediately adjacent to one another. Sentences were assigned to lists such that half of the late closure targets were preceded by late closure primes and half by early closure primes. Half of the early closure targets were preceded by early closure primes and half by late closure primes. The sentences were rotated across 8 lists of items so that every prime sentence (from one list) served as a target sentence (on another list). The 48 prime-target pairs were distributed among 100 filler sentences of various types. At least one filler sentence appeared between each experimental trial (a prime-target pair). Each sentence in a prime-target pair had the same initial verb in the subordinate clause. Verb repetition has been shown in some previous studies to increase the magnitude of observed priming effects (Carminati et al., 2008; Tooley et al., 2009; Traxler et al., in press).

Because every target sentence served as its own control, the priming manipulation was not confounded by sentence-specific factors (like length, lexical frequency, plausibility, intralexical associations, etc.). Because target and prime types were crossed, participants could not predict what type of sentence (early vs. late closure) would follow either type of prime sentence. This helps reduce concerns about special anticipatory strategies (see also Traxler & Tooley, 2008; Traxler et al., in press). Priming effects were estimated in two ways. First, reading times for targets were compared to reading times in the primes. If processing of a target sentence is facilitated by the presentation of a prime, reading time should be lower when the sentence appears as a target than when the sentence appears as a prime. Second, reading times in primed and unprimed targets were compared (where "primed" means that the prime and target had the same syntactic structure). If a syntactically matched prime sentence facilitates target processing, then the primed targets should have lower reading times than unprimed targets.

Self-Paced Reading Procedure—Participants were tested individually in a quiet room. They were instructed to read at a normal, comfortable pace in a manner that would enable them to answer comprehension questions. Comprehension questions were presented after 16 of the sentences, distributed among target and filler trials. Participants did not receive feedback on their answers. All of the participants in the analyses below scored at least 80% correct on the comprehension questions.

The texts were presented with a self-paced moving window procedure running on a desktop PC computer. Each trial began with a series of dashes on the computer screen in place of the letters in the words. Any punctuation marks appeared in their exact position throughout the trial. The first press of the space bar replaced the first set of dashes with the first word in the sentence. With subsequent space-bar presses, the next set of dashes was replaced by the next word, and the preceding word was replaced by dashes. The computer recorded the time from when a word was first displayed until the next press of the space bar.

Data from two words were analyzed. The *disambiguating verb* is the main verb in the sentence. This is the point at which the late closure analysis becomes untenable in the early closure sentences. Prior studies have consistently indicated processing difficulty at this point. The *next word* is the word that follows the main verb. Processing effects that arise from one word sometimes linger and affect reading times on the next word (Rayner & Pollatsek, 1989). Thus, analyzing the word after the main verb may produce evidence that a syntactic prime can reduce the lingering effects of syntactic misanalysis. Prior to analysis, any reading time less than 120 ms or greater than 3000 ms was deleted and treated as missing. These criteria affected less than 1% of the data.

Results and Discussion

Mean reading times for the disambiguating verb and the following word by condition appear in Figure 1. The data were first subjected to 1 × 6 (condition: "early" closure prime sentence vs. "late" closure prime sentence vs. primed early closure target vs. unprimed early closure target vs. primed late closure target vs. unprimed late closure target) ANOVAs. Condition was treated as a within-participants and within-items random factor. Significant effects of

condition were followed up by post-hoc comparisons (Tukey HSDs; Glass & Hopkins, 1984).

Disambiguating Verb—The ANOVAs on data from the main verb indicated a main effect of condition [F1 (5, 235) = 4.27, p = .01, MSe = 6911; F2 (5, 435) = 4.91, p < .01, MSe = 13459]. In terms of priming effects, only the early closure conditions produced evidence of priming. Reading time in the primed, early closure targets was shorter than reading time in the early closure primes [Q1, Q2 > 5.17, p1, p2 < .01]. Reading time in the early closure primed targets was also shorter than reading time in the early closure unprimed targets [Q1, Q2 > 4.57, p1, p2 < .05]. A further indication or priming in the early closure condition is that the disambiguating verbs were read just as quickly in the primed, early closure targets as in the late closure primes and the late closure targets [all Q < 2.5, NS]. Reading time in the early closure primes did not differ from reading time in the unprimed early closure targets [both q < 1, NS]. Late closure target sentences did not produce shorter reading times when they were primed versus unprimed [all q < 1, NS].

Next Word—ANOVAs on data from the next word indicated a main effect of condition [F1 (5, 235) = 6.97, p < .001, MSe = 4790; F2 (5, 435) = 4.54, p < .01, MSe = 16657]. The pattern of simple effects was the same as at the main verb. Priming effects in the early closure condition were indicated by differences between the early closure prime and early closure primed target conditions [both Q > 4.4, both p < .05]. Similarly the early closure primed targets produced shorter reading times than the early closure unprimed targets [both Q > 5.38, both p < .05]. The late closure prime condition differed from the early closure prime condition [both Q > 4.8, both p < .05], but not from the late closure target conditions [all Q < 1, NS].

The results of Experiment 1 show, for the first time, that the processing of disambiguating material in early closure sentences can be primed by a single preceding sentence whose syntactic form matches the target. In fact, when early closure target sentences followed early closure primes, the disambiguating verb and the following word were read no more slowly than the same words in late closure sentences, for which syntactic processing is thought to be relatively straightforward.

The lack of priming effects in the late closure conditions, and the lack of a priming effect in the early closure “unprimed” condition, suggest that semantic repetition does not, by itself, speed target sentence processing. In the case of the late closure sentences, this may be because reading times are already close to the floor. In the case of the early closure, unprimed condition, the absence of a reduction in reading time compared to the early closure prime sentence suggests that semantic repetition has little observable effect on processing of syntactically challenging material in this kind of sentence.

Experiment 2

Prior studies of both production and comprehension indicate that priming effects are greater when content words are repeated than when they are not (Arai et al., 2007; Branigan et al., 2005; Carminati et al., 2008; Branigan et al., 2005; Tooley et al., 2009; Traxler et al., in

press). Four studies of syntactic priming in comprehension have not demonstrated this pattern (Thothathiri & Snedeker, 2008a, b; Sturt et al., 2010; Traxler, 2008). Different outcomes between different studies that use the same dependent measures may reflect changes in the task (e.g., Arai et al., vs. Thothathiri & Snedeker's studies, which used similar stimuli, but different versions of the visual world paradigm). Different patterns across studies also likely reflect differences in the stimuli, which lead to differences in the parsing processes that are used to interpret the stimuli (e.g., Tooley et al., 2009 and Traxler, 2008a, were both conducted on the same eye-tracker, by the same personnel using the same general procedures, but the sentence types differed).

As yet, there is no evidence whether priming of early closure sentences is subject to the lexical boost. Experiment 2 was designed to test whether repetition of the initial verb would influence the degree of priming observed at the syntactically disambiguating main verb and the next word. To do so, the stimuli from Experiment 1 were rearranged to eliminate repetition of the subordinate clause verb. If early closure priming follows the pattern observed in other production and comprehension priming studies, then priming of early closure target sentences by early closure prime sentences should be reduced or eliminated in Experiment 2. If lexical repetition is key to the priming effects, then there should be no difference in reading times for different types of early closure targets (primed vs. unprimed). There should also be no difference in reading times between the early closure prime sentences and early closure targets following early closure primes.

Method

Participants—56 undergraduates from UC Davis participated under the same conditions as Experiment 1.

Stimuli—The stimuli were identical to Experiment 1. The only difference was that, by pseudo-randomly pairing prime and target sentences, lexical repetition between the primes and targets was eliminated.

Procedure—The data collection and analysis procedures were identical to Experiment 1. Less than 1% of the data were eliminated based on the same criteria. All of the participants included in the analysis scored greater than 80% correct on the comprehension questions.

Results and Discussion

As in the first experiment, the data from the verb and next word were subjected to 1 × 6 (condition) ANOVAs with condition treated as a within-participants and within-items random factor. Figure 2 shows mean reading time by condition for Experiment 2.

Verb—Data from the disambiguating verb produced a main effect of condition [F1 (5, 275) = 9.10, $p < .001$, MSe = 3654; F2 (5, 475) = 12.1, $p < .001$, MSe = 7358]. Post-hoc means comparisons indicated that there were no significant priming effects. The disambiguating verb in early closure targets was not read faster when the target sentence was primed versus when it was not primed [Q1, Q2 < 2.51, NS]. Similarly, reading times for the disambiguating verb in early closure primes and primed early closure target sentences did

not differ [Q1, Q2 < 1.83, NS]. Likewise, no significant priming effects were observed in the late closure conditions (replicating Experiment 1 for that sentence type, all Q < 1, NS). Thus, the main effect of condition resulted from overall slower reading times for the early closure sentences compared to the late closure sentences, regardless of priming status.

Next Word—Data from the next word also produced main effects of condition [F1 (5, 275) = 13.0, $p < .001$, MSe = 2246; F2 (5, 465) = 4.10, $p < .001$, MSe = 11305]. This main effect occurred because late closure sentences produced faster reading times than early closure sentences [all values of Q for relevant contrasts > 4.8, all $p < .05$, except for the contrast between the late closure prime and the early closure, unprimed condition, Q1 = 4.42, $p < .05$; Q2 = 3.42, NS]. As with the preceding verb, no priming effects were observed (all values of Q for relevant contrasts < 1.90, NS).

Experiment 2, unlike Experiment 1, produced no evidence that exposure to a prime sentence affected time taken to process syntactically disambiguating information in the target. Main effects of sentence type (early vs. late closure disambiguation) indicated that participants were processing syntactic information. The absence of syntactic priming effects suggests that disambiguating an immediately preceding sentence did not facilitate the process of disambiguating the target. Before interpreting this result further, the paper reports additional analyses that tested whether the pattern of results truly differed across the two experiments.

Between Experiment Contrast of Early Closure Priming

A 2 (experiment) by 6 (condition) ANOVA tested for differences in the pattern of effects between experiments. Experiment was treated as a between-participant and within-items random factor. Condition was treated as both within participants and items. These ANOVAs produced significant experiment by condition interactions in the verb and next word regions [verb region: F1 (5, 505) = 2.95, $p < .05$, MSe = 4395; F2 (5, 435) = 197, $p < .0001$, MSe = 12199. next word region, significant by F1 (5, 505) = 6.06, $p < .0001$, MSe = 3436; but not by F2 (5, 435) = 1.52, $p = .18$, MSe = 15227].

Data from the early closure conditions from both experiments were also subjected to a combined analysis. 2 (experiment: Experiment 1 vs. Experiment 2) x 3 (condition: early closure prime vs. unprimed early closure target vs. primed early closure target). Experiment was treated as a between-participants and within-items random factor. Condition was treated as a within-participants and within-items random factor. These analyses produced experiment by condition interactions at the verb [F1 (2, 204) = 4.73, $p < .01$, MSe = 6037; F2 (5, 435) = 7.25, $p < .01$, MSe = 17309] and the next word [significant by participants, with F1 (2, 204) = 9.74, $p < .001$, MSe = 4636; but not by items F2 (2, 184) = 1.76, $p = .18$, MSe = 28839]. Hence, these analyses confirmed that the priming effects in the early closure condition were larger in Experiment 1 than Experiment 2.

General Discussion

In Experiment 1, early and late closure target sentences followed early or late closure prime sentences. Within a given prime-target pair, the subordinate clause verb in the prime was the same as the subordinate clause verb in the target. Early closure targets were processed more

quickly when they followed an early closure prime than when the followed a late closure prime. The main verb and the next word in primed early closure targets were read faster than the same words in unprimed early closure targets. No priming effects were observed in the late closure conditions. These results indicate that processing an early closure prime sentence that has the same initial verb speeds processing of syntactically disambiguating information in an early closure target. This is the first time that priming has been demonstrated for this sentence type.

The results of Experiment 2 contrast with those of Experiment 1. In Experiment 1, priming effects were observed at both the main verb and the next word in the early closure sentences. In Experiment 2, no such effects appeared. The cross-experiment analysis verified that priming effects for the early closure conditions were larger in Experiment 1 than Experiment 2. In Experiment 2, only the difference between the late closure and the early closure conditions was statistically significant. The cross-experiment contrasts suggest that repetition of the subordinate clause verb may be critical to the appearance of the priming effects (i.e., that no priming occurs without such repetition). More conservatively, greater priming effects in Experiment 1 than Experiment 2 suggest that priming of early closure is subject to the lexical boost.

A stronger interpretation of this pattern of results is that structural repetition, in and of itself, does not substantially affect processing of target sentences. There are two aspects of the experiments that point towards this conclusion. Both experiments included substantial numbers of early closure sentences – sentences that were disambiguated towards an intransitive subordinate clause. Despite the relatively high proportion of such sentences in the experiment overall, there was no indication that processing of early closure target sentences was facilitated, except when the prime and target sentences shared an initial verb. A similar observation can be made about Experiment 2. Here, there were also a large proportion of early closure sentences overall, and many instances where two closure sentences appeared immediately adjacent to one another. Despite the repetition of structure, no priming effects were observed in Experiment 2. These results may indicate that purely abstract structural priming does not occur for this structure (which would resemble similar outcomes for sentences containing reduced relatives). Alternatively, it may indicate that priming effects are smaller for early closure sentences in the absence of verb repetition. That is, that the lexical boost increases the size of the priming effect to the point where it can be observed, but that a smaller, less detectable effect occurs in the absence of verb repetition.

This study adds to the growing catalog of sentence types that have been shown to produce syntactic priming effects. It may therefore be time to conclude that syntactic priming is a general phenomenon in sentence comprehension and to think about the implications this has for theories of representation and processing.

One implication is that theories of sentence processing should incorporate the syntax of recently encountered sentences among the contextual influences that need to be accommodated. The general principle may be that, while syntactic processing is largely driven by the syntactic cues available within the sentence, concurrent non-syntactic information (e.g., visual information, immediate referential context, prosody), long-term

contextual information (e.g., subcategory preference information), and immediate short-term context (e.g., the syntactic structure of the preceding utterance) can make a given syntactic analysis easier or harder to adopt (Altmann & Steedman, 1988; Ni et al., 1996; Speer & Blodgett, 2006; Tanenhaus et al., 1995; Trueswell et al., 1993). Within a given theory, the reasons why syntactic processing becomes easier or harder may differ based on corollary assumptions or prior theoretical commitments (e.g., Is a particular analysis given a more prominent rank amongst a set of syntactic representations activated in parallel? Does the estimated prior probability of an analysis change with exposure? Are recently fired procedures that build particular dependencies easier to re-fire than alternate procedures? Does a syntactic prime influence early stages of syntactic structure building during target-sentence processing, or are effects limited to processes responsible for recovery from syntactic misanalysis?). However, any complete theory of sentence processing should include mechanisms and processes that can produce syntactic priming. Given the available evidence, those mechanisms and processes should be capable of producing the *lexical boost* as well, although lexical influences may have greater effects for some sentence types or some tasks than others (Arai et al., 2007; Carminati et al., 2008; Thothathiri & Snedeker, 2008a, b; Traxler, 2008a, b; Tooley et al., 2009; Traxler et al., in press).

To date, two types of mechanisms, which need not be mutually exclusive, have been used to explain the nature of syntactic priming effects in both production and comprehension. The first of these are lexical-structural associations that can be implemented in a representational system such as Bock & Levelt's (1996; see also Levelt, 1989; Levelt et al., 1999). In this system, *lemmas* package information that is specific to a given word, such as its syntactic category, its meaning, its morphological requirements, and so on. Accounts such as MacDonald and colleagues' constraint-based lexicalist framework appeal to lexically stored structural information as a means to account for a variety of effects observed during on-line sentence comprehension, such as subcategory preference effects on processing time, the degree to which intervening material makes dependency formation difficult, and the degree to which semantic properties of particular words can influence comprehenders' commitments to one syntactic analysis over another (Trueswell et al., 1994; see also Traxler et al., 2002, 2005). This type of account is naturally aligned with representational theories, such as unification grammar and HPSG, which tie combinatory/structural representations to individual lexical items (Vosse & Kempen, 2000, 2009; Sag et al., 2003). According to accounts of this type, syntactic structures are built by mechanisms that take lexical representations as input and find matching open structural tags that are linked to lexical heads. The lexical entry for a noun like *sock*, for example, would have a linked structural description that indicates that it can take a preposition as its head (as in *The boy spilled soup on the sock*) or a verb (as in *The boy dropped the sock*). Structure-building in the former case would entail finding a linked structure for *spilled* that specifies a prepositional phrase as the post-verbal argument (V(*spilled*)+PP) rather than a direct object NP (V(*spilled*)+NP), as in *The boy spilled the soup*. The lexical boost may occur as a natural consequence of representational systems like this. It is easy to envision the lexical boost as a special case of (lexical) repetition priming or as a kind of residual activation. If one assumes distinct lexical entries for the different versions of *spilled*, then faster processing of *spilled on the ground* after *spilled on the sock*, would be due to repeated activation of the lexical entry (V(*spilled*)

+PP). If one assumes a single core entry for *spilled*, with links to combinatory/structural information (e.g., *spilled* has associations with the structural descriptions for PP, NP, and (Null-Intransitive)), then the lexical boost in this case would reflect persistent activation of the link between the "core" representation and the structural description for V+PP.

While representational accounts such as unification grammar or HPSG provide a reasonable way to account for the lexical boost, it is important to note that the lexical boost is not universal. Limits on the lexical boost have been documented in both production (e.g., Hartsuiker et al., 2008) and comprehension (e.g., Traxler, 2008a). These limitations may be task-driven (e.g., Arai et al., 2007; Carminati et al., 2010; Thothathiri & Snedeker, 2008a, b), but they may be driven by the organization of lexically linked syntactic representations. Boland and colleagues (Boland & Blodgett, 2006 ;Boland & Boehm-Jernigan, 1998) have proposed that lexical representation of syntactic structure information occurs only for arguments. Thus, structural relations that reflect arguments (such as Verb+Object; Preposition+Object; Subject-Verb) are lexically stored, but other types that signal (optional) relationships, such as manner, time, and place, are computed de-novo each time they are encountered (*construal* theory makes a compatible claim relating to how parsing heuristics are applied; Frazier & Clifton, 1996). According to the *argument structure* hypothesis, key structural relationships tested in the current experiments are lexically specified, because the key structural ambiguity involves treating a noun phrase as the direct-object argument of a preceding verb or not. Thus, the argument structure hypothesis is compatible with larger priming effects for conditions with repeated initial verbs (Experiment 1) and smaller effects for conditions without repeated initial verbs (Experiment 2). This account successfully predicts argument-driven effects in reduced relatives (as in Tooley et al., 2009), and the absence of such effects in adjunct processing (as in Traxler, 2008a).[v] On this account, parsing an early closure prime sentence involves sorting through structural representations that are activated in response to accessing a lexical representation. When readers encounter the verb *knitting*, they may initially favor the direct-object version (due to language-level probabilities or verb-linked probabilities, or because the object analysis is structurally simpler than the alternatives). However, encountering the main verb (without another NP that would allow *the sock* to serve as object of the subordinate verb), forces the comprehender to suppress or inhibit the link between the lexical representation of *knit* and the direct-object structural representation, and enhance the link between the lexical representation of *knit* and the (objectless) intransitive structure. When a subsequent sentence is encountered that uses the same verb, the structural information that has just been accessed via the lexical entry for that verb affects the choice of syntactic analysis for the target.

One final theoretical point is worth noting. There are now two (possibly three) sentence types for which evidence of priming in the absence of verb-repetition is scant or nonexistent (the current type, reduced relatives, and (possibly) double-object/prepositional-object datives). This means that priming can fail to occur even when a prime and a target are perfectly aligned with respect to syntactic structure. In the priming studies to date, comprehension of early/late closure sentences and reduced relatives both entail performing cognitive processes that allow the comprehender to recover from syntactic misanalysis (this is because the available cues are stacked in favor of the "garden path" analysis). The fact

that priming has not been shown in the absence of verb repetition suggests that undertaking syntactic reanalysis during prime processing does not, by itself, help comprehenders process disambiguating information in the target sentence. If so, two possibilities spring to mind. First, syntactic reanalysis may be achieved via a similar lexically driven process similar to initial syntactic analysis, as opposed to general purpose heuristics. Disambiguating a syntactic relationship involving one lexical item would then provide little benefit for a subsequent relationship involving different lexical items. Alternatively, deploying general purpose reanalysis heuristics may take place only after a lexically driven stage of analysis has failed. This latter hypothesis would seem to require the corollary assumption that initial syntactic analysis interferes with any abiding trace of prior reanalysis procedures to such a degree that that undertaking the same reanalysis process twice in succession does not lead to a measureable processing benefit.

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Appendix: Experimental Stimuli

1. As Jason watched the birds (the fox) came closer and closer.
2. While Albert watched the bell (the clock) struck midnight quite loudly.
3. After Captain Jack explained the plan (the boat) started to fall apart.
4. While Brian explained the situation (the weather) improved suddenly and significantly.
5. After Julie read the newspaper (the pencil) fell from her hands.
6. As Sami read the sign (its frame) dropped off the wall.
7. After Jack grew the beans (the beanstalk) took him on a magical journey.
8. Ever since Mona grew the oregano (the flowers) have been blooming early.
9. After Jacob painted the picture (his wall) looked vibrant.
10. After Sophie painted her door (the paint) took a while to dry.
11. After Maggie left her husband (the children) went through a rough couple of months.
12. As Jeff left the market (the aisles) became crowded with shoppers.
13. After Peter proposed the rule (his cautiousness) started to annoy his co-workers.
14. While Steve proposed marriage (the garlic toast he had eaten) began to seem like a bad idea.
15. After Raul drank his water (the beer) looked much cleaner to him.
16. As David drank the mead (his dinner)\ started to taste better and better.

17. After Lola was done choosing her class (registration) was canceled until further notice.
18. Even though Jerry chose the option (the decision) wasn't meant to be serious.
19. After Rupert ordered the food (the drinks) came out right away.
20. Before the businessman ordered the product (he) received great reviews.
21. After she shot (the rifle) her shoulder hurt immensely.
22. As he shot the tiger (a rabbit) ran off scared by the loud noise.
23. After she visited the zoo (the elephant exhibit) closed down for renovations.
24. While Alex visited his girlfriend (his mother) cooked a delicious dinner.
25. After Steve declined the offer (the gift card) was given to someone else.
26. Because Kyoko declined the promotion (the position) was offered to her coworker.
27. After the children learned the rules (the game) made more sense to them.
28. As Michelle learned the routine (the dance) became much easier to perform.
29. After the composer shouted the lyrics (the theater's acoustics) impressed the piano player.
30. Before Peter shouted the instructions (the comments) were relayed over the phone.
31. After the mechanic phoned the customer (the accountant) stopped in to pay his bill.
32. Since Paula phoned her husband (he) has moved out of their house.
33. After the office assistant quit her position (her desk) was posted as available.
34. Once Max quit smoking (cigarettes) were banned in the office.
35. After the student rehearsed the presentation (the transitions) flowed a bit more smoothly.
36. As Sherry rehearsed the lines (the poem) became easier to memorize.
37. After they debated the legislation (it) was passed by the senate.
38. Because the two influential scientists debated the theory (their paper) was scrutinized by scholars.
39. Although Eva understood the decision (it) upset her and her friends.
40. Even though the mathematician understood the equation (its variables) puzzled many of her colleagues.
41. Although Princess Buttercup hid her face (she) was recognized almost instantly.
42. As the magician hid her assistant (the ball) fell out of the mirror-box.
43. As Edward chewed the meatball (the spaghetti) slipped off his fork.
44. While the squirrel chewed the pinecone (a cool wind) blew through the trees.

45. After he practiced the song (the recording) sounded much better than before.

46. Since Joe practiced the lie (his voice) sounded more natural and believable.

47. After the mechanics assembled the engine (the machine) was quickly and easily fixed.

48. Before the scientists assembled the team (they) held a meeting to discuss candidates.

49. As Michael cooked the food (the microwave) began to burn and smoke.

50. Because I cooked the lasagna (the meal) was nutritious and delicious.

51. As Penelope spoke the warning (her words) fell on deaf ears.

52. While Desmond spoke the sentence (the sound of a trumpet) echoed on the wall.

53. As the dog scratched the lice (they) became more irritated.

54. Because Marco scratched the scab (his skin) could not heal properly.

55. As the army withdrew several battalions (the spies) were ambushed by enemy forces.

56. When the investor withdrew his money (his investments) had doubled.

57. As the bull charged the matador (the crowd) yelled loudly.

58. Before the soldiers charged the fortress (the enemies) waved a white flag of surrender.

59. As the chairwoman ruled the committee (the unhappy employee) plotted against her.

60. While Nero ruled Rome (the village) burned to the ground.

61. As the manager called the store (the cash register) was being ransacked and robbed.

62. Before Hank called his wife (his daughter) had already picked up the phone.

63. As the robot cautioned its creator (the mad scientist) planned some more experiments.

64. Ever since the lawyer cautioned the defendant (the room) has been very quiet.

65. As Tommy was dressing the salad (the lettuce) started to wilt and turn brown.

66. While Susan was dressing the baby (the cat) played in the corner.

67. Because Biff performed the last scene (the film) was a great success.

68. When Ella performed her song her voice filled the amphitheater with emotion.

69. Because Nguyen climbed the mountain (the peak) was named after him.

70. When Cynthia climbed the ladder (the hill) came into sight.

71. Before Jessica drew the picture (the masterpiece) took shape in her mind.

72. While the witness drew the criminal (the suspect) walked to the center of the lineup.
73. Before the apprentice fought his master (they) bowed to each other.
74. While the shepherds fought the wolf (the fox) ate some of their sheep.
75. Before the parents questioned the teenager (his girlfriend) escaped out of the window.
76. When the lawyer questioned the witness (the juror) twiddled her thumbs nervously.
77. Before the predator hunted the zebra (the prey) was no real threat.
78. When the vice president hunted the quail (his guns) were nowhere to be found.
79. Even though Bill protested the war (conflict) continued in the Middle East.
80. While Lily protested the decision (her confidence) pleased the rest of the teachers.
81. Before Bobby began the speech (his wrestling match) was scheduled.
82. Right after Jamie began the exam (the first question) was amended by the teacher.
83. Before the cowgirl moved her cattle (her horse) grazed on the grass.
84. Ever since the builders moved their equipment (the car) has stayed in the same spot.
85. When Stewart acted the role (the scene) was believable.
86. While Patrick acted the fool (his sister) mimed right behind him.
87. When the butler drove the aristocrats (Susanne) felt kind of queasy.
88. When the cabbie drove the car (the engine) never stalled or had any problems.
89. When Bob celebrated his birthday (the deadline) had already passed a week before.
90. While Joe celebrated the victory (the game) got played over and over on the news.
91. While the professor prepared the final exam (the midterm exam) was being administered by the TA.
92. Yesterday as I prepared my speech (my determination) impressed my little brother.
93. When he signed the form (the contract) became a legally binding document.
94. Just before Kanye signed the new band (the couple) broke up and left the studio.
95. Before the perpetrator asked the attorney (he) realized he should be quiet.
96. When Timmy asked his question (the matter) was addressed by his friend.

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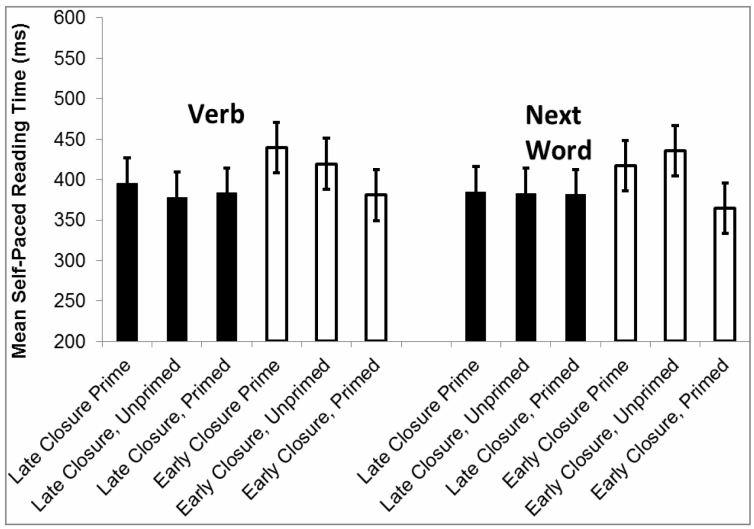

Figure 1. Experiment 1

Mean Reading time by Condition for the verb and the next word. The black bars represent the late closure conditions. The open bars represent the early closure conditions. The left-most bar in each set represents reading time in the prime sentence. The other two bars represent reading time in the **un**primed (left) and primed targets (right). Error bars reflect standard errors.

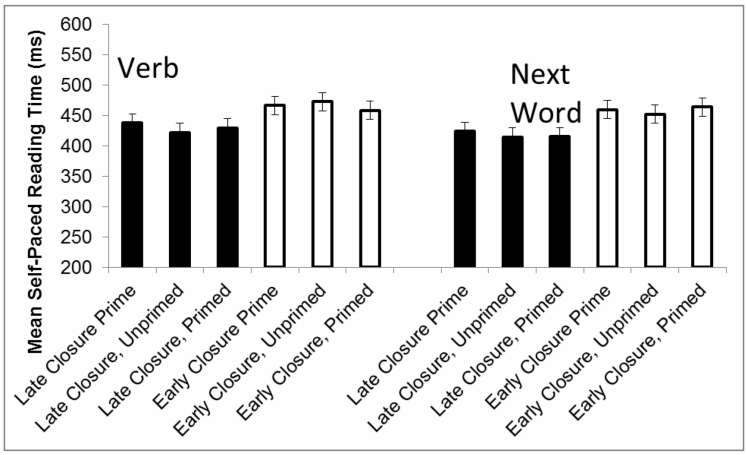

Figure 2. Experiment 2

Mean Reading time by Condition for the verb and the next word. The black bars represent the late closure conditions. The open bars represent the early closure conditions. The left-most bar in each set represents reading time in the prime sentence. The other two bars represent reading time in the **un**primed (left) and primed targets (right). Error bars reflect standard errors.