Published in final edited form as:
J Exp Psychol Learn Mem Cogn. 2014 July ; 40(4): 905–918. doi:10.1037/a0036377.

Syntactic Priming During Sentence Comprehension: Evidence for the Lexical Boost

Matthew J. Traxler,
University of California, Davis

Kristen M. Tooley, and
Texas State University

Martin J. Pickering
University of Edinburgh

Abstract

Syntactic priming occurs when structural information from one sentence influences processing of a subsequently encountered sentence (Bock, 1986; Ledoux et al., 2007). This article reports two eye-tracking experiments investigating the effects of a prime sentence on the processing of a target sentence that shared aspects of syntactic form. The experiments were designed to determine the degree to which lexical overlap between prime and target sentences produced larger effects, comparable to the widely observed 'lexical boost' in production experiments (Pickering & Branigan, 1998; Pickering & Ferreira, 2008). The current experiments showed that priming effects during on-line comprehension were in fact larger when a verb was repeated across the prime and target sentences (see also Tooley et al., 2009). The finding of larger priming effects with lexical repetition supports accounts under which syntactic form representations are connected to individual lexical items (e.g., Vosse & Kempen, 2000, 2009; Tomasello, 2003).

Keywords

Parsing; sentence processing; syntax; syntactic priming; reduced relatives; usage-based grammar; unification grammar

Syntactic priming occurs when elements of structure from a prime sentence influence performance on a subsequently encountered target sentence (Bock, 1986; see Pickering & Ferreira, 2008 for a review). For example, if a speaker produces or hears a sentence with passive voice, she is more likely than normal to produce a subsequent sentence with passive voice. Effects of syntactic repetition can be distinguished from other types of repetition. For example, syntactic priming effects in production do not depend on function-word repetition. Priming of prepositional datives is just as large when the prime sentence contains the preposition "to" and the target contains "for", and vice-versa. Likewise, priming effects in production do not depend on repetition of aspects of meaning across a prime and a target.[i]

Address Correspondence To: Matt Traxler, Department of Psychology, UC Davis, 1 Shields Avenue, Davis CA 95616, 530 752 2087 (fax) 530 754 9468 (o), mjtraxler@ucdavis.edu.

Bock and Loebell (1990) showed equivalent priming for prepositional datives (e.g., *The woman gave the Mercedes to the church*) and locative expressions (e.g., *The woman drove the Mercedes to the church*). Effects of this kind have been attributed to syntactic structure-building processes that mediate between purely conceptual representations and spoken or written output.

In comprehension, processing times for syntactically challenging sentences are often shorter than normal when those sentences are preceded by syntactically similar sentences (Tooley et al., 2009, in press; Traxler, 2008a, 2008b). Comparable influences of syntactic form occur in visual-world experiments (Arai et al., 2007; Carminati et al., 2008; Thothathiri & Snedeker, 2008a, 2008b). In event-related potential (ERP) experiments, syntactic repetition between sentences is associated with reduced positivities following syntactic disambiguation (Ledoux et al., 2007; Boudewyn et al., in press). Similar effects have been observed due to syntactic repetition within sentences (Frazier et al., 2000; Sturt et al., 2010; see also Trueswell & Kim, 1998).

This article explores mechanisms that contribute to priming effects that occur during the process of interpreting a sentence. The experiments focused on processing of sentences that contain reduced relative clauses, such as (1) (Bever, 1970; Clifton et al., 2003; Ferreira & Clifton, 1986; Trueswell et al., 1994):

(1) The defendant examined by the lawyer was unreliable.

Sentences of this type are challenging to process. The difficulty arises because the beginning of the sentence (*The defendant examined*) points towards a *main clause* interpretation, under which *the defendant* is the agent of the verb *examined* (as in, *The defendant examined...the evidence at the trial*). The prepositional phrase *by the lawyer* violates this pattern, necessitating syntactic and thematic revisions. That is, instead of being the agent of the examining action, *defendant* must ultimately be treated as patient or theme. The true agent of examining is expressed by the noun within the by-phrase (e.g., *lawyer*).

The current experiments tested whether processing a prime sentence facilitated processing of a syntactically identical target sentence. Lexical repetition across prime and target sentences was manipulated between Experiment 1 and 2. This manipulation allowed us to determine whether priming effects increase when lexical material is repeated between the prime and target sentence. In particular, we can determine whether repeating the initial verb leads to larger priming effects. Identifying the effect of lexical repetition can help us to better understand the cognitive mechanisms and procedures that give rise to facilitated processing during on-line comprehension.

Studies of Syntactic Priming in Comprehension

A large and growing literature documents syntactic priming during sentence production (see Pickering & Ferreira, 2008, for a review). There is a much smaller literature on syntactic priming during comprehension (see Branigan et al., 2005; Tooley & Traxler, 2010, 2012, for

[i]This does not imply that conceptual structure has no effect on syntactic formulation during production (e.g., Griffin & Weinstein-Tull, 2003). Still, priming studies have isolated effects of syntactic overlap from effects of semantic/conceptual similarity.

reviews). There is an even smaller literature on syntactic priming effects that occur during the process of sentence interpretation. This smaller literature is most relevant to the issues addressed by the current experiments. The available evidence suggests that syntactic priming can be reliably observed during sentence interpretation, but it leaves open questions that need to be answered before we can confidently draw conclusions about the mechanisms and processes that produce syntactic priming in comprehension.

To date, published studies indicate syntactic priming during interpretation for sentences containing reduced relative clauses (Ledoux et al., 2007; Tooley et al., 2009; Traxler, 2008b; Traxler & Tooley, 2008), prepositional object and double-object datives (Arai et al., 2007; Carminati & van Gompel, 2008; Thothathiri & Snedeker, 2008a, 2008b), modifier-goal ambiguities (Traxler, 2008a), coordinate noun-phrases within sentences (Frazier et al., 2000; Scheepers & Crocker, 2004; Sturt et al., 2010), object-complement ambiguities (Trueswell & Kim, 1998), and "high-low" attachment ambiguities (Boudewyn et al., in press). Repetition of syntactic form has also been shown to influence *repetition suppression* effects in an fMRI study of passive voice sentences, which extended to conditions where the prime was given in one language (e.g. German) and the target in another (e.g., English; Weber & Indefrey, 2009; see also Hagoort, 2013). Because fMRI does not allow for precise temporal measurement, the repetition suppression effects may reflect processing that takes place after a sentence has been interpreted, rather than the process of sentence interpretation itself. Two studies have also indicated that massed practice (i.e., repeated exposure to syntactically challenging sentences) can facilitate subsequent processing of similar sentences (Long & Prat, 2008; Wells et al., 2009; see also Noppeney & Price, 2004). These long-term effects may reflect facilitation of syntactic processing, but it is possible that such effects represent something that happens following syntactic analysis.

Prior studies of reduced relatives indicate that exposure to a prime sentence affects the on-line processing of a target sentence that follows the prime immediately (Tooley et al., 2009; Traxler, 2008b). These studies also suggest that priming effects are larger when the initial verb in the prime sentence appears in the target. For example, Tooley and colleagues (2009) performed ERP and eye-tracking experiments manipulating verb-repetition between primes and targets. In some conditions, the prime sentence had the same initial verb as the target (as in 1 and 2):

(2) Prime sentence: The engineer examined by the board passed with flying colors.

(1) Target (with repeated verb): The defendant examined by the lawyer was unreliable.

In another condition, the initial verb in the prime sentence was a synonym of the verb in the target:

(3) Prime sentence: The engineer inspected by the board passed with flying colors.

(1) Target (with synonymous verb): The defendant examined by the lawyer was unreliable.

In an eye-tracking experiment, the by-phrase (*by the lawyer*) was processed more quickly in the target than in the prime when the verb was repeated across the prime and target sentences (e.g., 2 and 1), but not when the verb in the prime was a synonym of the verb in the target (e.g., 3 and 1). In an ERP experiment, a late positivity based on time-locking to the word *by*, which disambiguates the syntax of the sentence, was reduced for pairs like 2 and 1, but not for pairs like 3 and 1.

The reduced-relative results suggest that lexical overlap may determine whether priming occurs during target-sentence processing, but results for other kinds of sentences are not as clear cut. In sentences containing modifier-goal ambiguities, such as 4, verb repetition has not been shown to increase priming effects (Traxler, 2008a; see also Tanenhaus et al., 1995).

(4) The girl dropped the blanket on the floor in the basket earlier today.

In this study, conditions involving verb repetition and conditions that did not involve verb repetition produced indistinguishable effects on target-sentence processing. Similarly, priming studies for prepositional-object and double-object datives have not always shown increased priming effects for conditions involving verb repetition. In two visual-world studies, priming effects were detected only when a verb was repeated across a prime and a target (as in 5 and 6; Arai et al., 2007; Carminati & van Gompel, 2008):

(5) The pirate {gave the necklace to the princess/gave the princess the necklace}.

(6) The clown {gave (sold) the toys to the tourist/gave (sold) the tourist the toys}.

By contrast, two other visual world experiments showed priming effects for primes and targets that had different verbs (Thothathiri & Snedeker, 2008a, 2008b).

Comprehension studies have also examined the influence of a prime sentence on the outcome of the interpretive process. This kind of study has taken two forms. First, picture-matching experiments have shown that interpreting a globally ambiguous prime sentence in a particular way biases the picture-matching response to a subsequent target sentence (Branigan et al., 2005). If a participant reads *The girl poked the policeman with the umbrella*, and interprets that as meaning that the policeman has the umbrella (and the girl does not have the umbrella), the participant is more likely than usual to interpret *The clown poked the nurse with the pencil* in the same way (i.e., the nurse has the pencil; see also Raffray & Pickering, 2010). Comparable effects occur in experiments where the prime is given as a mathematical equation and the target is a syntactically ambiguous sentence (Scheepers et al., 2011); or vice-versa. These results indicate that processing a prime stimulus can influence syntactic structure assignment in a target at a very abstract level, but neither of these studies assessed structure-building processes as they were unfolding.

Finally, preference-judgment studies have shown that massed exposure to syntactically marginal sentences leads to increased acceptability ratings (Kaschak & Glenberg, 2004; Luka & Barsalou, 2005). These effects occur even when as much as a week passes between the exposure and test sessions (Luka & Choi, 2012; Kaschak et al., 2011). Increases in acceptability ratings may reflect facilitated on-line processing (i.e., acceptability increases as ease of processing increases), but this cannot be determined based solely on acceptability judgment.

The Importance of Lexical Repetition

Because priming effects are sometimes larger when verbs are repeated across primes and targets, this may indicate that semantic repetition, rather than syntactic repetition accounts for some part of the observed effects. However, a number of findings suggest that syntactic, rather than semantic, processes are responsible for previously observed facilitatory effects (as has been observed in production; Bock, 1986; Bock & Loebell, 1990). If semantic overlap drives target sentence processing, then sentences where prime and target verbs are synonymous should lead to priming, and this does not seem to be the case (Tooley et al., 2009). Further, semantic overlap should lead to priming at the repeated verb, which often is not the case (e.g., Traxler, 2008b). Finally, semantic overlap should lead to reductions in the N400 during target sentence processing. This type of effect is sometimes observed at the repeated verb, but reductions in late positivities are typically found following syntactically disambiguating material in target sentences, rather than reduced negativities (Ledoux et al., 2007; Tooley et al., 2009, in press).[ii]

Because larger effects are often observed when verbs are repeated across primes and targets, a further possibility is that participants notice the repeated verbs and develop a strategy to deal with the syntactically challenging target sentences. However, Tooley and colleagues (2009) showed that priming effects are just as large for the first one or two trials of priming experiments as they are for the experiments as a whole. This should not have happened if participants needed to learn a strategy before they experienced priming effects. Further, experiments in which non-syntactic strategic cues are readily apparent do not produce evidence of priming at and following syntactically disambiguating material in target sentences (Traxler & Tooley, 2008). These results indicate that the presence or absence of strategic cues dissociates from the presence or absence of priming effects. Priming effects have been observed in the absence of strategic cues; and they have failed to appear in the presence of strategic cues. Hence, syntactic priming effects most likely do not depend on participant strategies.

While previous studies of syntactic priming in comprehension have established that facilitated target processing can be reliably observed, a number of questions remain unanswered. One important question is the degree to which priming effects during on-line interpretation depend on lexical repetition across prime and target sentences. The two experiments reported here provide additional evidence that can help answer this question. In two eye-tracking experiments, lexical repetition was manipulated within the same stimuli. In Experiment 1, prime and target sentences had the same initial verb. In Experiment 2, the stimuli from Experiment 1 were rearranged so that none of the target sentences had the same initial verb as the prime.

[ii]The factors that contribute to N400 and P600 effects in ERP experiments are a topic of considerable discussion (Kim & Osterhout, 2005; Kuperberg et al., 2007). In the syntactic priming ERP experiments, reduced positivities likely reflect reduced costs of syntactic error correction or, possibly, reductions in the proportion of syntactic errors during target sentence processing (Boudewyn et al., in press; Ledoux et al., 2007; Tooley et al., 2009, in press).

Experiment 1

In Experiment 1, participants read reduced-relative or main-clause sentences after reading another reduced-relative or main-clause sentence with the same verb. It asked whether participants would read a reduced-relative target sentence such as (7c) faster after reading a reduced-relative prime sentence such as (7a) compared to a main-clause prime sentence such as (7b); and whether they would read a main-clause target sentence such as (7d) faster after reading another main-clause prime sentence such as (7b) compared to a reduced-relative prime sentence such as (7a):

(7a) The defendant examined by the lawyer was unreliable. (Reduced Relative)

(7b) The defendant examined the glove but was unreliable. (Main Clause)

(7c) The engineer examined by the doctor had a large mole. (Reduced Relative)

(7d) The engineer examined the license in the doctor’s office. (Main Clause)

Method

Participants—40 undergraduates from UC Davis participated in return for course credit. All participants were native English speakers with normal vision and hearing.

Items—The items consisted of 48 prime-target pairs constructed from sentences such as (7a-d). The reduced-relative sentences all had animate initial nouns (e.g., *speaker, manager*), as such sentences have been shown previously to produce robust increases in reading time starting roughly at the word *by* when contrasted with syntactically unambiguous control sentences (e.g., Trueswell et al., 1994; Clifton et al., 2003).

Crossing prime and target types led to four conditions of prime-target pairs: reduced-relative prime, reduced-relative target (RR-RR); main-clause prime, reduced-relative target (MC-RR); reduced-relative prime, main-clause target (RR-MC); and main-clause prime, main-clause target (MC-MC). The sentences were assigned to eight lists such that every sentence appeared once as a prime sentence and once as a target sentence, and such that no participant saw more than one version of each sentence. For example, one set of participants would see either (7a) or (7b) as a prime sentence, and either (7c) or (7d) as a target sentence. A different set of participants would see (7c) and (7d) as prime sentences, and (7a) and (7b) as target sentences. This design meant that each sentence served as its own control, and facilitated direct comparisons between the processing of prime and target sentences.

The prime-target sentence pairs were presented along with 61 fillers of various types. None of the filler sentences contained reduced-relative constructions or the same initial verb as the prime sentences. At least one filler sentence intervened between each prime-target pair.

Procedure—A Fourward Technologies Gen 6.6 Dual Purkinje Image Eye Tracker monitored participants’ eye movements while they read the experimental stimuli. The tracker has angular resolution of 10’ of arc. It monitored only the right eye’s gaze location. A PC displayed materials on a VDU 70 cm from participants’ eyes. The display consisted of Borland C default font with approximately 4 characters per degree of visual angle. The location of participants' gaze was sampled every millisecond and the software recorded the tracker's output to establish the sequence of eye fixations and their start and finish times. At the beginning of the experiment, the experimenter seated the participant at the tracker and used a bite plate and head rests to minimize head movements. After the tracker was aligned and calibrated, the experiment began. After reading each sentence, the participant pressed a key. Between each trial, a pattern of boxes appeared on the computer screen along with a cursor that indicated the participant's current gaze location. If the tracker was out of alignment, the experimenter recalibrated it before proceeding with the next trial.

The participant responded to a comprehension question after some of the filler sentences and did not receive feedback on their responses. All of the participants in the analyses reported below were at least 90% accurate.

Results and discussion

We report results for three regions of the target sentences. The *verb region* consists of the initial verb or past participle (e.g., *examined* in sentence 7). The *disambiguating region* consists of the phrase that followed the verb (a prepositional phrase in reduced-relative conditions, e.g., *by the lawyer*; a noun phrase in main-clause conditions, e.g., *the glove*). The *post-disambiguating region* consists of the two words immediately following the disambiguating region. The disambiguating region is the most critical, because it is the earliest point at which there is reliable information about whether the initial choice of analysis was correct or not, and is the point at which previous studies have shown differences between ambiguous and unambiguous sentences (e.g., Clifton et al., 2003; Trueswell et al., 1994).

We report four standard dependent measures (see Table 1). *First-pass time* is the sum of fixations in a region until the reader fixates outside the region. *Total time* is the sum of all fixations in a region. For these measures, trials on which the region was initially skipped were excluded. *First-pass regressions* (expressed as a percentage) include any eye movement that crossed a region's left-hand boundary immediately following a first-pass fixation. *Regression-path time* includes all of the fixations within a region as well as-refixations of previous regions starting with the first fixation and ending when the reader's gaze crosses the region's right-hand boundary. All fixation times less than 80 ms or greater than 3000 ms were excluded (e.g., Rayner & Pollatsek, 1989), thereby eliminating 8.8% of the data.

To assess effects of syntactic structure and prime type, we first performed 2 (Target type: reduced-relative vs. main-clause target) × 2 (Prime type: reduced-relative vs. main-clause prime) repeated measures ANOVAs.[iii] 2 × 2 ANOVAs were conducted for each dependent measure for each scoring region. Separate analyses treated participants (F_1) and items (F_2) as random effects. Both factors were treated as within-participants and within-items. These

[iii]Note that in these analyses, the disambiguating region in reduced relatives included the word "by" plus a noun phrase. The corresponding region in the main clause sentences included only the noun phrase (the noun phrases were identical across sentence types). However, the pattern of main effects, interactions, and differences between means was the same in another set of analyses in which the word "by" was omitted from the reduced relative conditions.

ANOVAs are reported in Table 2. Follow-up means comparisons were conducted to assess differences between individual conditions.

Disambiguating Region—The clearest evidence of priming is the finding that the form of the prime sentence affected reading time on the disambiguating region of the target sentence.

The target sentences showed interactions of prime and target types in first pass time, regression path time, and total time. As predicted, reduced-relative targets were easier to process following a reduced-relative prime than a main clause prime on first-pass time [F1 (1, 39) = 7.02, $p = .01$, MSe = 8079; F2 (1, 47) = 3.44, $p = .07$, MSe = 15021], regression-path time [F1 (1, 39) = 49.3, $p < .0001$, MSe = 25347; F2 (1, 47) = 37.0, $p < .0001$, MSe = 23358], and total time [F1 (1, 39) = 18.5, $p < .0001$, MSe = 18380; F2 (1, 47) = 17.7, $p < .0001$, MSe = 22791]. Main-clause targets were processed equally quickly whether they followed main-clause or reduced-relative primes (all $p > .10$).

There were also main effects of target type in the first-pass, regression-path time, and total time data (all $p < .001$). Reduced relative sentences proved more difficult to process than main clause sentences.[iv] These results replicate the commonly-observed pattern showing that reduced relatives are harder to process and interpret than main clause sentences.

Verb Region—No effects in the verb region were significant by both participants and items.

Post-Disambiguating Region—In this region of the target sentences, there was a main effect of target type in all of the dependent measures. These effects reflect greater difficulty overall in the reduced relative target sentences than in the main clause sentences. In addition, prime and target type interacted in the first-pass regressions data. Reduced relative targets following reduced relative primes had fewer regressions from the post-disambiguating region than reduced relative targets following main clause primes [F1 (1, 39) = 5.91, $p < .05$, MSe = 94.0; F2 (1, 47) = 7.05, $p = .01$, MSe = 100]. By contrast, there was no effect of prime type on regressions from the post-disambiguating region in the main clause target sentences [both F < 1].

Experiment 1 demonstrated that participants found a temporarily ambiguous reduced-relative sentence easier to process when it was immediately preceded by another reduced-relative sentence containing the same initial verb. These effects started to emerge shortly after the reader first encountered the disambiguating region (i.e., in first-pass time and regression-path time for the disambiguating region; in first-pass regressions from the post-disambiguating region). Thus, repetition of grammatical form can rapidly facilitate target sentence processing. Note that these effects appeared in the absence of any effects of

[iv]A combined analysis treating Sentence (prime vs. target sentence) as a further within-participants and within-items factor revealed three-way interactions (marginal by items for first-pass time, significant for total time) which confirmed different patterns of processing for prime and target sentences [first-pass time: F1 (1, 39) = 4.41, $p < .05$, MSe = 9320; F2 (1, 47) = 2.81, $p = .10$, MSe = 14314; total time: F1 (1, 39) = 4.30, $p < .05$, MSe = 19261; F2 (1, 47) = 6.39, $p < .02$, MSe = 16230].

repetition *at* the initial verb. Hence, they are unlikely to reflect differential spillover effects from the verb across the different conditions.

Experiment 2

To understand the nature of the representations and mechanisms that led to facilitation in Experiment 1, we need to know which aspects of the sentence need to be repeated. Experiment 2 therefore asks whether facilitated target processing occurs in the absence of repetition of the initial verb. Experiment 2 was identical to Experiment 1, except that the initial verb differed between the prime and target sentences.

Method

Participants—32 further participants from UC Davis took part.

Items and procedure—The sentences were identical to Experiment 1, but the two sentences that formed a prime-target pair had different verbs. The test sentences from Experiment 1 were rearranged in the experimental lists to eliminate the repetition of verbs across the prime and target sentences. In all other respects, the design and procedure were identical to Experiment 1.

Results and Discussion

The method of identifying outliers was identical to Experiment 1, with 5.3% of the data being eliminated. Table 3 presents mean values of the four dependent measures by region and condition. Table 4 presents results of the 2 (target type: reduced relative vs. main clause) × 2 (prime type: reduced relative vs. main clause) ANOVAs. In sharp contrast to Experiment 1, there were no effects of repetition. In particular, no interactions of prime and target type were significant by both participants and items.

Disambiguating Region—Data from the disambiguating region showed effects of target type, as reduced relatives proved more difficult to process than equivalent regions of main clause sentences. This main effect appears in first-pass time, regression-path time, and total time. However, no evidence of syntactic priming appeared in this region, as target and prime type did not interact.

Verb Region—Difficulty with reduced relatives is also indicated by greater total time on the verb region for reduced relatives compared to main clause sentences.

Post-Disambiguating Region—Difficulty processing the reduced relatives extended into the post-disambiguating region. The post-disambiguating region of the target sentences had greater first pass, regression-path time, and total time in the reduced relative condition than the main-clause condition.

When the initial verb was not repeated, a locally ambiguous reduced-relative sentence was processed no more easily following another reduced-relative sentence than following a main-clause sentence. These effects resemble Tooley and colleagues' (2009) results, where the initial verb in the prime sentence was a synonym of the initial verb in the target.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Experiments 1 and 2: Combined Analyses

To confirm that the pattern of priming in Experiment 1 differed from that in Experiment 2, we conducted additional analyses comparing target-sentence processing across the two experiments. We performed a series of 2 (Experiment: Experiment 1 vs. 2) × 2 (Target: reduced relative vs. main clause target) × 2 (Prime: reduced relative vs. main clause target) ANOVAs with all factors treated as within-participants and within-items, except for Experiment, which was treated as between-participants. These analyses focused on the disambiguating region, as this is where important aspects of syntactic processing are thought to occur. Figures 1 and 2 present mean first pass and total time for the disambiguating region, comparing the results from Experiment 1 and 2.

First-pass, total time, and regression-path time data, but not first-pass regressions, from the disambiguating region produced three way interactions [first pass: $F1\ (1, 70) = 9.59$, $p < .01$, $MSe = 8903$; $F2\ (1, 47) = 9.78$, $p < .01$, $MSe = 12655$; total time: $F1\ (1, 70) = 7.33$, $p < .01$, $MSe = 16551$; $F2\ (1, 47) = 7.00$, $p = .01$, $MSe = 22627$; regression-path time: $F1\ (1, 70) = 5.75$, $p < .05$, $MSe = 17321$; $F2\ (1, 47) = 6.74$, $p < .05$, $MSe = 18975$]. These analyses confirm that verb repetition affected the magnitude of priming. Significant priming effects occurred in the reduced-relative target sentences in first pass, regression-path time, and total time when the initial verb was repeated, but not when the verb was not repeated. The results also demonstrate that facilitated target processing could not have been due to repetition priming of the word *by*, because this did not differ between the two experiments.

Experiment 1 demonstrated that the processing of reduced-relative sentences is facilitated following another reduced-relative sentence using the same verb. Because these effects occurred on first-pass time during the disambiguating region immediately following the initial verb, these priming effects appeared to result from relatively early processing events. Indeed, the effects occurred at the same point as effects of animacy and other semantic factors (Clifton et al., 2003; McRae et al., 1998; Trueswell et al., 1994). In contrast, Experiment 2 found no evidence that reduced-relative sentences were facilitated following another reduced-relative sentence using a different verb, and the combined analysis confirmed this difference.

Readers may adopt (or favor) the main-clause analysis for the test sentences when they reach the initial verb. They may reanalyze the syntactic form of the sentence once they encounter the *by*-phrase. Presentation of the reduced-relative prime with the same verb likely facilitates this reanalysis, meaning that readers may initiate syntactic reanalysis even before encountering the by-phrase, but it may also change readers' initial degree of preference for the main-clause analysis.

The results of Experiments 1 and 2 suggest that the sentences' syntactic representations must incorporate lexical information associated with the initial verb. This accounts for the greater sized priming effects with verb repetition than without. The results do not cleanly discriminate between an account under which each lexical item has its own pool of syntactic structure representations and an account under which the 'lexical boost' is driven by associations between lexical entries and a pool of shared syntactic structure representations. However, the results are compatible with syntactic structure-building processes that are influenced by the lexical properties of critical words (e.g., MacDonald et al., 1994; Vosse & Kempen, 2000, 2009).

General Discussion

In two experiments, we used eye-tracking to investigate the conditions under which fixation times and regressions are affected by the form of an immediately preceding sentence. Experiment 1 showed that priming occurred in reduced-relative target sentences when prime and target sentences used the same initial verb. Experiment 2 did not find priming when prime and target sentences used different initial verbs, and the combined analysis showed a significant effect of verb repetition on priming (i.e., a 'lexical boost'; see also Tooley et al., 2009). We therefore conclude that verb repetition affects priming for reduced relative target sentences. Greater priming with verb repetition suggests that comprehenders access syntactic representations that are linked to lexical entries (MacDonald et al., 1994; Sag et al., 2003; Vosse & Kempen, 2000, 2009). Notice, however, that priming occurs when the verb is repeated but does not require the first noun to be repeated. In fact, previous eye-tracking studies have shown that subject-noun repetition does not facilitate processing of the syntactically disambiguating region of reduced-relative clauses (Traxler & Tooley, 2008, Experiment 2), even though priming occurs on the repeated noun itself and spills over to a following verb. Presumably priming occurs over a representation in which the verb is specified but not the first noun phrase; this noun phrase is then itself inserted into the representation.

Theoretical Frameworks

Different theoretical frameworks have been developed to explain the pattern of observed syntactic priming effects (see Tooley & Traxler, 2010, 2012, for overviews). Some of these accounts appeal to short-lived activation of stored representations (Branigan et al., 2005). The *residual activation* account appeals to processes involving the *lemma stratum* of lexical representation for effects in both production and comprehension. According to this account, syntactic alternatives are encoded as part of a word's lexical representation (see also MacDonald et al., 1994; Vosse & Kempen, 2000; Sag et al., 2003). Figure 3 represents a possible set of connections between a verb lemma and, syntactic structure representations, and aspects of morphology. [v] In this figure, the base representation for the lemma "examine" connects to two different structural possibilities, representing main verb syntax and relative clause syntax. In the main verb syntax, the verb "asks" for a noun phrase to its left, the subject noun phrase, and an object noun phrase on its right (as in categorial grammar, Moortgat, 1997). In the relative clause syntax, the verb "asks" for an optional relativizer on its left and an optional prepositional phrase on its right. [In our stimuli, the prime sentences never had a relativizer and always had an agent in the oblique position (which was an animate entity in all but one test sentence), but these are not required.]

According to the residual activation hypothesis, when people produce or comprehend sentences, they activate connections between lemma nodes (the left-most oval in Figure 3)

[v] This is only a rough sketch of the way different aspects of representation could be tied together. See Jackendoff, 2003; Vosse & Kempen, 2000, 2009, for more complete, linguistically motivated descriptions of "vertically integrated" representations.

and syntactic structure representations that encode information about how a given lexical item (e.g., *examine*) can combine with other items (e.g., *defendant, lawyer, glove*), in what order the items should be expressed, and how they should be inflected. Processing of a prime sentence leads to temporary increases in the activation of structural representations needed to form dependencies between words in the sentence. If a subsequently encountered target sentence requires those same structural representations, processing will be facilitated. Importantly, the association of syntactic structure representations to word-level (lexical) representations provides a means to generate the *lexical boost* (larger priming effects when a prime and target share a lexical item). That is, priming may occur when the same structural representations are required for both a prime and a target, but if a word in the target sends the comprehender back to the same lemma as the prime, this will increase priming, as the connection between the lemma and the necessary syntactic structure representation will enjoy a degree of *residual activation*.

It might be argued that the critical syntactic configuration involves the initial noun, as it ends up being the head of phrase in which the reduced relative clause appears. In fact, lexicalized syntax accounts such as unification grammar (Vosse & Kempen, 2000, 2009) view parsing as a process of selecting lexical representations that have the appropriate "tags" that allow them to combine with other words in a sentence. In the case of the reduced relative, the initial lexical choice for the subject noun would normally be the version that has the noun at its core and an "S" node at the "top". That choice would allow the subject noun to combine with a main verb, which also has an "S" node at its "top". However, except under very limited and special circumstances [vi] the preposition "by" rules out these lexical choices and their corresponding syntactic consequences. At that point, resolving the conflict involves choosing another "flavor" of the head noun, one that allows a relative clause on the right, rather than a main verb. Making that choice entails a further alternative choice for the verb, as the initial main verb interpretation does not allow for a prepositional phrase on the right (for transitive verbs; again, except under special circumstances). Prior experimental results suggest that the relative clause configuration is not primed when two sentences share an initial noun (Traxler & Tooley, 2008). It remains an open question whether noun-associated syntactic structures can be primed in comprehension (there does appear to be a noun-associated lexical boost in production; Cleland & Pickering, 2003). The current results, which indicate that having the same initial verb leads to facilitated target processing, may indicate that verb-linked syntactic representations remain activated across sentence boundaries or that such connections are more easily retrieved or reactivated when disambiguating information in the target sentence is encountered. At the moment, we have evidence that verb repetition matters when sentence structure is repeated in reduced relatives, but there is as yet no evidence that noun repetition matters.

Other frameworks appeal to *implicit learning* as a mechanism contributing to syntactic priming, especially relatively durable priming effects. One type of implemented model (Chang et al., 2000, 2003, 2006; see also Chang et al., 2012; Fitz et al., 2011) was developed in part to account for long-lived patterns of priming in production studies. It has since been

[vi] Such as heavy-NP shift, "The girl dressed by the man the salad that had very fresh greens that were picked lovingly…"

extended to account for patterns of syntactic structure learning in children and adults (Rowland et al., 2012). The basic processing architecture in this family of models is rooted in the parallel-distributed processing tradition, Elman's simple-recurrent network model in particular (Elman, 2004). Prediction and error-based learning are core features of this class of model. In the case of comprehension, the model would predict the next constituent as each new word is encountered. When the actual input differs from the predicted input, as when a relative clause appears instead of a direct object NP, the model changes the connection weights between input, hidden, and output units. In this way, the model's predictions can change due to exposure, and preferences for different types of sentence can increase or decrease.

According to this type of account, the strength of the underlying syntactic structure representations increases with exposure to sentences of the appropriate type. This type of learning takes place without conscious effort on the part of the comprehender and outside of conscious awareness. Implicit learning of this kind may explain facilitatory effects that appear in studies involving large-scale exposure to sentences of a given type (Long & Prat, 2008; Wells et al., 2009), as well as changes in preferences for unusual syntactic forms (Luka & Barsalou, 2005; Luka & Choi, 2012; Kaschak & Glenberg, 2004; Kaschak et al., 2011).

The implicit learning account can operate on features of the input beyond structural configurations or sequences of categories. Implicit learning can be applied to simple word sequences (as in Arnon & Snider, 2010). This viewpoint would attribute priming effects in the current study to increases in the likelihood attributed to specific bigrams. That is, reading the prime sentence *The defendant examined by*, would increase the bigram probability of *examined by*, which would facilitate processing of a subsequent sentence that has the same bigram, such as *The engineer examined by the board...* While this viewpoint is compatible with the current results, it is not as compatible with a range of other priming effects. For example, "short relatives" that do not include a by-phrase are as effective as full and reduced relatives in priming of reduced relative targets (Traxler et al., 2014). Hence, bigram repetition is not necessary for priming. Other priming experiments in which the primes and targets have different forms of reduced relative clauses also show facilitated target processing (Traxler, 2008b). Finally, some abstract structural relations are expressed via different sentences that have the same overt structural cues. These types of sentences can prime one another, even though the overt structural cues, by themselves, are not reliable indicators of structural relationships. A sentence such as *The girl hit the boy with the bruise* primes a sentence such as *The policeman hit the robber with the mustache*. A sentence such as *The girl hit the boy with the paddle* does not. Hence, bigram repetition is not sufficient for priming. Because bigram repetition is neither necessary nor sufficient for priming, priming is likely independent of bigram repetition. This does not mean that bigram repetition can have no effect on processing. Rather, it suggests that any effects of bigram repetition likely occur via a mechanism that differs from the one that produced the priming effects observed in Experiment 1.

While a model that relies on prediction and error-correction can account for many phenomena related to syntactic priming, Chang and colleagues' model, as currently implemented, does not have a mechanism that can readily produce the *lexical boost*. The fundamental problem is that, if the model can adjust the connection strengths fast enough to produce trial-to-trial lexical boost effects, this will lead to catastrophic forgetting of previously learned patterns. “(A) large learning rate, which is needed to explain large lexical boost effects, will cause verb-structure associations to fluctuate violently and eventually knowledge about the frequency of verb-structure associations will be lost (Chang et al., 2012, p. 265).”

Because priming in comprehension appears to be subject to the “lexical boost”, it might make sense to favor the residual activation account of syntactic priming in comprehension. However, the wider pattern of effects observed in comprehension and production priming studies does not necessarily justify this conclusion. For example, a recent study indicates that the lexical boost occurs only when prime and target expressions are immediately adjacent (Hartsuiker et al., 2008). Further, despite the absence of the lexical boost, priming effects in production and comprehension can persist when unrelated sentences intervene between the prime and the target (Bock & Griffin, 2000; Tooley et al., in press). Residual activation is not likely responsible for relatively long-lasting priming effects. Ideally, an account of syntactic priming would cover phenomena in both production and comprehension. It is possible to construct an account that applies to only one modality, and that move may be ultimately warranted when all of the facts are in. For the moment, however, we are working on the assumption that the correct account of priming should accommodate both production and comprehension phenomena. Because neither residual activation nor implicit learning via error correction appears compatible with the full range of observed effects, it is possible that more than one mechanism contributes to the observed outcomes. In fact, a number of theorists have advocated d*ual-mechanism* accounts (Tooley, 2009; see also Traxler & Tooley, 2007; Hartsuiker et al., 2008; Chang et al., 2012, Fitz et al., 2011). This type of account proposes that short-lived residual activation accounts for the lexical boost, while more durable implicit learning (instantiated in Chang’s models as long-lived changes in connection weights in a PDP network) accounts for lasting changes in structural preferences. (Chang and colleagues attribute effects occurring over different time scales to different neural structures; slow-changing representations are hypothesized to reside in cortical structures, faster changing representations are supported by hippocampal systems. This is an intriguing hypothesis that could be investigated by adapting the experimental paradigm from Experiments 1 and 2 for a neuroimaging study.)

The current experiments do not allow us to definitively locate the specific parsing operations that are affected by the prime sentence. Conceptually, there are two salient, plausible types of procedures that prime sentences could influence. Prime sentence-processing could weaken comprehenders’ tendency to adopt the simpler, more frequent (main clause) interpretation of a temporarily ambiguous reduced relative. In addition, and perhaps separately, prime sentence processing could influence the ease with which participants recover an alternative syntactic and thematic analysis of these ‘garden-path’ sentences (i.e., priming could affect syntactic analysis, syntactic reanalysis, or both). These effects could emerge during the initial construction of a syntactic analysis of the target sentence; or the effects could emerge during syntactic reanalysis (i.e., during “garden-path recovery”). The pattern of effects across the experiments reported here suggests that both processes may have contributed. The priming effects showed up relatively quickly during target sentence processing, appearing in first-pass reading of the disambiguating region and first-pass regressions from the region immediately following the disambiguating region. This may indicate that reading the prime sentence affected the likelihood that readers considered the reduced relative analysis during early syntactic processing. Note, however, that total time for ambiguous reduced relative target sentences was still longer than comparable regions of main clause targets even in the ‘primed’ conditions (whether the word “by” was included or not). This would seem to indicate that processing the prime sentence did not completely alleviate processing difficulty associated with the reduced relative form. However, because we did not test unambiguous (e.g., full relative) target sentences, we do not have a direct comparison of ambiguous and unambiguous target sentences containing relative clauses. Further, it is possible that prime sentences eliminated ‘garden-path’ effects on some proportion of trials, but not on all of them. This would reduce mean fixation times for the targets, without making them equivalent to the syntactically simpler and more frequent main clause sentences.

The final interpretation of reduced relatives entails revising both syntactic and thematic commitments. A noun phrase that is initially treated as containing only a determiner and noun must be reanalyzed to incorporate a relative clause. In the same vein, there is an associated semantic consequence, as the initial noun must be “demoted” from agent (initiator of action) to theme, experiencer, or patient (the target of an action performed by the noun expressed within the prepositional phrase). Hence, the observed facilitatory effects may result from facilitated thematic processing, rather than facilitated structural analysis or reanalysis. That account explains target-sentence facilitation as resulting from more rapid rejection of the agent thematic role interpretation of the initial noun. Given a correlation between patient-first semantics and relative clause syntax, the reduced relative would be less jarring if the initial noun is treated as patient. In fact, prior studies show that processing of the syntactically disambiguating by-phrase is reduced when semantic cues favor the patient interpretation for the initial noun (Trueswell et al., 1994; Clifton et al., 2003).[vii] Similar logic can be applied to modifier-goal priming, which also involves revision of thematic commitments (a prepositional phrase changes from goal to location; see also Tanenhaus et al., 1995; Boudewyn et al., in press; Traxler, 2008a).

The current experiment was not designed specifically to adjudicate between an account in which thematic assignment precedes syntactic configuration and an account in which syntactic role assignment drives thematic role assignment. However, the presence of the lexical boost reduces the viability of any simple thematic account. That is, a prime sentence that has the same thematic role order as the target does not always lead to facilitated target-sentence processing (this is true across a variety of sentence types; including the current Experiment 2, Tooley et al., 2009; Traxler & Tooley, 2008; Arai et al., 2007). The thematic account also does not appear to apply in a straightforward fashion to Trueswell and Kim’s

[vii]Trueswell and colleagues’ results indicated that early semantic cues could eliminate the “garden-path” effect associated with reduced relatives. Clifton and colleagues’ results indicated that semantic cues reduced, but did not eliminate the reduced relative penalty.

(1998) fast priming results. In that case, the prime stimulus was a briefly presented verb that either was or was not likely to take a sentence complement as its post-verbal argument. The lexicalized syntax hypothesis is straightforwardly compatible both with the lexical boost in reduced relative comprehension priming and the verb subcategory effect in the fast priming paradigm.

These experiments will likely not be the final chapter in the search for lexically independent priming of reduced relative target sentences. Repetition of thematic role order may have been insufficient for priming in these experiments because the reduced relative primes place main clause thematic and syntactic configuration (agent-patient; subject-main verb) in competition with reduced relative configuration (patient-agent; subject (relative clause) – main verb). It is possible that a full relative prime that had a different verb from a reduced relative target would be an effective prime, as the relative clause syntactic and thematic configuration might have greater durability as a consequence of reduced conflict with the main clause configuration. Such an outcome would, in addition, provide evidence that precise syntactic repetition is not necessary for priming to occur, and this would point towards a more vital role for thematic-role order.

In the experiments reported here, priming effects were observed only when the prime and target sentences had the same critical verb (see also Arai et al., 2007; Tooley et al., 2009). Viewed in isolation, these results would imply that syntactic structure information is tied very closely to individual lexical entries (as in, e.g., Vosse & Kempen, 2000). However, priming studies from other on-line comprehension studies (Thothathiri & Snedeker, 2008a, b; Traxler, 2008b) and production studies (see Pickering & Ferreira, 2008) suggest that priming can be reliably observed when prime and target sentences do not have content-word overlap. A safer conclusion, then, would be that lexical repetition is not strictly necessary for priming to occur, but that effects tend to be larger with repetition than without. Thus, comprehension priming appears to display the ‘lexical boost.’ Further studies will be required to determine whether and when priming in comprehension occurs in the absence of lexical overlap.

Conclusions

Encountering a reduced relative sentence facilitates processing of a reduced relative target sentence. In this study, priming effects depended on lexical repetition between primes and targets, suggesting that connections between lexical entries and syntactic representations contributed to the observed effects. Main clause primes with the same verb as the targets failed to produce priming. These results indicate that structural overlap, not just repeated meaning, repeated verbs by themselves, or spillover effects from repeated verbs, causes priming. Hence we favor an account under which abstract structural and thematic information can make dis-preferred analyses of sentences more salient or accessible, leading to the observed priming effects.

Acknowledgments

The authors wish to thank Jason Golubock and Lori Miyasato for assistance in data collection. This work was supported in part by awards from the National Institutes of Health (#1R01HD073948) and by the National Science Foundation (#1024003), both awarded to the first author.

Appendix: Experimental Stimuli

Experiments1-2 (RR = reduced-relative, FR = full relative, SR = short relative, RRDV = reduced-relative with different verb, MC = main clause)

1

(RR) The speaker proposed by the group would work perfectly for the program.

(MC) The speaker proposed the solution to the group at the space program.

(RR) The manager proposed by the directors was a bitter old man.

(MC) The manager proposed the changes to the bitter old man.

2

(RR) The man paid by the parents was unreasonable.

(MC) The man paid the bill even though it was unreasonable.

(RR) The accountant paid by the company had a masters degree in finance.

(MC) The accountant paid the company back for his masters degree.

3

(RR) The lawyer sent by the governor arrived late.

(MC) The lawyer sent the files to the governor late last week.

(RR) The referee sent by the league office had excellent vision.

(MC) The referee sent the report to the league office.

4

(RR) The student accepted by the school was very pleased.

(MC) The student accepted the offer from the school yesterday.

(RR) The candidate accepted by the party ran for governor.

(MC) The candidate accepted the offer from the party last night.

5

(RR) The woman sketched by the artist was very beautiful.

(MC) The woman sketched the artist who was very beautiful.

(RR) The student sketched by the painter had a mole on her hip.

(MC) The student sketched the model who had a mole on her hip.

6

(RR) The defendant examined by the lawyer turned out to be unreliable.

(MC) The defendant examined the bloody glove but it did not fit right.

(RR) The engineer examined by the licensing board passed with flying colors.

(MC) The engineer examined the license on the wall in the doctor's office.

7

(RR) The specialist requested by the hospital had finally arrived.

(MC) The specialist requested the instrument that had finally arrived.

(RR) The surgeon requested by the patient was one of the finest.

(MC) The surgeon requested the nurse who was one of the finest.

8

(RR) The artist studied by the historian was relatively unknown.

(MC) The artist studied the history of the Italian renaissance.

(RR) The general studied by the journalist led the campaign.

(MC) The general studied the maps before the campaign.

9

(RR) The man recognized by the spy took off down the street.

(MC) The man recognized the spy who took off down the street.

(RR) The criminal recognized by the victim had a long rap sheet.

(MC) The criminal recognized the parole officer with the rap sheet.

10

(RR) The man recorded by the secretary could not be understood.

(MC) The man recorded the notes that the secretary could not understand.

(RR) The singer recorded by the studio had a nasty reputation.

(MC) The singer recorded the song at the studio with the bad reputation.

11

(RR) The author read by the student was very difficult to understand.

(MC) The author read the review but it was difficult to understand.

(RR) The poet read by the class impressed the English teacher.

(MC) The poet read the note to the class who were very impressed.

12

(RR) The director watched by the cop was in a bad part of the town.

(MC) The director watched the actor pretending to be in a bad part of town.

(RR) The lifeguard watched by the swimmer had a deep dark suntan.

(MC) The lifeguard watched the swimmer who had a deep dark suntan.

13

(RR) The scientists considered by the committee each had limitations.

(MC) The scientists considered the formula that had some limitations.

(RR) The applicant considered by the board had a good track record.

(MC) The applicant considered the job and had a good track record.

14

(RR) The assistant graded by the professor was very interesting.

(MC) The assistant graded the papers that were very interesting.

(RR) The competitors graded by the panel were trying to win a prize.

(MC) The competitors graded the products and tried to win a prize.

15

(RR) The mailman expected by the secretary arrived too late.

(MC) The mailman expected the secretary to arrive very late.

(RR) The pregnant mother expected by the hospital arrived in the morning.

(MC) The pregnant mother expected the infant to arrive in the morning.

16

(RR) The man towed by the garage was parked illegally.

(MC) The man towed the car after it was parked illegally.

(RR) The driver towed by the police had left his lights on.

(MC) The driver towed the police car but left his lights on.

17

(RR) The prisoner transported by the guards was closely watched.

(MC) The prisoner transported the guards that he kidnapped.

(RR) The courier transported by the airline had secret documents.

(MC) The courier transported the secret documents to the airport.

18

(RR) The teacher loved by the class was very easy to understand.

(MC) The teacher loved the class and was very easy to understand.

(RR) The actress loved by the fans looked great in a blue dress.

(MC) The actress loved the fans who turned up to see the premier.

19

(RR) The contestant selected by the judges did not deserve to win.

(MC) The contestant selected the wrong answer and did not win.

(RR) The customer selected by the security guard had not stolen anything.

(MC) The customer selected the jacket but had not stolen anything.

20

(RR) The thief identified by the victim was held for questioning.

(MC) The thief identified the victim's address after questioning.

(RR) The victim identified by the coroner had been wearing a blue shirt.

(MC) The victim identified the assailant who had worn a blue shirt.

21

(RR) The troops attacked by the terrorists suffered heavy losses.

(MC) The troops attacked the terrorists who suffered heavy losses.

(RR) The pilot attacked by the angry crowd disappeared forever.

(MC) The pilot attacked the angry crowd and disappeared forever.

22

(RR) The boy described by the lady was quite handsome.

(MC) The boy described the lady who was quite beautiful.

(RR) The secretary described by the visitor had green eyes.

(MC) The secretary described the visitor as having green eyes.

23

(RR) The woman scratched by the cat was badly injured.

(MC) The woman scratched the cat behind the ears.

(RR) The child scratched by the thorn bush was looking for her ball.

(MC) The child scratched her head as she was looking for her ball.

24

(RR) The client wanted by the advertiser was worth a lot of money.

(MC) The client wanted the advertiser to do a better job.

(RR) The personal trainer wanted by the athlete was very busy.

(MC) The personal trainer wanted the athlete to work much harder.

References

Arai M, Van Gompel RPG, Scheepers C. Priming ditransitive structures in comprehension. Cognitive Psychology. 2007; 54:218–250. [PubMed: 16973144]

Arnon I, Snider N. More than words: Frequency effects for multi-word phrases. Journal of Memory and Language. 2010; 62:67–82.

Bever, TG. The cognitive basis for linguistic structures. In: Hayes, JR., editor. Cognition and the development of language. New York: Wiley; 1970. p. 279-362.

Bock JK. Syntactic persistence in language production. Cognitive Psychology. 1986; 18:355–387.

Bock JK, Loebell H. Framing sentences. Cognition. 1990; 35:1–39. [PubMed: 2340711]

Bock K, Griffin ZM. The persistence of structural priming: Transient activation or implicit learning? Journal of Experimental: General. 2000; 129:177–192.

Boudewyn MA, Zirnstein M, Swaab TY, Traxler MJ. Priming prepositional phrase attachment: Evidence from eye-tracking and ERPs. Quarterly Journal of Experimental Psychology. in press.

Branigan HP, Pickering MJ, McLean JF. Priming prepositional-phrase attachment during language comprehension. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2005; 31:468–481.

Carminati MN, van Gompel RPG, Scheepers C, Arai M. Syntactic priming in comprehension: The role of argument order and animacy. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2008; 34:1098–1110.

Chang F, Bock JK, Goldberg A. Can thematic roles leave traces of their places? Cognition. 2003; 90:29–49. [PubMed: 14597269]

Chang F, Dell GS, Bock K. Becoming syntactic. Psychological Review. 2006; 113:234–272. [PubMed: 16637761]

Chang F, Dell GS, Bock K, Griffin ZM. Structural priming as implicit learning: A comparison of models of sentence production. Journal of Psycholinguistic Research. 2000; 29:217–229. [PubMed: 10709186]

Chang F, Janciauskas M, Fitz H. Language adaptation and learning: Getting explicit about implicit learning. Language and Linguistics Compass. 2012; 6:259–278.

Cleland AA, Pickering MJ. The use of lexical and syntactic information in language production: Evidence from the priming of noun-phrase structure. Journal of Memory and Language. 2003; 49:214–230.

Clifton C Jr, Traxler MJ, Mohammed MT, Williams RS, Morris RK, Rayner K. The use of thematic role information in parsing: Syntactic processing autonomy revisited. Journal of Memory and Language. 2003; 49:317–334.

Elman JL. An alternative view of the mental lexicon. Trends in Cognitive Sciences. 2004; 8:301–306. [PubMed: 15242689]

Ferreira F, Clifton C. The independence of syntactic processing. Journal of Memory and Language. 1986; 25:75–87.

Fitz, H.; Chang, F.; Christiansen, MH. A connectionist account of the acquisition and processing of relative clauses. In: Kidd, E., editor. The Acquisition of Relative Clauses: Processing, Typology, and Function. Amsterdam, The Netherlands: John Benjamins; 2011. p. 39-60.

Griffin ZM, Weinstein-Tull J. Conceptual structure modulates structural priming in the production of complex sentences. Journal of Memory and Language. 2003; 49:537–555.

Frazier L, Munn A, Clifton C Jr. Processing coordinate structures. Journal of Psycholinguistic Research. 2000; 29:343–371. [PubMed: 10953824]

Hagoort, P. Should Psycholinguistics Ignore the Language of the Brain?; Paper presented to the 26th annual CUNY Conference on Human Sentence Processing; Columbia, SC. 2013 Mar.

Hartsuiker RJ, Bernolet S, Schoonbaert S, Speybroeck S, Vanderelst D. Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. Journal of Memory and Language. 2008; 58:214–238.

Jackendoff, R. Foundations of Language. Oxford, England: Oxford University Press; 2003.

Kaschak MP, Glenberg AM. This Construction Needs Learned. Journal of Experimental Psychology: General. 2004; 133:450–467. [PubMed: 15355149]

Kaschak MP, Kutta TJ, Schatschhneider C. Long-term cumulative structural priming persists for (at least) one week. Memory & Cognition. 2011; 39:381–388. [PubMed: 21264596]

Kim A, Osterhout L. Semantic control of combinatory language processing in syntactically unambiguous sentences: Evidence from event related potentials. Journal of Cognitive Neuroscience. 2005:211–211.

Kuperberg GR, Kreher DA, Sitnikova T, Caplan DN, Holcomb PJ. The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. Brain and Language. 2007; 100:223–237. [PubMed: 16546247]

Ledoux K, Traxler MJ, Swaab TY. Syntactic priming in comprehension: Evidence from event-related potentials. Psychological Science. 2007; 18:135–143. [PubMed: 17425534]

Long DL, Prat CS. Individual differences in syntactic ambiguity resolution: Readers vary in their use of plausibility information. Memory & Cognition. 2008; 36:375–391. [PubMed: 18426067]

Luka BJ, Barsalou LW. Structural facilitation: Mere exposure effects for grammatical acceptability as evidence for syntactic priming in comprehension. Journal of Memory and Language. 2005; 52:436–459.

Luka BJ, Choi H. Dynamic grammar in adults: Incidental learning of natural syntactic structures extends over 48 hours. Journal of Memory and Language. 2012; 66:345–360.

MacDonald MC, Pearlmutter NJ, Seidenberg MS. The lexical nature of syntactic ambiguity resolution. Psychological Review. 1994; 101:676–703. [PubMed: 7984711]

McRae K, Spivey-Knowlton MJ, Tanenhaus MK. Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. Journal of Memory and Language. 1998; 38:283–312.

Moortgat, M. Categorial type logics. In: van Benthem, J.; ter Meulen, A., editors. Handbook of Logic and Language. Amsterdam, The Netherlands: Elsevier; 1997. p. 93-178.

Noppeney U, Price CJ. An fMRI study of syntactic adaptation. Journal of Cognitive Neuroscience. 2004; 16:702–713. [PubMed: 15165357]

Pickering MJ, Branigan HP. The representation of verbs: Evidence from syntactic priming in language production. Journal of Memory and Language. 1998; 39:633–651.

Pickering MJ, Ferreira VS. Structural priming: A critical review. Psychological Bulletin. 2008; 134:427–459. [PubMed: 18444704]

Raffray CN, Pickering MJ. How do people construct logical form during language comprehension? Psychological Science. 2010; 21:1090–1097. [PubMed: 20587697]

Rayner, K.; Pollatsek, A. The psychology of reading. New York: Prentice-Hall; 1989.

Rowland CF, Chang F, Ambridge B, Pine JM, Lieven EVM. The development of abstract syntax: Evidence from structural priming and the lexical boost. Cognition. 2012; 125:49–63. [PubMed: 22986018]

Sag, IA.; Wasow, T.; Bender, EM. Syntactic Theory: A Formal Introduction. Palo Alto, CA: Center for the Study of Language and Information; 2003.

Scheepers, C.; Crocker, MW. Constituent order priming from listening to comprehension: A visual-world study. In: Carreiras, M.; Clifton, C., Jr, editors. The on-line study of sentence comprehension: Eyetracking, ERPs, and beyond. New York: Psychology Press; 2004. p. 167-185.

Scheepers C, Sturt P, Martin CJ, Myachykov A, Teevan K, et al. Structural priming across cognitive domains: From simple arithmetic to relative-clause attachment. Psychological Science. 2011; 22:1319–1326. [PubMed: 21873569]

Sturt P, Keller F, Dubey A. Syntactic priming in comprehension: Parallelism effects with and without coordination. Journal of Memory and Language. 2010; 62:333–351.

Tanenhaus MK, Spivey-Knowlton MJ, Eberhard KM, Sedivy JC. Integration of visual and linguistic information in spoken language comprehension. Science. 1995; 268:1632–1634. [PubMed: 7777863]

Thothathiri M, Snedeker J. Give and take: Syntactic priming during spoken language comprehension. Cognition. 2008a; 108:51–68. [PubMed: 18258226]

Thothathiri M, Snedeker J. Syntactic priming during comprehension in three and four-year old children. Journal of Memory and Language. 2008b; 58:188–213.

Tomasello, M. Constructing a language: A usage-based theory of language acquisition. Cambridge, MA: Harvard University Press; 2003.

Tooley, KM. Is Syntactic Priming in Sentence Comprehension Really Just Implicit Learning?; Paper presented to the 22nd Annual CUNY Conference on Human Sentence Processing; Davis, CA. 2009 Mar.

Tooley KM, Swaab TY, Boudewyn MA, Zirnstein M, Traxler MJ. Evidence for priming across intervening sentences during on-line sentence comprehension. Language and Cognitive Processes. In Press.

Tooley, KM.; Traxler, MJ. Syntactic priming in comprehension: A dual mechanism account. In: Mishra, R., editor. The Relationship between Language and Thought. Munich, Germany: Lincom Europa; 2012.

Tooley KM, Traxler MJ. Syntactic priming effects in comprehension: A critical review. Language and Linguistics Compass. 2010; 4:925–937.

Tooley KM, Traxler MJ, Swaab TY. Electrophysiological and behavioral evidence of syntactic priming in sentence comprehension. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2009; 35:19–45.

Traxler MJ. Lexically independent priming in online sentence comprehension. Psychonomic Bulletin & Review. 2008a; 15:149–155. [PubMed: 18605495]

Traxler MJ. Structural priming among prepositional phrases: Evidence from eye-movements. Memory & Cognition. 2008b; 36:659–674. [PubMed: 18491504]

Traxler MJ, Tooley KM. Lexical mediation and context effects in parsing. Brain Research. 2007; 1146:59–74. [PubMed: 17112486]

Traxler MJ, Tooley KM. Priming in sentence comprehension: Strategic or syntactic? Language and Cognitive Processes. 2008; 23:609–645.

Traxler MJ, Tooley KM, Pickering MJ. Effects of Structural, Lexical, Phonological, and Thematic Repetition on Sentence Processing. Manuscript submitted for publication. 2014

Trueswell JC, Kim AE. How to prune a garden path by nipping it in the bud: Fast priming of verb argument structure. Journal of Memory and Language. 1998; 39:102–123.

Trueswell JC, Tanenhaus MK, Garnsey SM. Semantic influences on parsing: Use of thematic role information in syntactic disambiguation. Journal of Memory and Language. 1994; 33:285–318.

Vosse T, Kempen G. Syntactic structure assembly in human parsing: A computational model based on competitive inhibition and lexicalist grammar. Cognition. 2000; 75:105–143. [PubMed: 10771275]

Vosse T, Kempen G. The Unification Space implemented as a localist neural net: Predictions and error-tolerance in a constraint-based parser. Cognitive Neurodynamics. 2009; 3:331–346. [PubMed: 19784798]

Weber K, Indefrey P. Syntactic priming in German–English bilinguals during sentence comprehension. Neuroimage. 2009; 46:1164–1172. [PubMed: 19328233]

Wells JB, Christiansen MH, Race DS, Acheson DJ, MacDonald MC. Experience and sentence processing: Statistical learning and relative clause comprehension. Cognitive Psychology. 2009; 58:250–271. [PubMed: 18922516]

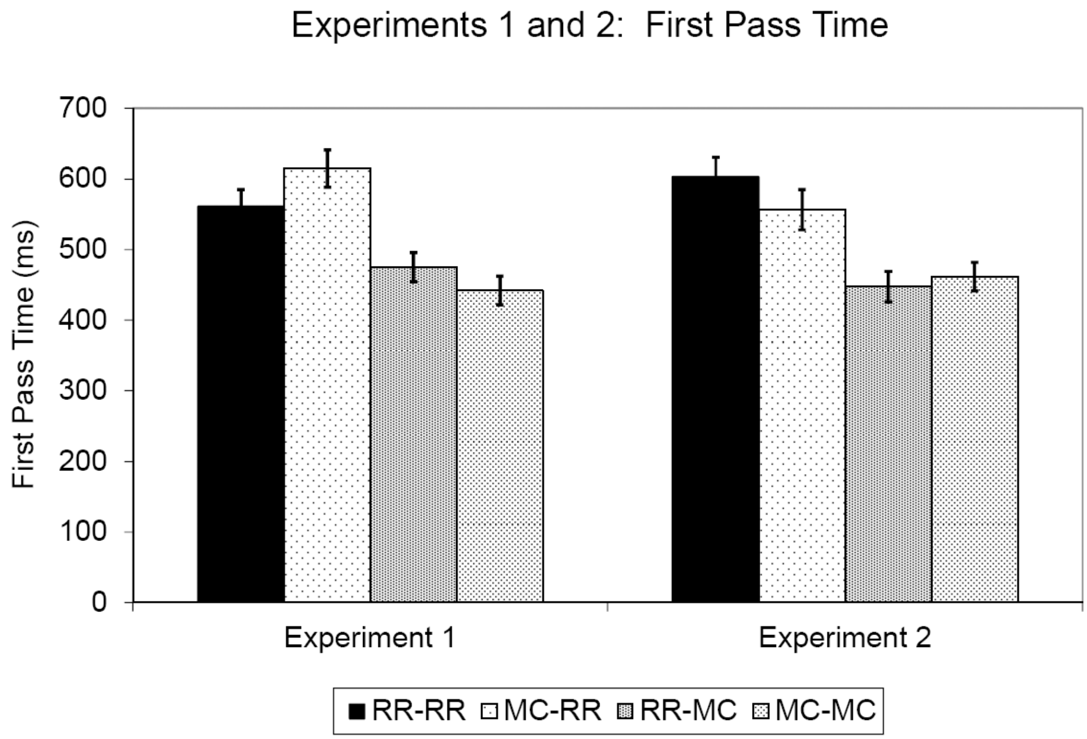

Figure 1. Experiments 1 and 2, Target Sentence First Pass Time in the Disambiguating Region
First pass time from the target sentence disambiguating region by condition for Experiments 1 and 2. Error bars represent standard errors.

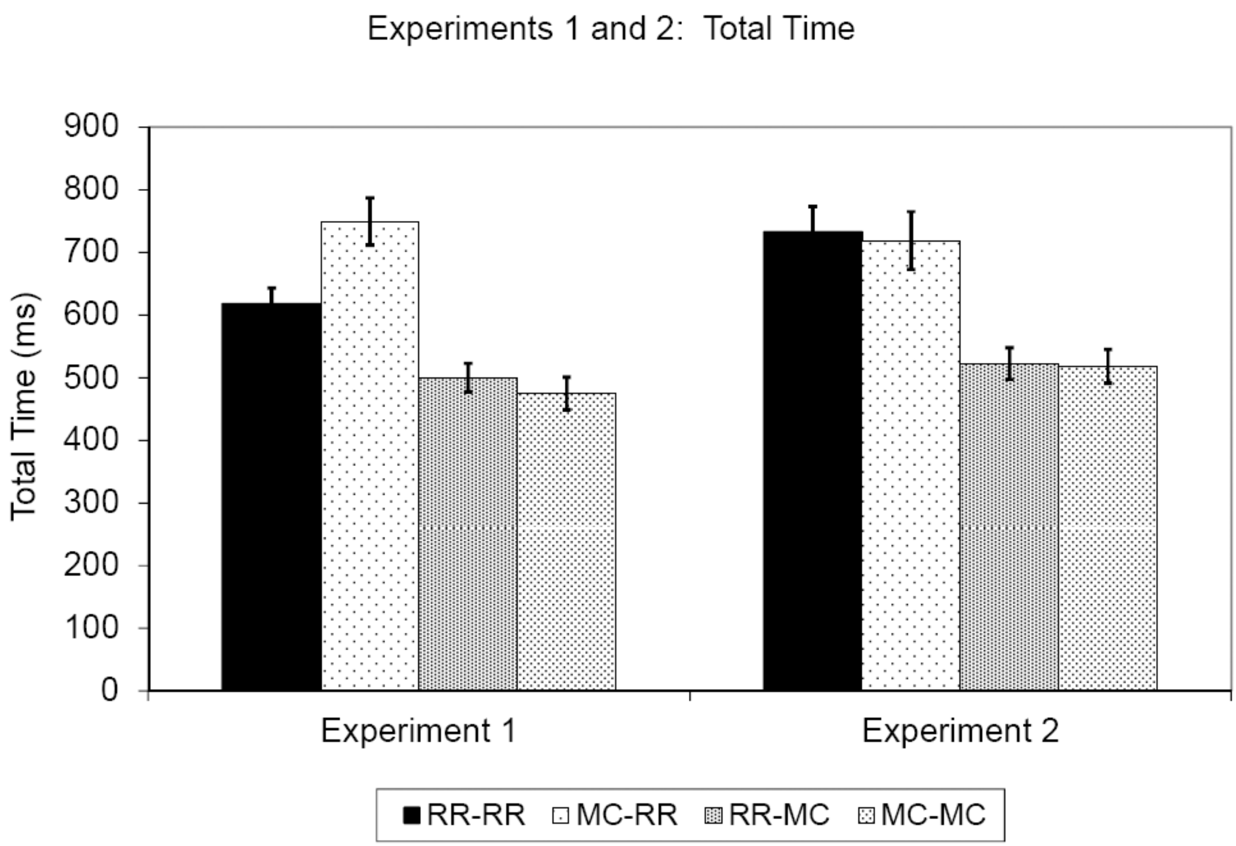

Figure 2. Experiments 1 and 2, Target Sentence Total Time in the Disambiguating Region

Total time data from the target sentence disambiguating region by condition for Experiments 1 and 2. Error bars represent standard errors.

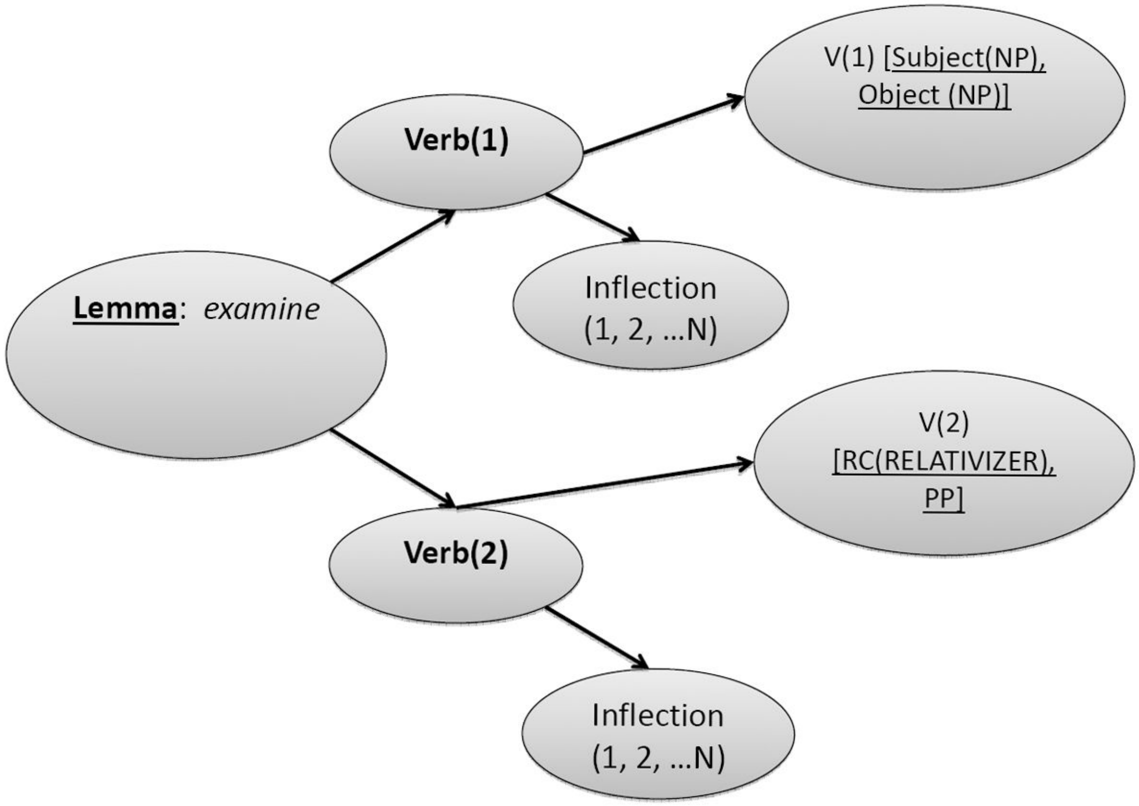

Figure 3.
Possible lemma-structure associations

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Experiment 1 Target sentence mean first pass, first-pass regressions, and total time by region and condition.

Target Sentence Results by Condition		**Scoring Region**	
		Disambiguating	**Post-Disambiguating**
First Pass Time	Verb Region	Region	Region
RR Prime-RR Target	357	561	404
MC Prime-RR Target	349	614	427
RR Prime-MC Target	343	475	371
MC Prime-MC Target	341	441	373
First Pass Regressions			
RR Prime-RR Target	7.4%	7.6%	8.1%
MC Prime-RR Target	6.0%	13.7%	13.7%
RR Prime-MC Target	5.6%	8.1%	5.1%
MC Prime-MC Target	4.6%	7.4%	3.2%
Regression Path Time			
RR Prime-RR Target	375	597	484
MC Prime-RR Target	369	710	536
RR Prime-MC Target	355	504	404
MC Prime-MC Target	352	474	402
Total Time			
RR Prime-RR Target	396	618	491
MC Prime-RR Target	451	748	540
RR Prime-MC Target	388	500	435
MC Prime-MC Target	408	474	426

Table 2

Results of 2 (target type: reduced relative vs. main clause) × 2 (prime type: reduced relative vs. main clause) ANOVAs for Experiment 1

First-Pass Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	1.14 (4094)	0.97 (4485)	96.2^{***} (6978)	33.3^{***} (25382)	11.6^{**} (6568)	4.69^{*} (18903)
Prime Type	0.53 (2243)	0.04 (3910)	0.85 (4643)	0.18 (16420)	1.42 (4629)	0.46 (7559)
Prime × Target Type	0.08 (3819)	0.51 (2976)	9.29^{**} (8079)	4.75^{*} (15021)	0.48 (9055)	0.06 (6634)
First-Pass Regressions	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	0.29 (60.0)	1.34 (126.2)	2.27 (132.8)	2.60 (157.3)	16.0^{***} (101)	16.5^{***} (121)
Prime Type	2.77 (100.2)	0.61 (86.1)	1.58 (161.9)	3.45 (154.6)	1.53 (80.8)	1.11 (152)
Prime × Target Type	2.79 (83.6)	0.16 (120.9)	2.29 (177.4)	6.16^{*} (86.5)	5.25^{*} (94.0)	6.02^{*} (100)
Regression Path Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	1.84 (7524)	1.11 (11749)	60.5^{***} (17883)	38.7^{***} (35136)	33.2^{***}(13961)	8.87^{**}(46052)
Prime Type	0.11 (5719)	0.03 (6783)	4.05 (16738)	3.95 (19807)	1.45 (14583)	2.67 (17650)
Prime × Target Type	0.02 (8556)	0.26 (7282)	12.5^{**} (16308)	11.1^{**} (21025)	1.12 (23233)	1.53 (18603)
Total Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	4.16^{*} (8038)	3.06 (11695)	135.8^{***} (11332)	44.8^{***} (42535)	45.0^{***} (6503)	7.71^{**} (38112)
Prime Type	3.85 (6916)	5.31^{*} (10165)	8.98^{**} (12326)	5.78^{*} (23033)	2.35 (6871)	1.27 (12737)
Prime × Target Type	2.39 (5441)	1.35 (10080)	13.2^{***} (18380)	12.5^{***} (22791)	2.07 (16595)	3.24 (11175)

Note: MSe in parentheses.

* = $p < .05$,

** = $p < .01$,

*** = $p < .001$.

df 1 (1, 39), df 2 (1, 47)

Table 3

Experiment 2 Target sentence mean first pass, first-pass regressions, and total time by region and condition.

Target Sentence Results by Condition		**Scoring Region**	
		Disambiguating	**Post-Disambiguating**
First Pass Time	Verb Region	Region	Region
RR Prime-RR Target	342	603	418
MC Prime-RR Target	350	556	397
RR Prime-MC Target	334	447	346
MC Prime-MC Target	348	462	374
First Pass Regressions			
RR Prime-RR Target	7.8%	13.5%	11.5%
MC Prime-RR Target	8.3%	16.1%	8.9%
RR Prime-MC Target	10.9%	13.0%	6.8%
MC Prime-MC Target	6.8%	8.9%	5.7%
Regression Path Time			
RR Prime-RR Target	389	740	739
MC Prime-RR Target	405	704	713
RR Prime-MC Target	400	538	543
MC Prime-MC Target	405	510	513
Total Time			
RR Prime-RR Target	457	732	515
MC Prime-RR Target	471	718	515
RR Prime-MC Target	397	522	405
MC Prime-MC Target	415	518	424

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Results of 2 (target type: reduced relative vs. main clause) × 2 (prime type: reduced relative vs. main clause) ANOVAs for Experiment 2

First-Pass Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	0.23 (3136)	0.37 (5048)	61.5*** (8149)	29.9*** (28396)	17.3*** (4038)	4.23* (19500)
Prime Type	1.12 (3585)	1.98 (6110)	1.14 (7176)	0.60 (13681)	0.07 (5632)	0.44 (9008)
Prime × Target Type	0.10 (2721)	0.30 (6847)	3.23 (9223)	2.65 (20001)	3.61 (5260)	4.25* (10064)
First-Pass Regressions	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	0.15 (132)	0.12 (194)	1.95 (251)	2.75 (278)	2.23 (219)	2.50 (294)
Prime Type	1.27 (83.9)	0.96 (182)	.012 (167)	0.07 (329)	1.34 (79.5)	0.71 (226)
Prime × Target Type	1.77 (100)	1.36 (180)	2.00 (183)	2.19 (264)	0.20 (100)	0.18 (162)
Regression Path Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	0.12 (8004)	0.01 (23590)	49.3*** (25347)	37.0*** (50881)	16.4*** (18917)	6.17* (67290)
Prime Type	0.65 (4963)	0.28 (17715)	1.79 (18566)	1.16 (33131)	0.44 (13109)	0.02 (26742)
Prime × Target Type	0.10 (11052)	0.44 (22064)	0.02 (19872)	0.01 (23358)	0.62 (14133)	0.74 (25029)
Total Time	**Verb Region**		**Disambiguating Region**		**Post-Disambiguating Region**	
	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)	F1 (MSe)	F2 (MSe)
Target Type	9.60** (11242)	9.42** (22938)	52.1*** (25861)	33.2*** (62715)	29.3*** (11083)	8.80** (45724)
Prime Type	1.16 (6758)	0.57 (21315)	0.33 (8026)	0.11 (27252)	0.22 (11554)	0.44 (15427)
Prime × Target Type	0.02 (7247)	0.02 (19224)	0.05 (14249)	0.04 (22332)	0.42 (6547)	0.62 (21191)

Note: MSe in parentheses.

[*] = $p < .05$,

[**] = $p < .01$,

[***] = $p < .001$.

df 1 (1, 39), df 2 (1, 47)