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Priming prepositional phrase attachment: Evidence from eye-tracking and event-related potentials

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Abstract

Three syntactic-priming experiments investigated the effect of structurally similar or dissimilar prime sentences on the processing of target sentences, using eye tracking (Experiment 1) and event-related potentials (ERPs) (Experiments 2 and 3) All three experiments tested readers' response to sentences containing a temporary syntactic ambiguity. The ambiguity occurred because a prepositional phrase modifier (PP-modifier) could attach either to a preceding verb or to a preceding noun. Previous experiments have established that (a) noun-modifying expressions are harder to process than verb-modifying expressions (when test sentences are presented in isolation); and (b) for other kinds of sentences, processing a structurally similar prime sentence can facilitate processing a target sentence. The experiments reported here were designed to determine whether a structurally similar prime could facilitate processing of noun-attached modifiers and whether such facilitation reflected syntactic-structure-building or semantic processes. These findings have implications for accounts of structural priming during online comprehension and for accounts of syntactic representation and processing in comprehension.

Keywords

Syntax; Priming; Sentence processing; Event-related potentials; Eye tracking

Syntactic-structure-building processes play an important role in sentence comprehension. Such processes determine how words in sentences relate to one another, which in turn influences the assignment of thematic roles, semantic interpretation, and situation model building (Jackendoff, 2002; Pickering & van Gompel, 2006; Traxler, 2012). Theories of performance in this domain differ from one another in the priority that is afforded to purely syntactic information, as well as the nature and timing of a variety of lexical and contextual influences on syntactic-structure building and semantic interpretation (e.g., Altmann & Kamide, 1999; Altmann & Steedman, 1988; Ferreira, 2003; Frazier, 1987; Frazier & Clifton, 1996; Friederici, 1995, 2002; Hagoort, 2003, 2005; Kuperberg, 2007; Levy, 2011; MacDonald, Pearlmutter, & Seidenberg, 1994; Ni, Crain, & Shankweiler, 1996; Pickering, Tooley, & Traxler, 2011; Tabor, Galantucci, & Richardson, 2004; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Parsing theories can be differentiated based on

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whether they allow for the simultaneous activation and ranking of alternative structural possibilities, or whether a single syntactic analysis is pursued at any one time. These accounts can also be divided into those that restrict the range of possible influences on initial structure-building processes and those that suggest that all relevant sources of information influence syntactic choices as soon as they become available.

Studies of syntactic-ambiguity resolution have played an important role in distinguishing between these alternative descriptions of the human sentence parser (e.g., Bever, 1970; Brown, van Berkum, & Hagoort, 2000; Friederici, 2002; Hagoort, 2005; Rayner, Carlson, & Frazier, 1983; Tanenhaus et al., 1995; Traxler & Tooley, 2007; van Berkum, Brown, & Hagoort, 1999; see Pickering & van Gompel, 2006; Traxler, 2012, for overviews). Studies in this tradition indicate that a variety of contextual information, including visual and referential context, can have substantial effects on rapidly unfolding syntactic processes. This article focuses on a specific kind of contextual manipulation: the influence of a preceding prime sentence on a syntactically similar target sentence.

Syntactic-priming experiments have provided a useful test bed to investigate the nature of syntactic representations and the way comprehenders access and use those representations during online sentence interpretation (Arai, van Gompel, & Scheepers, 2007; Carminati, van Gompel, Scheepers, & Arai, 2008; Ledoux, Traxler, & Swaab, 2007; Thothathiri & Snedeker, 2008a; Tooley, Traxler, & Swaab, 2009; Tooley, Swaab, Boudewyn, Zirnstein, & Traxler, in press). These priming studies have established that repeating a syntactic structure across a prime and a target sentence facilitates online processing of the target sentence. Syntactic priming may also influence the final choice of interpretation in globally ambiguous sentences (Branigan, Pickering, & McLean, 2005). Previously observed facilitatory effects reflect aspects of syntactic-structure-building operations and occur independently of strategic cues or semantic associations between prime and target sentences (Tooley et al., 2009; Tooley et al., in press; Traxler, 2008; Traxler & Tooley, 2008).

To date, syntactic priming in comprehension has been observed during online processing in only three sentence types: reduced relatives (e.g., 1); prepositional-object (PO) and double-object (DO) datives (e.g., 2a and 2b), and modifier-goal ambiguities (e.g., 3).[1]

1. The defendant examined by the lawyer proved to be unreliable. (Reduced relative)

2a. The pirate gave the necklace to the princess. (PO dative)

2b. The pirate gave the princess the necklace. (DO dative)

3. The girl dropped the blanket on the floor on the bed this morning. (Modifier—goal)

In experiments on sentences containing reduced-relative clauses, exposure to a prime sentence with the same overall syntactic structure and the same critical verb (e.g., *examined*) leads to facilitated processing of the syntactically disambiguating byphrase (e.g., *by the*

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[1] There is additional evidence for “fast priming” of the complement interpretation in object–complement ambiguities (Trueswell & Kim, 1998).

lawyer) (Ledoux et al., 2007; Tooley et al., 2009; Tooley et al., in press; Traxler, 2008; Traxler & Tooley, 2008). This facilitated processing can occur in the absence of repetition of the verb, and some experiments also show facilitated processing of both the relative clause verb and the following prepositional phrase. Semantic repetition, whether established by repeating the relative clause verb (but not the overall syntactic structure) or the subject noun, does not lead to facilitated processing of the prepositional phrase following the by-phrase. However, it should be noted that syntactic-priming effects in comprehension have been most frequently found when prime and target sentences share a verb, which is sometimes termed the “lexical boost” (see Tooley & Traxler, 2010, 2012). A complete discussion of the theoretical implications of the lexical boost is beyond the scope of this paper (see Tooley & Traxler, 2010, 2012, for a review), but two points are particularly relevant. First, the studies reported in the current paper used the same verb in both prime and target sentences, in order to maximize the likelihood of finding evidence of syntactic priming in the sentence types tested here. Second, while the lexical boost could be interpreted as evidence that syntactic priming is either fully or partially driven by lexically linked syntactic-structure information, several studies have found syntactic-priming effects even when verbs were not shared between prime and target sentences (e.g., Thothathiri & Snedecker, 2008a, 2008b; Traxler, 2008).

In event-related potential (ERP) experiments, electrophysiological evidence of facilitated syntactic processing for sentences containing reduced-relative clauses has been found when sentences such as (1) are preceded by syntactically identical sentences (Ledoux et al., 2007; Tooley et al., in press; Tooley et al., 2009). Overall, these findings suggest that exposure to a reduced-relative prime sentence facilitates the mental processes by which comprehenders construct or recover the abstract syntactic forms needed to parse a structurally related target sentence.

In PO and DO datives, priming effects in comprehension have been observed in the visual world paradigm (Arai et al., 2007; Carminati et al., 2008; Thothathiri & Snedeker, 2008a, 2008b). In these experiments, participants view an image that depicts different characters and objects (such as a pirate, a princess, and a necklace). If participants hear a PO dative prime sentence, their eye movements tend to be drawn to an inanimate object (e.g., *necklace*) as they are listening to sentences like (2a) and (2b), repeated here:

2a. The pirate gave the necklace to the princess. (PO dative)

2b. The pirate gave the princess the necklace. (DO dative)

If participants instead hear a DO dative prime, they are more likely to fixate on an animate entity (e.g., *princess*). These effects begin to appear as participants are listening to the critical verb (e.g., *gave*), and have been found both when verbs were repeated across prime and targets (Arai et al., 2007, Experiment 1; Carminati et al., 2008; Thothathiri & Snedeker 2008a, Experiments 1a, 2a) and, in some studies, when different verbs were used (Thothathiri & Snedeker, 2008a, Experiments 1b, 2b; Thothathiri & Snedeker, 2008b; but see Arai et al., 2007, Experiment 2). These findings indicate that syntactic processes specify slots that are defined in terms of abstract semantic properties (e.g., animate vs. inanimate) in addition to abstract phrasal categories (e.g., noun phrase). They indicate further that participants more strongly anticipate particular constituent orderings as a result of exposure to a prime sentence (see also Altmann & Kamide, 1999; Kamide, Scheepers, & Altmann, 2003).

Sentences such as (3) are temporarily ambiguous between a goal interpretation (*The girl dropped the blanket on the floor,* where *floor* is the location where the blanket ends up) and a modifier interpretation (as in *The girl dropped the blanket on the floor on the bed*, where *bed* is the actual final location and *on the floor* provides information that the comprehender can use to distinguish between different blankets in a set). These sentences generally produce processing difficulty when comprehenders reach the second of the two prepositional phrases (*on the bed*). This difficulty presumably occurs because the preceding prepositional phrase had been interpreted as a goal location, but must now be reinterpreted as a nongoal modifying expression. This processing difficulty can be reduced if concurrent visual information supports the modifier reading of the first prepositional phrase (*on the floor*) over the goal interpretation (Tanenhaus et al., 1995). In an eye-tracking study, it was shown that processing difficulty associated with modifier–goal sentences is also reduced if the sentence is preceded by another sentence with the same syntactic structure (Traxler, 2008). For this sentence type, the same degree of facilitation occurred whether or not the prime and target sentences shared a verb.

The chief goal of the current study was to investigate the nature of syntactic-priming effects, using both behavioural and neurophysiological methods, by comparing directly across different sentence types to examine whether common mechanisms underlie facilitative effects of repeating a structure. While a growing body of evidence indicates that temporarily ambiguous sentences can be processed faster than normal when a structurally similar sentence has been recently encountered, we still do not know a great deal about the range of sentences over which facilitatory effects occur. Thus, we need data from a wider range of sentence types before we can draw general conclusions about the nature of the underlying processes that give rise to observed facilitation effects. In the current study, we chose to investigate two types of sentences containing temporarily ambiguous prepositional phrase modifiers: so-called high–low attachment ambiguities (see 4 and 5 below), and modifier–goal ambiguities (as in 3 above). Both of these structures involve a temporarily ambiguous prepositional phrase. We chose these structures because there is limited empirical evidence available regarding the online processing of these sentence types and because there is theoretical debate as to the processes involved in recognizing and resolving the syntactically ambiguous portions of such sentences. Specifically, the minimal attachment (structural reanalysis) and referential hypotheses attribute the difficulty associated with these sentences to fundamentally different processes.

In our study, the first two experiments tested readers' response to verb–noun attachment ambiguities (sometimes called high–low attachment ambiguities; Rayner et al., 1983), like Sentence 4:[2]

4. The girl hit the boy with the paddle earlier today.

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[2] We use "verb–noun" terminology to describe the ambiguity as a more theory-neutral option.

Sentences like (4) are syntactically and semantically ambiguous because, while semantic properties of *paddle* make it a likely instrument of the action of *hitting,* it could serve to modify the preceding noun *boy*—as in *Which boy did the girl hit (with her fist)? The one with the paddle.* Typically, sentences like (4), where the modifying expression *with the paddle* can be felicitously associated with the preceding verb, are easier to process than sentences where the modifying expression must attach to the direct-object noun, as in (5):

5. The girl hit the boy with the bruise earlier today.

The *minimal attachment* and *construal* accounts attribute the difficulty of (5) to syntactic-structure-building preferences (Frazier, 1979, 1987; Frazier & Clifton, 1996). Briefly, the *minimal attachment* heuristic causes the human sentence parser to prefer simpler structures over more complex ones. Given specific representational assumptions, verb attachment leads to a less complex syntactic structure than noun attachment. Hence, (4) will take less time to process than (5), because the prepotent syntactic choice leads to a more plausible or sensible interpretation in (4) than in (5). In sentences like (5), the infelicity of *bruise* as an instrument of *hit* triggers a syntactic reanalysis. During this process of syntactic reanalysis, comprehenders discover an alternative structural configuration (noun attachment) that produces a more felicitous semantic outcome. Average processing time for sentences like (5) is greater than that for (4) due to the time taken to complete these additional syntactic processes.

In contrast, the *referential hypothesis* offers a different explanation for increased processing load in Sentence 5 (Altmann, Garnham, & Henstra, 1994; Altmann & Steedman, 1988; Ni et al., 1996). According to this account, comprehenders favour interpretations that lead to referential success and that minimize unattested presuppositions. Consider the noun phrase *the boy* in Sentence 5. If a sentence like (5) is presented in isolation, the definite article in the noun phrase *the boy* would normally indicate that only one boy is relevant to the situation described by the sentence. Thus, comprehenders initially build a discourse representation that contains only one boy. Given that state of affairs, additional information in the sentence that further specifies properties of *the boy* will be unexpected, redundant, and therefore infelicitous (Grice, 1989). Having successfully established a connection between the definite noun phrase *the boy* and a unique entity in a discourse representation, comprehenders are surprised when the subsequent prepositional phrase differentiates that unique entity from a set of related, but unmentioned, entities. The referential account predicts that the modifying expression will be easier to process in a context where the earlier noun phrase *the boy* does not successfully identify a unique referent. This would be the case if a preceding sentence introduced some larger set of boys. In fact, processing times for modifiers are reduced when sentences like (5) follow contexts like (6):

6. There were three boys on the playground this morning. One had recently fallen off his bike.

5. The girl hit the boy with the bruise earlier today.

Similar logic can be applied to the processing of other types of modifiers, such as modifier–goal ambiguities. Sentences containing this type of prepositional phrase modifier were tested in Experiment 3. In this case, as in the verb–noun attachment ambiguities discussed above (and tested in Experiments 1 and 2), the processing difficulty upon encountering the second prepositional phrase could reasonably be attributed either to a parsing preference for a simpler syntactic structure (minimal attachment hypothesis) or to the pragmatic oddity of encountering additional specifying information about a noun when none is needed (because there is a single referent in play; referential hypothesis).

Overview of the experiments

In the current study, we used a priming paradigm to test novel predictions following from the minimal attachment (structural reanalysis) and referential hypotheses. In the first two experiments (eye tracking and ERPs), the priming paradigm involved presenting noun-attached target sentences, such as in 5 above. The third experiment (ERPs) tested modifier–goal ambiguities (such as in 3 above), which are related, but distinct, sentence types. In previous priming experiments on other sentence types, the most robust priming effects have been found when the prime and target sentences had the same critical verb (Arai et al., 2007; Pickering & Traxler, 2004; Traxler & Pickering, 2005; Traxler & Tooley, 2008; Weber & Indefrey, 2009; priming effects in production also tend to be larger when verbs are repeated across prime and target stimuli); therefore, here we also repeated the same critical verb across the prime and target sentences. Experiment 1, which used eye tracking to measure participants' responses, was conducted to see whether presenting the prime sentence had any effect on processing of the target. Target sentences were presented immediately following prime sentences that also contained a noun-attached prepositional phrase or after a prime sentence that contained a verb-attached prepositional phrase. If attachment decisions can be primed, either by facilitating more complex syntactic-structure-building operations or by speeding the reconfiguration of discourse representations (or via some other means), then noun-attached target sentences should be processed faster when they follow noun-attached prime sentences than when they follow verb-attached prime sentences.

Speeded processing of noun-attached target sentences does not, by itself, indicate what causes the observed facilitatory effects. To obtain further evidence as to the nature of these effects, we conducted two ERP experiments. ERPs have the potential to differentiate semantic processing difficulties from difficulties that arise when syntactic revision is required. Specifically, the N400 is sensitive to semantic processing difficulties, and a reduced N400 amplitude is found to words that are semantically plausible, related, or predictable given the preceding language context (e.g., Federmeier & Kutas, 1999; Kutas & Hillyard, 1984; van Berkum, Hagoort, & Brown, 1999; van Petten, 1993; for a review, see Swaab, Ledoux, Camblin, & Boudewyn, 2011). In addition, a reduced N400 is also found to anaphors that are easily related to their antecedents (Camblin, Ledoux, Boudewyn, Gordon, & Swaab, 2007; Ledoux et al., 2007; Swaab, Camblin, & Gordon, 2004).

In contrast, the P600 was initially found to be modulated by syntactic manipulations, ranging from syntactic violations (e.g., Osterhout & Mobley, 1995) to syntactic complexity (e.g., Kaan, Harris, Gibson, & Holcomb, 2000). Following from this work, the P600 was interpreted as reflecting attempts to revise the syntactic structure following syntactic violations or ambiguity (Hagoort, Brown, & Groothusen, 1993; Kaan & Swaab, 2003; Osterhout & Holcomb, 1992). More recently, P600 effects have been found to manipulations that may cause conflict at the interface of syntax and semantics, such as reversible thematic roles (e.g., The eggs would eat … ; Kim & Osterhout, 2005; Kolk & Chwilla, 2007; Kolk, Chwilla, van Herten, & Oor, 2003; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Nakano, Saron, & Swaab, 2010). Thus, the P600 is a sensitive indicator of syntactic violations and difficulty, but also is found when there is a conflict between semantics and syntax (e.g., Kuperberg, 2007). In general, a reduced P600 waveform for one condition compared to another indicates a structural element to the facilitation for that condition, whereas a reduced N400 waveform does not. Notably, previous studies that have focused on sentences containing reduced-relative clauses have found that priming syntactic structure results in modulations of the P600 effect (Ledoux et al., 2007; Tooley et al., 2009).

The different functional profiles of the N400 and P600 effects were used to examine the nature of potential syntactic-priming effects for sentences containing (temporarily) ambiguous prepositional phrase modifiers. The two ERP experiments (Experiments 2 and 3) were syntactic-priming experiments analogous to the eye-tracking experiment (Experiment 1). Experiment 2 tested the same kind of sentence as Experiment 1, while Experiment 3 tested a related type also involving a choice between verb and noun modification. If noun-attached primes facilitate the syntactic-structure-building processes that are required to interpret noun-attached targets, during initial analysis or reanalysis, then those facilitated syntactic operations should cause a decrease in the amplitude of the P600 when target sentences are compared to primes. This is the pattern that has been observed in previous ERP priming studies on a different sentence type (Ledoux et al., 2007; Tooley et al., 2009, in press). Although, as noted above, the P600 effect is unlikely to be a marker of “purely” syntactic processing, its presence does implicate a syntactic component to the processing difficulty in question. If, by contrast, noun-attached primes facilitate aspects of semantic, rather than syntactic, processes, then we should observe a reduced N400 when target sentences are compared to primes.

EXPERIMENT 1: EYE TRACKING

Experiment 1 was designed to determine whether the presentation of noun-attached and verb-attached prime sentences influences the processing of noun-attached target sentences. Facilitatory effects have been obtained under similar conditions for reduced-relative clauses, PO and DO datives, and modifier–goal ambiguities. However, no online priming experiments have yet been conducted on sentences containing verb–noun modifier attachment ambiguities. Therefore, as noted above, we repeated the verb across prime and targets sentences, as the most robust syntacticpriming effects have been found with repeated verbs (Arai et al., 2007; Pickering & Traxler, 2004; Traxler & Pickering, 2005; Traxler & Tooley, 2008; Weber & Indefrey, 2009). Further, because the priming effects in both comprehension and production tend to be larger for more difficult sentence types, all of our target sentences contained noun-attached prepositional phrases. Thus, an individual trial in the experiment would have either a verb-attached (e.g., 4) or a noun-attached (e.g., 5) prime sentence, but the targets were always noun attached (e.g., 7).

4. The girl hit the boy with the paddle earlier today. (Verb-attached prime)

5. The girl hit the boy with the bruise earlier today. (Noun-attached prime)

7. The policeman hit the man with the mustache earlier today. (Noun-attached target)

Method

Participants—A total of 44 UC Davis undergraduates participated in partial fulfilment of a course requirement. All of the participants had normal hearing and vision and were native speakers of English. One participant was excluded from the analyses because of excessive missing data.

Stimuli—The stimuli were adapted from Altmann and Steedman's (1988) stimulus set. Each participant read 26 target sentences. Half of the target sentences followed noun-attached primes, and half followed verb-attached primes. Each target sentence was presented immediately after a prime sentence. The noun-attached prime and target sentences were rotated across experimental lists so that each prime (from one list) served as a target sentence (on another list), and vice versa. This procedure controls for a number of potential nuisance variables, including length and frequency of the words in the sentence, semantic plausibility, and intralexical associations within the sentences. The participants also read 132 filler sentences of various grammatical types (including simple active voice sentences, simple passive voice sentences, sentences with subject relative clauses, and other innocuous forms). None of the verbs used in the experimental items appeared in the filler items. At least one filler sentence appeared between each prime–target pair.

"Catch" trials.: While strategic cues have not previously been shown to influence the magnitude of syntactic-priming effects (see Tooley et al., 2009; Traxler & Tooley, 2008; for extensive discussion), we included 15 "catch" trials to minimize the potential effects of processing strategies. In these "catch" trials, noun- or verb-attached sentences were followed by a filler sentence that did not contain a prepositional phrase modifier and was not a "garden-path" sentence. By including "catch" trials, participants could not predict what type of sentence would follow a noun-attached or verb-attached prime sentence.

Eye movement monitoring procedure.: A Fourward Technologies dual-Purkinje image eye-tracker monitored participants' eye movements while they read the sentences. The tracker has angular resolution of 10′ of arc. The tracker monitored only the right eye's gaze location. A PC displayed sentence materials on a visual display unit (VDU) 70 cm from participants' eyes. The location of participants' gaze location was sampled every millisecond, and the PC software recorded the tracker's output to establish the sequence of eye fixations and their start and finish times. Before the experiment, the participant was seated at the eye tracker and was positioned with a chin cup and head rests to minimize head movements during the experiment. Before the experiment began, the tracker was aligned and calibrated. Participants were instructed to read each sentence at a normal, comfortable pace and be prepared to answer comprehension questions that would follow some, but not all, of the sentences. Participants were instructed to press a button as soon as they finished reading each sentence. After 20 of the filler sentences, the participant responded to a true–false comprehension question. Participants did not receive feedback on their responses. Between each trial, a pattern of squares appeared on the computer screen along with a cursor that indicated the participants' current gaze location. If the tracker was out of alignment, it was recalibrated before proceeding with the next trial.

Analyses.: We report four standard eye movement dependent measures. (a) *First-pass time* is the sum of all fixation durations beginning with the first fixation in a region until the reader's gaze leaves the region, left or right; (b) *first-pass regressions* reflect eye movements that cross a region's left-hand boundary immediately following a first-pass fixation; (c) *regression-path time* includes all of the fixations from the first fixation in a scoring region until the reader fixates somewhere to the right of the scoring region (Traxler, Bybee, & Pickering, 1997); this measure includes time spent refixating previous regions and the target region itself; (d) *total time* is the sum of all fixation durations in a region, regardless of order.

Prior to determining fixation durations, an automatic procedure incorporated fixations of less than 80 ms into the largest fixation within one character. In the next stage, the procedure eliminated all individual fixations greater than 1000 ms and less than 80 ms. Subsequently, first-pass times and total times of less than 120 ms were excluded from the analyses. Further, first-pass or total times exceeding 2000 ms for a given scoring region were excluded. Very short fixations often reflect slight oculomotor error and are usually followed by very short saccades to a nearby location, followed by a much longer fixation. Very long fixations normally reflect track loss or inattention.

We computed these four dependent measures for four scoring regions. The *verb* region included the main verb (e.g., *hit* in Sentence 7). The *noun phrase (NP)* region included the determiner and noun immediately following the main verb (*the man*). The *prepositional phrase (PP)* region included the preposition *with* and the following determiner and noun (*with the moustache*). Considerable preprocessing or outright word identification frequently happens when readers fixate short, highly frequent function words, like *with* and *the.* Thus, fixation durations on these words were probably influenced by response to the following noun. The *post-PP* region included the two words that immediately followed the PP region (*earlier today*).

7. The policeman/ hit/ the man/ with the mustache/ earlier today./

Separate by-participant and by-items analyses were conducted for each dependent measure for each scoring region. The data were analysed using *hierarchical linear modelling (HLM;* Blozis & Traxler, 2007; Raudenbush & Bryk, 2002; Traxler, Williams, Blozis, & Morris, 2005). HLM is appropriate for analysing data sets where random observations are nested within random clusters, such as reaction times within items within participants. Unlike repeated measures analysis of variance (ANOVA), HLM does not require that individuals have the same number of observations (Snijders & Bosker, 1993), and it does not require aggregation across trials. Reading times were modelled as a function of sentence characteristics (whether the sentence appeared in the list as a prime sentence or a target). Each participant contributed up to 39 responses (13 responses to noun-attached primes and 26 responses to noun-attached targets, 13 of which followed noun-attached primes and 13 of which followed verb-attached primes). At the first level of the model, outcomes (dependent measures) were considered a function of *condition* (noun-attached prime vs. target following verb-attached prime vs. target following noun-attached prime). At the second level of the model, Level 1 parameter slopes and error terms were allowed to vary randomly between individuals.

The by-participants multilevel models were configured as follows (see Blozis & Traxler, 2007; Raudenbush & Bryk, 2002; Traxler et al., 2005):

Level 1:	RT for person *i*, for item *j* = Boi + B1i (target following verb attached prime)j + B2i (target following noun attached prime)j + eij
Level 2:	Boi = goo + uo
	B1i = g10 + u1
	B2i = g20 + u2

For the by-items models, transpose person and item. Boi reflects reading time (RT) for the scoring region in the prime sentence (baseline RT); B1i reflects the change from baseline reading time associated with the target sentences that followed verb-attached primes; B2i reflects the change from baseline reading time associated with the target sentences that followed noun-attached primes; eij reflects random measurement error; goo is the difference between group baseline reading time and baseline reading time for person *i*; g10 reflects the difference between the average effect of having a verb-attached prime and that effect in person *i* on target reading time; g20 reflects the difference between the average effect of having a noun-attached prime and that effect in person *i* on target reading time; uo, u1, and u2 reflect random error in the Level 2 parameters.

Results and discussion

Table 1 presents mean values of the four dependent measures and standard errors (in parentheses) for each condition (noun-attached prime, noun-attached target following a noun-attached prime, and noun-attached target following a verb-attached prime; the verb-attached primes themselves were not analysed) in each scoring region. For the verb region, repetition of the verb was expected to result in facilitation for both verb-attached targets and noun-attached targets, compared to prime sentences. This repetition effect was also expected to spill over into the NP region. If present, syntactic-priming effects were expected to manifest in the PP and/or post-PP regions, as facilitation for noun-attached targets following primes of the same structure (i.e., as compared to following verb-attached primes).

Verb region—There were no significant effects in the verb region in first-pass time, regression path time, or total time. There were fewer regressions from the verb region in the target sentences than in the primes for both the verb-attachment [$t_1(42) = 1.8$, $p = .08$; $t_2(51) = 2.00$, $p = .05$] and the nounattachment conditions [$t_1(42) = 2.57$, $p = .01$; $t_2(51) = 2.70$, $p = .01$]. These effects may reflect facilitated lexical access to the repeated verb.

NP region—There were fewer regressions from the NP region in the target sentences than in the primes for both the verb-attachment [$t_1(42) = 2.83$, $p < .01$; $t_2(51) = 2.85$, $p = .02$] and the noun-attachment conditions [$t_1(42) = 2.34$, $p < .05$; $t_2(51) = 1.98$, $p = .05$]. Targets following noun-attached primes had lower total time than baseline [$t_1(42) = 2.57$, $p < .05$; $t_2(51) = 2.70$, $p = .01$], but targets following verb-attached primes did not (t_1, $t_2 < 1$, *ns*).

PP region—Total time for targets following noun-attached primes was lower than baseline [$t_1(42) = 1.84$, $p = .07$; $t_2(51) = 2.14$, $p < .05$], but total time for targets following verb-attached primes was not (t_1, $t_2 < 1$; *ns*).

Post-PP region—In the post-PP region, there were more regressions in targets that followed verb-attached primes than in the baseline condition [$t_1(42) = 2.89$, $p < .01$; $t_2(51) = 3.14$, $p < .01$].

There were no significant effects in first-pass time or regression-path time in any of the scoring regions. Target sentences had fewer regressions than prime sentences in the verb and NP regions for both conditions—noun-attached targets following verb-attached primes and noun-attached targets following noun-attached primes. These effects may reflect facilitated lexical access based on repetition of the verb.

In the post-PP region, noun-attached targets following verb-attached primes had more regressions than noun-attached prime sentences. This result most probably reflects a kind of enhanced “garden-path” effect. Having just processed a verb-attached prime, participants were less prepared to process the noun-attached target. That is, the assumption that a PP-modifier will be interpretable as an instrument of the preceding verb may be strengthened in the period immediately following the construction of such an interpretation. Alternatively, participants may have undertaken a shallower semantic analysis of the verb-attachment interpretation in targets following verb-attached primes, with greater regressions from the post-PP region in the targets reflecting a kind of delayed realization that something is semantically wrong with the verb-attachment interpretation. Overall, these regressions results suggest that processing a verb-attached modifier in the prime sentence reinforced the instrument interpretation of the modifying expression. This, in turn, may have delayed recovery of the correct noun-modification interpretation of the target sentence.

Total time for targets that followed noun-attached primes was lower in the NP and PP regions than for comparable regions of the noun-attached primes. Thus, processing a noun-attached prime sentence facilitated attachment of the modifying PP to the noun during processing of the target sentences. No such benefit accrued for noun-attached targets following verb-attached primes, suggesting that the facilitatory effects were not simply the result of repetition priming from the verb (because the verbs were repeated in targets following verb-attached primes and targets following noun-attached primes). These results indicate that processing a noun-attached modifier in the prime sentence facilitated processing of the noun-attached modifier in the target sentence.

EXPERIMENT 2: ERPs

Experiment 1 showed that the processing of a noun-attached target sentence was facilitated by immediate prior exposure to a similar noun-attached prime sentence. This result, does not, by itself, indicate what aspect of processing was facilitated. Therefore, in the present experiment, we used ERPs in a design similar to Ledoux and colleagues' (2007) ERP experiment in order to further examine how exposure to prime sentences influences target processing. All of the prime and target sentences shared a critical verb; all of the prime sentences were temporarily ambiguous (between verb attachment and noun attachment), and half of the target sentences had the same overall structure as the prime, while the rest instantiated an alternative interpretation. If the prime sentence influences processing of the target by facilitating aspects of semantic interpretation, we should observe reductions in the mean amplitude of the N400 at and following the point at which the target sentences are disambiguated. If, instead, the prime sentence facilitates aspects of syntactic processing, such as the operation that attaches the modifier to the noun rather than the verb, we predict that this would result in a reduction of the mean amplitude of the P600, which is the pattern we have observed in our previous ERP studies with other syntactic structures.

Method

Participants—Twenty-three undergraduates from the University of California, Davis gave informed consent and took part in this study. All were compensated with course credit and were right-handed native speakers of English with no reported psychological/neurological disorders and normal or corrected-to-normal vision and hearing. The average age was 19.5 years (range: 18–23).

Stimuli—Each participant read 40 noun-attached target sentences that followed noun-attached prime sentences (80 experimental sentences). An additional 40 prime–target "catch-trial" pairs were included so that it was not possible to predict the type of target sentence based on the type of prime sentence; in these pairs, prime sentences were noun attached, and target sentences were verb attached. All prime–target pairs contained the same verb (repeated from 5 and 7 in the eye-tracking study):

Prime:	The girl hit the boy with the bruise earlier today.
Target:	The policeman hit the man with the mustache earlier today.

Finally, 130 filler sentences of variable syntactic structure were included. Primes and targets were counterbalanced across four lists, so that each prime sentence in a particular list was used as a target sentence in a different list. Each participant was presented with one of the four lists. This counterbalancing allowed for the comparison across prime and target items of the same sentences, controlling for any potential differences in lexical frequency or length between items.

Procedure—Participants were seated in a comfortable chair in an electrically shielded, sound-attenuating booth, and stimuli were presented using Presentation software (neurobs.com). Participants were instructed to read the sentences for comprehension and to refrain from blinking or making other eye movements or other movements during presentation of the sentences. This was done in order to minimize subject-generated artefacts in the electroencephalography (EEG) signal. Trials began with a white fixation cross that appeared for 1000 ms against a black background on a computer screen that was about 100 cm in front of the participants. The fixation cross was replaced by the first word of the sentence; sentences were presented word by word using rapid serial visual presentation (RSVP), at a rate of 300 ms per word with a 200-ms interstimulus interval. Words were presented in white, 16-point, Tahoma font, between white bars, which served as a fixation aid. The last word of each sentence was presented with a period, and the first word of each sentence began with a capital letter. Prime and target sentences were separated by a 3000-ms interval. True/false comprehension questions followed all target sentences of both experimental and catch trials (but never followed a prime sentence). Comprehension questions did not focus on the critical manipulation (e.g., Target: The policeman hit the man with the mustache earlier today. T or F: The officer struck the man). Participants responded with a button press on a keyboard. Comprehension questions appeared on the screen 1500-ms following the offset of the previous trial, and the next trial began 1500 ms after participants made a response. In addition, comprehension questions followed half of the filler trials. Accuracy was 90.7% on average (range: 85.2–95.3%) and did not differ between experimental and filler trials ($p = .65$).

EEG recording and data reduction.: The electroencephalogram was recorded from 29 electrodes mounted in a custom electrode cap (ElectroCap International), referenced to the right mastoid (except for the electrodes that were used to measure potential blinks and eye movements: One electrode placed beneath the left eye was referenced to FP1, and two placed at the outer canthi of both eyes were referenced to each other). The left mastoid was also recorded, and the algebraic average of the right and left mastoids was used for offline re-referencing. The EEG signal was amplified with band pass cut-offs of 0.01 and 30 Hz and was digitized at a sampling rate of 250 Hz using a Neuroscan Synamps system. Impedances were kept below 5 kΩ.

Prior to offline averaging, all trials were screened for amplifier blocking, muscle artefacts, horizontal eye movement artefacts, and blinks over epochs of 2000 ms, starting 200 ms before the onset of the critical regions (see below). Averaged ERPs were computed for artefact-free trials and were filtered with a Gaussian low-pass filter (25 Hz half-amplitude cut-off). On average, 16% of trials were rejected due to the presence of artefacts, and 33 trials per condition, per participant were included in the analysis (range: 25–40). There were no significant differences in the number of trials rejected in each condition ($p > .6$). Statistical analyses were calculated using the filtered data.

Analogous to the eye-tracking study, we averaged ERPs in three regions. The *verb + noun phrase* region included the matrix verb (e.g., *hit* in Sentence 7) and the determiner and noun immediately following the matrix verb (*the man*). For the ERPs, this NP was combined with the verb, because our previous studies have shown an N400 effect of lexical repetition on the verb in the target sentences (Tooley et al., 2009), and this precludes calculation of a reliable prestimulus baseline for the determiner following the matrix verb, since it would be baselined on the N400 effect to the verb. The *PP* region included the preposition *with* and the following determiner and noun (*with the mustache*). The post-PP region consisted of the two words immediately following the noun in the PP region (*earlier today*). Results are reported below for all the words in these three regions (i.e., … / hit the man/ with the mustache/ earlier today).

Results and discussion

The ERPs for the three regions are displayed in Figures 1-3. As can be seen in Figure 1 (and supported by the statistical analyses reported below), there was indeed a large N400 effect of lexical repetition on the verb (reduced N400 to verbs in the target sentences) and on the word immediately following the verb (*the*). No N400 effects were observed two words after the repeated verb, reflecting a return to overlapping waveforms for both conditions at this point, which could then serve as a reliable baseline for the following PP region. Figure 2 shows the ERPs to the words in the PP region. Here we found a trend towards an N400 effect of repetition to the preposition (reduced N400 to “with” in the target sentence). There was also a significant difference on the determiner at midline electrode sites (with the determiner being more positive in primes than targets). No significant differences were found for the noun of the prepositional phrase, and this therefore served as a reliable baseline for the post-PP region. Finally, Figure 3 shows the ERPs to the words in the post-PP region, as well as topographic maps of the distribution of the syntactic-priming effects: A reduced P600 was found in the target sentences to each of the two words immediately following the critical disambiguating noun, with reduced positivities for targets compared to primes for noun + 1 and noun + 2.

Separate repeated measures ANOVAs (rANOVAs) were conducted for midline (electrodes Afz, Fz, Cz, Pz, POz), medial (electrodes FC1, FC2, C3, C4, CP1, CP2), and lateral (electrodes F3, F4, FC5, FC6, CP5, CP6, P3, P4) columns. Each rANOVA used the within-subjects factors of type, with two levels (prime, target), and topographic factors: For the midline column this was electrode site (five levels), and for the medial and lateral analyses, this was hemisphere (left, right) and anteriority (medial: frontocentral, centroparietal, parietal; lateral: frontal, frontocentral, centroparietal, parietal). These ANOVAs were conducted on the mean amplitude of the critical words corresponding to the 300–500-ms (N400) and the 500–800-ms (P600) epochs following the onset of each of the words in the critical regions. The Greenhouse–Geisser correction was used for F tests with more than one degree of freedom in the numerator for all relevant analyses reported in this paper. ANOVA results for the main effects and interactions of sentence type (prime vs. target) are reported in Tables 2-4.

Verb region results—A main effect of type was found in the 300–500-ms window in response to the verb at the midline, $F(1, 22) = 32.6$, $p < .001$, medial, $F(1, 22) = 29$, $p < .001$, and lateral columns, $F(1, 22) = 17.24$, $p < .001$, such that waveforms to target verbs were reduced in amplitude (less negative) than prime verbs (the N400 effect). A main effect of type was found in the 500–800-ms window in response to the verb at midline, $F(1, 22) = 7.1$, $p < .05$, and medial, $F(1, 22) = 7.2$, $p < .05$, columns, reflecting the reduced negativity for target verbs in this time window as well (rather than a P600 effect). There were significant interactions by electrode for this time window at midline sites, $F(4, 88) = 4.25$, $p < .05$, and by anteriority at lateral sites, $F(3, 66) = 4.68$, $p < .05$, reflecting a more central-posterior distribution (seen in Figure 1). For the word immediately following the verb (verb + 1), a main effect of type was found in the N400 window at midline sites, $F(1, 22) = 4.47$, $p < .05$, and medial sites, $F(1, 22) = 4.39$, $p < .05$, with targets being less negative than primes. At lateral sites this interacted with anteriority, $F(3, 66) = 4.68$; $p < .05$. There was also an interaction by anteriority at lateral sites for verb + 1 in the 500–800-ms time window, $F(3, 66) = 3.7$, $p < .05$. For verb + 2, no significant effects of type or interactions were found in either of the time windows (Fs < 2), other than an interaction by anteriority at lateral sites in the 500–800-ms window, $F(3, 66) = 3.81$, $p < .05$. Importantly, there were no significant differences in the 300–500-ms window following the verb + 2, so that this window could then serve as a reliable baseline for the following PP region.

Prepositional phrase region results—A main effect of type was found in the 300–500-ms time window in response to *with* at midline sites, $F(1, 22) = 10.51$, $p < .005$, such that waveforms to target sentences were reduced in amplitude (less negative) than prime sentences (N400 repetition effect). In the 500–800-ms epoch, no interaction by electrode or main effects were found in any columns, in response to *with* (Fs < 2). A main effect of type was found in the 300–500-ms time window in response to the determiner at midline sites, $F(1, 22) = 8.27$, $p < .005$, such that waveforms to prime sentences were more positive than those to target sentences (P600 effect). No other significant effects were found at the determiner (Fs < 2) or at the noun (Fs < 1).

Postprepositional phrase region results—No significant effects were found to the first word in this region (noun + 1) in the 300–500-ms time window (Fs < 1). However, a main effect of type was found in the P600 time window in response to the noun + 1 at midline sites, $F(1, 22) = 6.74$, $p < .05$, medial sites, $F(1, 22) = 8.83$, $p < .005$, and lateral sites, $F(1, 22) = 6.11$, $p < .05$, such that waveforms to targets were reduced in amplitude (less positive) than those to primes. No interactions by electrode or topographic factor were found (Fs < 1). For the second word in this region (noun + 2), significant main effects of type were found in the 300–500-ms time window at midline sites, $F(1, 22) = 8.73$, $p < .005$, medial sites, $F(1, 22) = 10.99$, $p < .005$, and lateral sites, $F(1, 22) = 8.3$, $p < .005$, such that waveforms in response to targets were less positive than those to primes. The direction of this effect was reversed in polarity from an N400 effect of repetition; in addition, words in this region were not repeated between prime and target sentences. We therefore interpret this effect as an early and continued effect of syntactic priming (as in Ledoux et al., 2007). No interaction by electrode was found ($F < 1$). In addition, a significant main effect of type was found in the P600 time window following noun + 2 at midline sites, $F(1, 22) = 4.37$, $p < .05$, medial sites, $F(1, 22) = 5.31$, $p < .05$, and lateral sites, $F(1, 22) = 5.44$, $p < .05$, also such that the response to targets was less positive than that to primes. No interaction by topographic factor was found ($F < 2$), other than an interaction of type by anteriority by hemisphere at lateral sites, $F(2, 44) = 4.34$, $p < .05$.

Consistent with the eye-tracking results found in Experiment 1, Experiment 2 showed repetition priming at the repeated verb in the target sentence (as indexed by the N400), which lingered on the verb + 1, which was followed by a reduced negativity for targets compared to primes at the preposition (repetition effects of the preposition *with*), and a small reduced positivity for determiners in target sentences compared to determiners in prime sentences. Immediately following exposure to the disambiguating material in the target sentences, noun-attached targets showed a reduced positivity relative to noun-attached primes. These results suggest that processing a prime sentence facilitates those syntactic processes that are responsible for building or recovering the syntactic structures required for noun attachment.

EXPERIMENT 3

Experiments 1 and 2 showed that processing of a prime sentence containing a noun-attached PP-modifier facilitated processing of a structurally identical target. The ERP experiment suggested that the prime both caused repetition priming of the main verb itself and facilitated syntactic processing following the point at which the sentence was disambiguated towards noun modification. Experiment 3 was designed to investigate priming effects in a related, but distinct, sentence type, modifier–goal ambiguities, as in (8) and (9):

8. The chef dropped the egg *in the bowl* before breakfast. (Goal prime)

9. The chef dropped the egg on the counter *in the bowl* before breakfast. (Modifier prime)

Prime sentences like (8) and (9) were followed by *modifier* target sentences, like (10):

10. The girl dropped the blanket on the floor *on the bed* last night. (Modifier target)

These sentences contain a temporary ambiguity between verb and noun modification, but the semantic interpretation of the modifying expression is either as a goal location (related to the verb) or an attribute of the preceding noun (as opposed to an instrument versus an attribute, as in Experiments 1 and 2). Prior eye-tracking experiments (Traxler, 2008) showed that reading a matching prime facilitates processing of structurally related targets at and following disambiguation (e.g., at *on the bed,* in 10). Like Experiment 2, Experiment 3 tested whether this facilitation reflected aspects of semantic versus syntactic processing, or perhaps a combination of both.

Method

Participants—Twenty-four undergraduates from the University of California, Davis gave informed consent and participated in this study for course credit. All were right-handed native speakers of English with no reported psychological/neurological disorders and normal or corrected-to-normal vision and hearing. The average age was 19.7 years (range: 18–23).

Stimuli—Each participant read 80 experimental sentences: 40 prime and 40 target sentences containing modifier–goal ambiguities, like (8–10) above.

An additional 40 prime–target “catch-trial” pairs were included, in which the prime sentence also contained modifier–goal ambiguities, but the target sentences did not, as in the example below:

Catch-trial prime:	The teacher read the letter to the class to the principal at the staff meeting.
Catch-trial target:	The celebrity read the appeal to the director before filming started.

This was done so that it was not possible to predict the syntactic structure of the target sentences. All prime–target pairs contained the same verb.

Finally, 130 filler sentences of variable syntactic structure were included. Some filler sentences had main clause structures (*The biologist discovered a new species of frog*), some contained relative clauses (*The drummer that criticized the guitarist quit the band*), and some contained multiple prepositional phrases (*The couple on the park bench looked at the spaniel near the toddlers that chase after squirrels*).

Primes and targets were counterbalanced across four lists, so that each prime sentence in a particular list was used as a target sentence in a different list. Each participant was presented with one of the four lists. This counterbalancing allowed for the comparison across prime and target items of the same sentences, controlling for any potential differences in lexical frequency or length between items.

Procedure—The procedures, EEG recording details, and data reduction methods were the same as those reported above for Experiment 2. As in Experiment 2, comprehension questions did not focus on the critical manipulation (e.g., Target: The chef dropped the egg on the counter in the bowl before breakfast. T or F: The chef dropped an egg.). On average, 15.7% of trials were rejected due to the presence of artefacts, and, on average, 34 per condition per participant were included in the analysis (range: 25–40). There were no significant differences in the number of trials rejected in each condition ($p > .6$). Accuracy on the comprehension questions for Experiment 3 was 93% on average (range: 85.7–100%) and did not differ between experimental and filler trials ($p = .68$).

As in Experiment 2, we averaged ERPs corresponding to critical regions rather than individual critical words. Here, the verb region included the verb (e.g., *dropped* in Sentence 8) and the determiner and noun immediately following the verb (e.g., *the blanket* in Sentence 8). The critical PP region included the disambiguating preposition (the second *on* in Sentence 8), extending through the determiner and noun (*the bed* in Sentence 8). In other words, the critical PP region was the second prepositional phrase. Results are reported below for all the words in these two regions (e.g., … /dropped the blanket/ … /on the bed).

Results and discussion

The ERPs for the verb and prepositional phrase are shown in Figures 4 and 5. As can be seen in Figure 4 (and supported by the statistics below), a small but significant N400 effect of repetition priming was found in response to the repeated verb, with a reduction in the N400 amplitude for verbs in target sentences compared to verbs in prime sentences. Figure 5 shows the ERPs to words in the prepositional phrase region, as well as topographic maps showing the distribution of the syntactic-priming effects; P600 amplitudes were reduced in response to determiners and nouns in target sentences compared to those in prime sentences.

As in Experiment 2, repeated measures ANOVAs were conducted for midline (electrodes Afz, Fz, Cz, Pz, POz), medial (electrodes FC1, FC2, C3, C4, CP1, CP2), and lateral (electrodes F3, F4, FC5, FC6, CP5, CP6, P3, P4) columns. Each rANOVA used the within-subjects factors of type (prime, target), and topographic factor(s): for the midline column this was electrode site (five levels), and for the medial and lateral analyses, this was hemisphere (left, right), and anteriority (medial: frontocentral, centroparietal, parietal; lateral: frontal, frontocentral, centroparietal, parietal). These ANOVAs were conducted on the mean amplitude of the critical words corresponding to the 300–500-ms (N400) and the 500–800-ms (P600) epochs following the onset of each of the words in the critical regions. Results for the main effects and interactions with sentence type (prime vs. target) are reported in Tables 5-7.

Verb region results—There was a Type × Anteriority interaction at lateral sites in the 300–500-ms time window, $F(3, 66) = 4.38$, $p < .05$, and a Type × Hemisphere × Anteriority interaction at lateral sites in the 500–800-ms time window, $F(3, 66) = 3.26$, $p < .05$, with a reduced negative deflection for verbs in target sentences relative to those in the prime sentences. No main effects or interactions with topographic factors reached significance for the words following the verb (verb + 1, verb + 2) in either the 300–500-ms or 500–800-ms time windows, relative to critical word onset (Fs < 2).

Prepositional phrase region results—No main effects or interactions with topographic factors reached significance in response to the preposition, in either the N400 or P600 time windows (Fs < 2.3). In response to the determiner, there was a significant effect in the N400 window at midline sites, $F(1, 22) = 4.56$, $p < .05$, and there was a Type × Electrode interaction in the P600 window at midline sites, $F(28, 616) = 6.34$, $p < .005$, and a Type × Anteriority interaction at medial sites, $F(2, 44) = 7$, $p < .005$, and lateral sites, $F(3, 66) = 5.13$, $p < .05$, with determiners in prime sentences having a larger positive deflection than those in target sentences. At the noun, there was an interaction by electrode in the N400 window, $F(1, 22) = 3.66$, $p < .05$, at midline sites, and a main effect of type in the lateral columns, $F(1, 22) = 5.88$, $p < .05$, with nouns in prime sentences having a larger positive deflection than those in target sentences.

In summary, as in Experiment 2, Experiment 3 also showed repetition priming at the repeated verb in the target sentence, indexed by an N400 effect. This lexical repetition effect was less robust than that in Experiment 2 and was present only at some lateral electrode sites. This may be because the length of the sentences in Experiment 3 (average = 13.5 words; range: 10–17) was, on average, longer than that in Experiment 2 (average = 11.2; range: 10–14; $p < .005$). Since the verbs always occurred early (Word 3) in the sentence, longer sentence length means that there was more material (i.e., a longer duration) separating the verb in the prime sentence from the verb in the target sentence in Experiment 3 than in Experiment 2. This could have led the verb repetition effect to be smaller in Experiment 3 than in Experiment 2.

Most importantly for the current study, modifier targets showed reduced P600 amplitudes in response to the determiner and noun of the disambiguating prepositional phrase, compared to modifier primes. As can be seen in the topographic maps at the bottom of Figure 5, these syntactic-priming effects showed a more posterior distribution than those found in Experiment 2, which were more widely distributed across the scalp (see Figure 3). Overall, consistent with Experiment 2, the results of Experiment 3 provide evidence that processing a prime sentence containing a syntactically ambiguous prepositional phrase facilitates syntactic processing of a subsequent target sentence containing the same structure.

GENERAL DISCUSSION

In Experiment 1, exposure to a noun-attached prime sentence facilitated the processing of noun-attached target sentences, starting shortly after participants encountered disambiguating material. As far as we know, this is the first demonstration of priming during online interpretation of this sentence type. Experiment 2, consistent with previous ERP experiments, showed reduced P600s following syntactically disambiguating material when noun-attached targets followed noun-attached primes (Ledoux et al., 2007; Tooley et al., 2009). These reduced positivities occurred while participants were processing the words immediately following the noun that disambiguated prepositional phrase attachment in favour of noun modification. The results from Experiment 2 suggest that facilitated syntactic analysis or reanalysis contributed to speeded target-sentence processing. Experiment 3 also showed reduced P600 effects following disambiguating material when a noun-attached prime preceded a noun-attached target in sentences containing modifier–goal ambiguities.

Taken together, the results of Experiments 1–3 suggest the following scenario: First, participants have an overall bias for verb attachment when processing our test sentences (and similar sentences) when they are presented in isolation. In Experiments 1 and 2, verb-attachment bias causes processing difficulty in the prime sentences because an instrument interpretation is not correct in this case (e.g, " … hit with the bruise … "), but this is reduced when the structure is repeated in the target sentences. In Experiment 3, the initial goal interpretation of the first PP-modifier proves incorrect upon encountering a second PP-modifier (the actual goal), and readers are forced to undertake a kind of syntactic displacement, in which the previously verb-attached modifying phrase must be reattached to a preceding noun.

All of the experiments support an account under which processing a prime sentence that shares aspects of syntactic form with the (ultimately) correct reading of the target facilitates structural reanalysis. This facilitation could occur because the prime sentence makes the specific structural alternative to the initial interpretation more salient. Alternatively, processing the prime could facilitate more general structural revision processes, such as the operations that undo prior syntactic choices and replace them with other licensed options. This account explains the basic facilitation effects found with eye tracking (Experiment 1), as well as why processing a noun-attached prime leads to reduced positivities when processing a noun-attached target (Experiments 2 and 3). (This does not mean that verb-attachment bias cannot be over-ridden, nor that all primes will produce reduced positivities under all circumstances, however.)

The current results provide a further demonstration of the value of ERP methods in studying syntactic-priming effects during online sentence processing. Previous studies on other sentence types have shown that exposure to a prime sentence can influence behaviour, including decisions about when and where to move the eyes during reading and while listening (Arai et al., 2007; Carminati et al., 2008; Thothathiri & Snedeker, 2008a, 2008b;

Traxler & Tooley, 2008), as well as judgements about the ultimate interpretation of globally ambiguous sentences (Branigan et al., 2005). Changes in behaviour in response to a prime sentence should occur irrespective of whether semantic or syntactic processes are facilitated. Hence, behavioural measures can show that exposure to a prime sentence affects some aspect or aspects of target sentence processing, but they may not, by themselves, provide substantial evidence regarding what precise aspects of processing are being facilitated. ERPs provide a valuable supplement because some aspects of the response are sensitive to syntactic properties of stimuli, while others are sensitive to semantic properties (Kutas, van Petten, & Klueder, 2006; Nakano et al., 2010; but see Kim & Osterhout, 2005; Kuperberg, 2007; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007). More specifically, manipulations that ease semantic processing are associated with reduced N400s, while manipulations that ease syntactic processing are associated with reduced P600s (Brown &Hagoort, 1993; Osterhout & Holcomb, 1992).

The fact that the current experimental manipulation facilitated behavioural responses (Experiment 1) and led to reduced positivities during target processing (Experiments 2 and 3) may inform various aspects of parsing theory. The data suggest that, despite the substantial influence of referential factors on the processing of verb–noun attachment ambiguities, a syntactic decision is still being made during the interpretive process. Full exploration of the compatibility of verb–noun attachment priming effects will require additional experimentation. For example, the construal account suggests that relative clause modifiers will be treated differently from prepositional phrase modifiers (the former reflecting *nonprimary* relations, the latter reflecting *primary relations*). In short, according to the construal account, all possible structures compatible with the input are built when readers encounter nonprimary relations (e.g., relative clause modifiers), and contextual factors can quickly influence the “ranking” of activated candidate structures. As such, encountering an unexpected relative clause modifier may not require syntactic revision; instead, it may simply lead to an increase in the activation of the relative clause parse. If such a sentence (e.g., The driver of the car that had the mustache …) was additionally primed by a preceding sentence with a similar structure, a different pattern of ERPs might occur from that seen in the current experiment. Namely, syntactic priming of nonprimary relations, such as relative clause modifiers, could result in reduced negativities (indicative of facilitated semantic processing) rather than reduced positivities (which indicate a syntactic component to the priming effect).

The referential hypothesis views the difficulty of processing noun-attached modifiers as reflecting a kind of pragmatic oddity (Altmann et al., 1994; Altmann & Steedman, 1988; Ni et al., 1996). That is, when a sentence is presented in a null context, comprehenders’ discourse representations will include only those entities for whom explicit evidence is available in the input. If a definite, singular noun phrase appears, comprehenders assume a single relevant entity. If a sentence continues with an expression that modifies the single, relevant entity, that material will often times be treated as redundant or anomalous. Minimally, comprehenders will have a strong tendency to revise their discourse model to include contrasting entities. On this account, interpreting noun-attached modifiers in the processing environment that prevailed in the current experiments will involve making and revising semantic commitments. While the results of the two priming experiments did not produce any strong or direct evidence of semantic revision, the absence of a reduced negativity at and following the point of syntactic disambiguation does not rule out such effects. The most conservative interpretation would be that comprehenders rejected the preferred verb-attachment solution because of properties of the noun within the prepositional phrase. However, the ERP results suggest that, when the verb-attachment interpretation was abandoned, a syntactic revision accompanied semantic reinterpretation. This account can explain the reduced positivity in targets that followed noun-attached primes in Experiments 2 and 3. It may also indicate why there were greater first-pass regressions from the postnoun scoring region in Experiment 1 when the noun-attached target sentence followed a verb-attached prime. It is an open question as to the ERP response that would occur based on contextual manipulation of discourse entities, but one fairly obvious prediction is that embedding our noun-attached targets in referentially supportive contexts would lead to reduced negativities at and following the critical noun, something that we are currently testing in a new study (e.g., *mustache* in 7).

The second set of conclusions relates to the *good-enough* parsing hypothesis (Christianson, Williams, Zacks, & Ferreira, 2010; Ferreira, 2003; Swets, Desmet, Hambrick, & Ferreira, 2007). Comprehenders sometimes misinterpret sentences that they hear or read. These misinterpretations may linger, despite the available syntactic and semantic cues. Misinterpretations may occur even in cases where the grammar would seem to rule out the syntactic structure that accompanies that interpretation, as in *The coach smiled at the player tossed the frisbee* (Tabor et al., 2004). The good-enough parsing hypothesis attributes these various failures to underspecification or lack of specification of syntactic relations in sentences. Syntactic relations may be underspecified when lexical cues provide sufficient information about the event to which a sentence refers (e.g., *mouse, cheese*, and *eat* specify an event in which the mouse eats and the cheese gets eaten, any syntax being absent), when comprehension demands are low (as in most psycholinguistic experiments), or when syntax is more difficult (as in passives, *garden-path* sentences, or globally ambiguous sentences). One version of this account indicates that “syntactic reanalysis may not be an all-or-nothing process and might not be completed unless questions probing unresolved aspects of the sentence structure challenge the resultant interpretation” (Christianson et al., 2010, p. 205). This approach to parsing differs from the vast majority of other accounts, whether they assume two-stage, restricted information systems (Frazier, 1979; Frazier & Clifton, 1996), constraint-based accounts (e.g., MacDonald et al., 1994; Tanenhaus et al., 1995; Vosse & Kempen, 2000, 2009), or unrestricted race-based parsers (e.g., Pickering et al., 2011; Traxler, Pickering, & Clifton, 1998), all of which assume that parsing is obligatory (by whatever means).

In the current experiments, comprehension questions were asked after all critical target sentences, but did not focus on the temporary syntactic ambiguity (e.g., *Who got hit?* or *What did the girl use to hit the boy?*) Focusing questions can strongly influence the interpretation of prepositional phrase modifier ambiguities (see, e.g., Liversedge, Pickering, Branigan, & van Gompel, 1998; Liversedge, Pickering, Clayes, & Branigan, 2003). In addition, metalinguistic judgement tasks, such as those requiring participants to judge the acceptability of critical sentences, may influence the P600 effect. For example, in one study, P600 deflections in response to syntactic anomalies that were embedded in syntactically complex (object-relative) sentences were found when participants made acceptability judgements about the sentences, but not when participants read for comprehension and answered true/false comprehension questions to a subset of sentences (Kolk et al., 2003). These and other results (see Kuperberg, 2007, for a discussion of the influence of task demands on the P600 effect) suggest that questions highlighting the syntactic manipulation under examination can enhance the P600 effect. However, in the current experiments, participants were not required to make an acceptability judgement about the sentences, nor were they asked focusing questions. Instead, the true/false comprehension questions that appeared after target sentences were akin to a simple memory test. This task was intended to encourage attentive reading, but was unlikely to highlight the particular structure being tested or the difference between experimental conditions the way an acceptability judgement or other metalinguistic task might have.

Despite a lack of focusing questions, the overall syntactic structure of the prime sentence appeared to influence readers' response to the target sentences. When the prime and target sentences had matching syntactic structures, in that both had a prepositional phrase that modified a noun (rather than the preceding main verb), processing was facilitated (reading times were shorter, and the ERPs to the targets were less positive). These results would seem to indicate that considerable syntactic work was being undertaken to resolve a temporary ambiguity, despite the absence of focusing questions or a high-stakes experimental context. We might therefore conclude that readers routinely compute syntactic relations under conditions that are conducive to good-enough solutions. Alternatively, we may have discovered that repeated syntactic structures are sufficient to overcome the comprehenders' tendency to underspecify syntactic relationships. If so, that would beg the question of how readers register the repetition of structure if, during the processing of the prime sentence, they apply good-enough heuristics.

Limitations and future directions

One potential concern with the current experiment is that all of the target sentences had verbs that also appeared in the prime sentences. This procedure was adopted because prior comprehension priming studies have usually shown the most robust effects under these conditions. However, we do not know whether priming would occur if different verbs appeared in the prime and target sentences. Further, we do not know whether this change would affect the ERP outcomes. It is possible that a reduced N400, rather than a reduced P600, would occur in the target sentence in the absence of verb repetition. We plan to test this hypothesis in a future experiment. It will also be important to gather further evidence with regard to potential distinctions between processing before and after verb-argument saturation. One possibility would be to look at other processing environments involving adjunct modifiers, such as noun-modifying full relative clauses (e.g., Traxler et al., 1998).

CONCLUSIONS

An eye-tracking experiment and two ERP experiments showed that exposure to a difficult noun-attached prime sentence influenced processing and interpretation of a subsequent noun-attached target sentence. As in previous priming studies, reading times were reduced when the overall syntactic form of the prime sentence matched that of the target. ERPs provided evidence that the noun-attached prime affected syntactic processes during interpretation or reinterpretation of a modifying expression in the target sentence. Hence, syntactic-structure-building processes are subject to priming in verb–noun attachment ambiguities, as they are in other sentence types.

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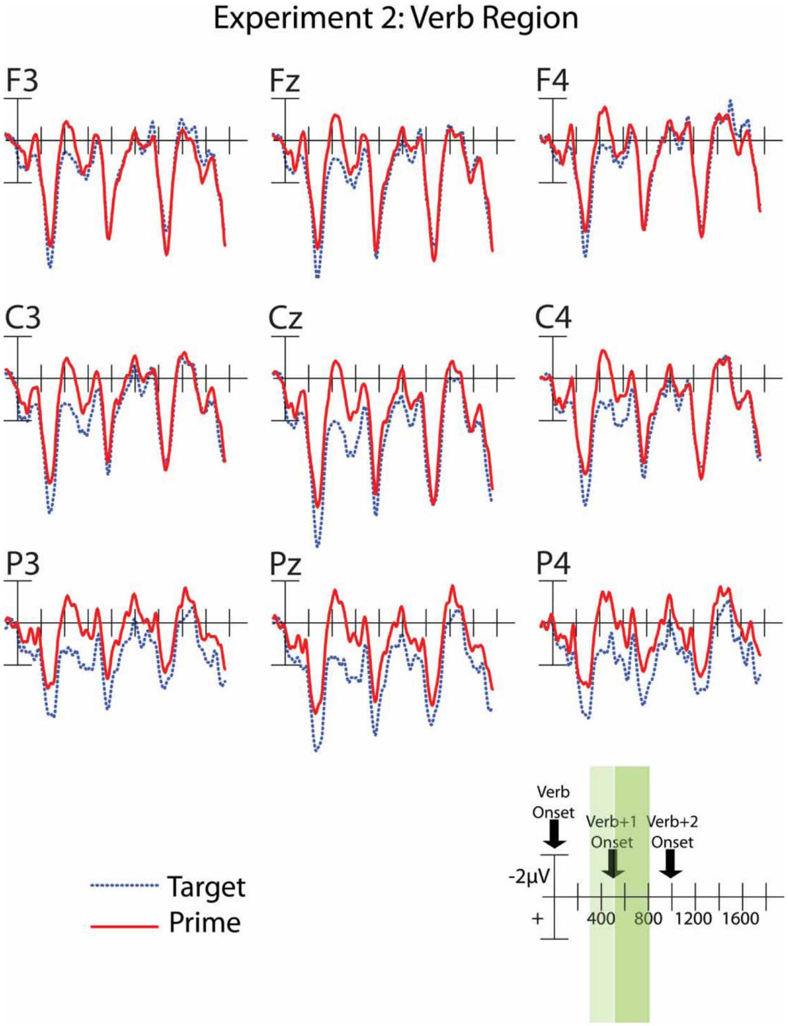

Figure 1.

Effect of type for the verb region for Experiment 2. Red lines represent waveforms in response to the prime sentence; in blue (dotted line) is the response to the target sentence. Nine electrodes representing frontal, central, and posterior sites are shown. Negative is plotted up. The verb region is shown (2000-ms epoch), covering the main verb, verb + 1 and verb + 2. The N400 time window (for the main verb) appears shaded in light green (light gray), while the P600 time window is shaded in darker green (dark gray). To view a colour version of this figure, please see the online issue of the Journal.

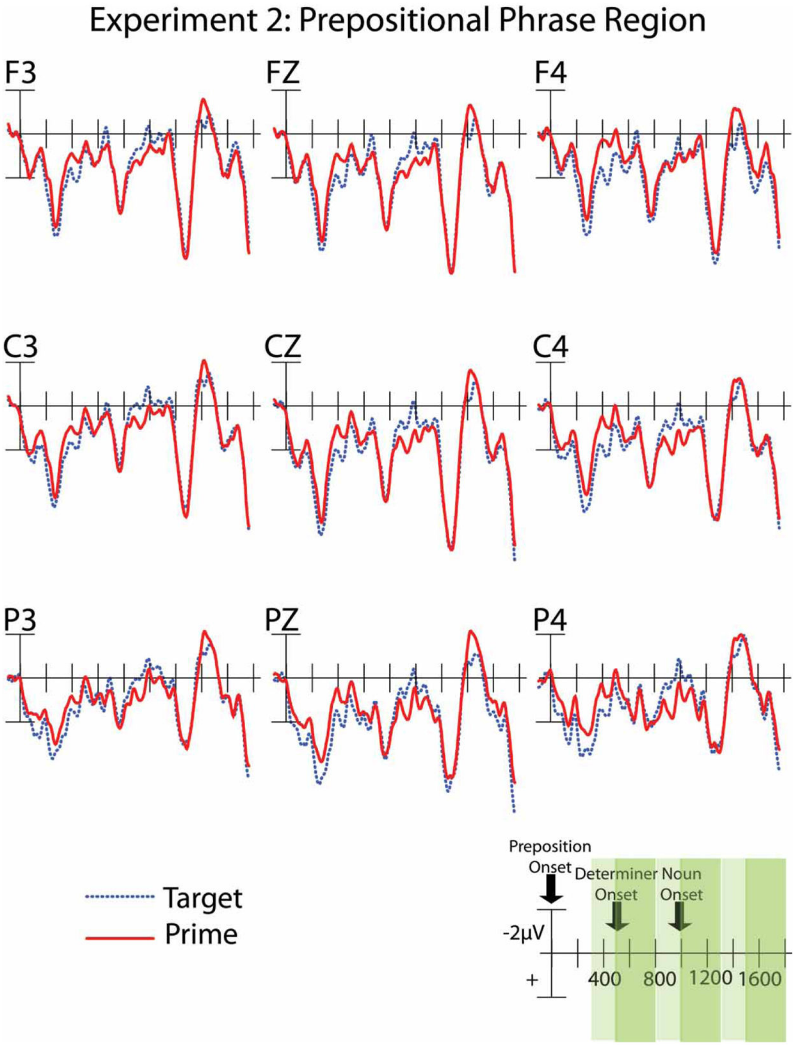

Figure 2.

Effect of type for the prepositional phrase region for Experiment 2. Red lines represent waveforms in response to the prime sentence; in blue (dotted line) is the response to the target sentence. Nine electrodes representing frontal, central, and posterior sites are shown. Negative is plotted up. The prepositional phrase region is shown (2000-ms epoch), covering the preposition, determiner, and noun. The N400 time windows corresponding to the preposition, determiner, and noun appear shaded in light green (light gray), while the P600 time windows are shaded in darker green (dark gray). To view a colour version of this figure, please see the online issue of the Journal.

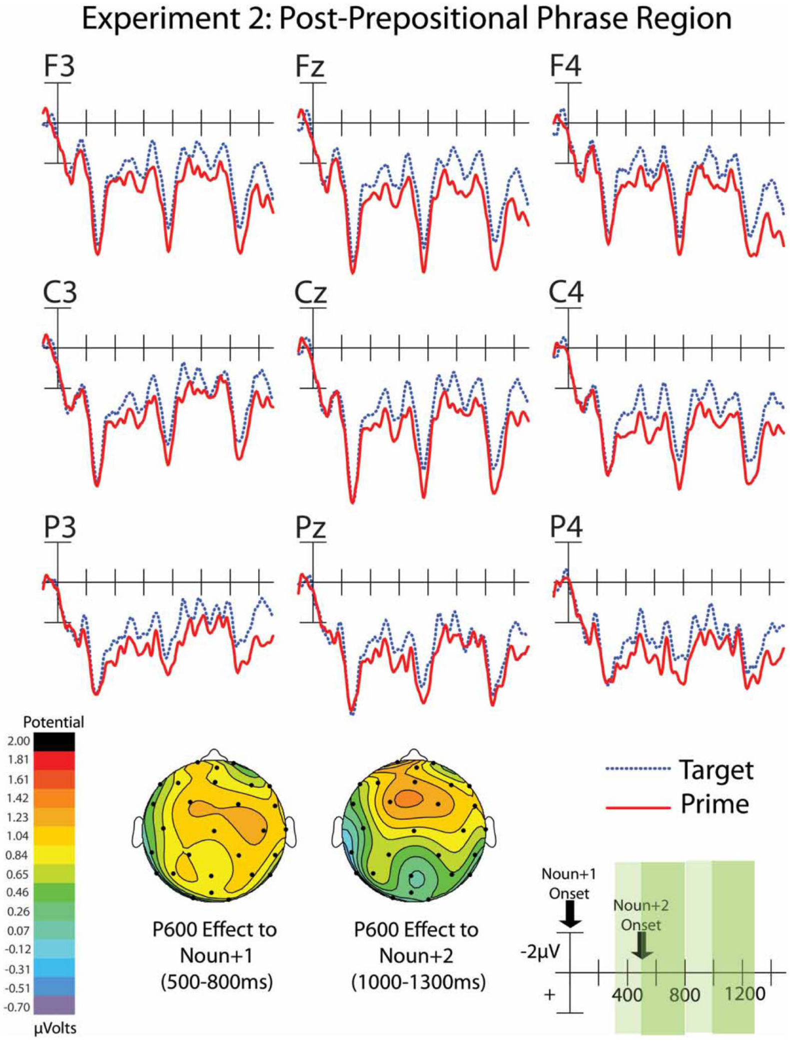

Figure 3.

Effect of type for the postprepositional phrase region for Experiment 2. Red lines represent waveforms in response to the prime sentence; in blue (dotted line) is the response to the target sentence. Nine electrodes representing frontal, central, and posterior sites are shown. Negative is plotted up. The postprepositional phrase region is shown (1600-ms epoch), covering noun + 1 and noun + 2. The N400 time windows corresponding to noun + 1 and noun + 2 appear shaded in light green (light gray), while the P600 time windows are shaded in darker green (dark gray). At the bottom left of the figure are topographic maps displaying the distribution of the effects in the P600 time windows corresponding to noun + 1 and noun + 2. To view a colour version of this figure, please see the online issue of the Journal.

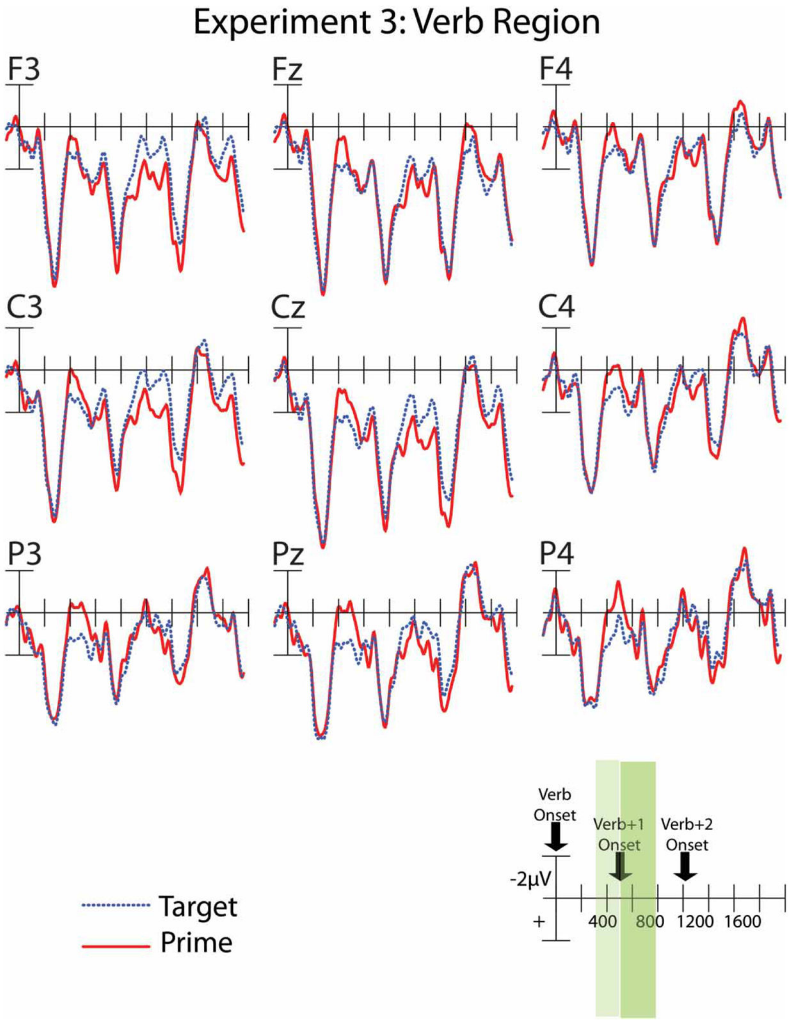

Figure 4.

Effect of type for the verb region for Experiment 3. Red lines represent waveforms in response to the prime sentence; in blue (dotted line) is the response to the target sentence. Nine electrodes representing frontal, central, and posterior sites are shown. Negative is plotted up. The verb region is shown (2000-ms epoch), covering the main verb, verb + 1, and verb + 2. The N400 time window (for the main verb) appears shaded in light green (light gray), while the P600 time window is shaded in darker green (dark gray). To view a colour version of this figure, please see the online issue of the Journal.

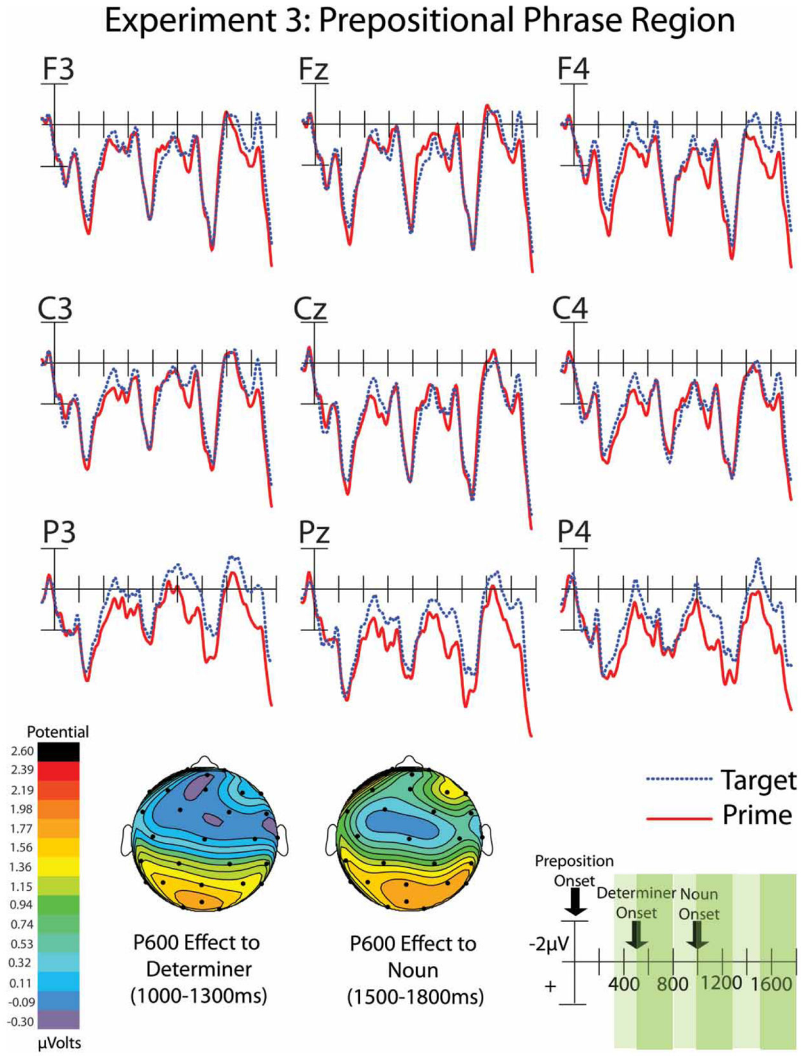

Figure 5.

Effect of type for the prepositional phrase region for Experiment 3. Red lines represent waveforms in response to the prime sentence; in blue (dotted line) is the response to the target sentence. Nine electrodes representing frontal, central, and posterior sites are shown. Negative is plotted up. The prepositional phrase region is shown (2000-ms epoch), covering the preposition, determiner, and noun. The P600 time windows corresponding to the determiner and noun are shaded in darker green (dark gray). At the bottom left of the figure are topographic maps displaying the distribution of the effects in the P600 time windows corresponding to the determiner and the noun. To view a colour version of this figure, please see the online issue of the Journal.

Table 1.

Mean values of the four dependent measures by scoring region and condition, Experiment 1

		Scoring region			
Dependent measure	**Condition**	**Verb**	**NP**	**PP**	**Post-PP**
First pass (ms)	Noun-attached prime	340 (6.98)	376 (10.6)	544 (17.3)	391 (14.9)
	Target after verb-attached prime	343 (7.04)	375 (9.46)	549 (11.0)	390 (9.02)
	Target after noun-attached prime	334 (7.56)	370 (7.77)	540 (11.9)	398 (9.51)
First-pass regressions (%)	Noun-attached prime	10.8 (1.29)	10.1 (1.30)	8.8 (1.16)	19.6 (1.75)
	Target after verb-attached prime	8.7* (1.16)	7.2* (1.02)	7.3 (1.12)	24.4 (1.68)
	Target after noun-attached prime	8.0* (1.09)	7.6* (1.08)	7.5 (1.15)	20.1 (1.52)
Regression path time (ms)	Noun-attached prime	379 (9.09)	398 (12.0)	590 (20.6)	448 (19.8)
	Target after verb-attached prime	372 (7.63)	392 (9.89)	583 (13.4)	441 (12.0)
	Target after noun-attached prime	366 (10.4)	386 (8.56)	570 (13.5)	454 (13.1)
Total time (ms)	Noun-attached prime	405 (11.0)	471 (23.7)	720 (36.4)	443 (23.4)
	Target after verb-attached prime	397 (14.1)	459 (17.9)	717 (25.2)	426 (19.8)
	Target after noun-attached prime	384 (12.0)	428 (16.6)	678 (23.0)	434 (19.8)

Note: Standard errors (based on the by-participants analyses) appear in parentheses. NP = noun phrase; PP = prepositional phrase.

* $p < .05$.

Table 2.

Main effects of type and interactions with electrode site for the midline column in Experiment 2

			Type		*Type × Electrode*	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(28, 616)***	**p**
Verb region	Verb	300–500	**32.6**	**.0001**[**]	2.91	*ns*
		500–800	**7.1**	**.0142**[*]	**4.25**	**.0484**[*]
	Verb + 1	300–500	**4.47**	**.0462**[*]	1.72	*ns*
		500–800	1.45	*ns*	1.84	*ns*
	Verb + 2	300–500	<1	*ns*	1.19	*ns*
		500–800	<1	*ns*	1.58	*ns*
Prepositional phrase region	Preposition	300–500	**10.51**	**.0037**[**]	<1	*ns*
		500–800	<1	*ns*	1.15	*ns*
	Determiner	300–500	**8.27**	**.0088**[**]	1.54	*ns*
		500–800	<1	*ns*	<1	*ns*
	Noun	300–500	<1	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*
Postprepositional phrase region	Noun + 1	300–500	2.53	*ns*	<1	*ns*
		500–800	**6.74**	**.0165**[*]	<1	*ns*
	Noun + 2	**300–500**	**8.73**	**.0073**[**]	<1	*ns*
		500–800	**4.37**	**.0484**[*]	<1	*ns*

Note: Type: prime versus target. Time windows are relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

[*] $p < .05$.

[**] $p < .01$.

Table 3.

Main effects of type and interactions with topographic factors for the medial column in Experiment 2

			Type		*Type* × *Hemisphere*		*Type* × *Anteriority*		*Type* × *Hemisphere* × *Anteriority*	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(1, 22)***	**p**	**F*(2, 44)***	**p**	**F*(2, 44)***	**p**
Verb region	Verb	300–500	**29**	**.0001** **	<1	*ns*	2.32	*ns*	1.21	*ns*
		500–800	**7.2**	**.0136** *	<1	*ns*	3.47	*ns*	<1	*ns*
	Verb + 1	300–500	**4.39**	**.0478** *	<1	*ns*	2.6	*ns*	<1	*ns*
		500–800	1.58	*ns*	<1	*ns*	2.22	*ns*	<1	*ns*
	Verb + 2	300–500	<1	*ns*	<1	*ns*	1.75	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	1.58	*ns*	<1	*ns*
Prepositional phrase region	Preposition	300–500	2.82	*ns*	2.35	*ns*	<1	*ns*	2.25	*ns*
		500–800	<1	*ns*	<1	*ns*	1.07	*ns*	<1	*ns*
	Determiner	300–500	2.24	*ns*	<1	*ns*	2.32	*ns*	1.04	*ns*
		500–800	<1	*ns*	<1	*ns*	3.47	*ns*	<1	*ns*
	Noun	300–500	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	<1	*ns*	2.12	*ns*
Postprepositional phrase region	Noun + 1	300–500	2.79	*ns*	<1	*ns*	<1	*ns*	1.22	*ns*
		500–800	**8.83**	**.0071** **	<1	*ns*	<1	*ns*	<1	*ns*
	Noun + 2	300–500	**10.99**	**.0032** **	<1	*ns*	<1	*ns*	<1	*ns*
		500–800	**5.31**	**.0311** *	<1	*ns*	1.62	*ns*	**4.34**	**.0201** *

Note: Type: prime versus target. Time windows relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

* *p* < .05.

** *p* < .01.

Table 4.

Main effects of type and interactions with topographic factors for the lateral column in Experiment 2

			Type		*Type* × *Hemisphere*		*Type* × *Anteriority*		*Type*× *Hemisphere* × *Anteriority*	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(1, 22)***	**p**	**F*(2, 44)***	**p**	**F*(2, 44)***	**p**
Verb region	Verb	300–500	**17.24**	**.0004****	<1	*ns*	3.76	*ns*	1.33	*ns*
		500–800	3.31	*ns*	<1	*ns*	**4.68**	**.0387***	<1	*ns*
	Verb +1	300–500	1.66	*ns*	<1	*ns*	**5.26**	**.0287***	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	**3.7**	**.0351***	<1	*ns*
	Verb + 2	300–500	<1	*ns*	<1	*ns*	2.1	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	**3.81**	**.0318***	<1	*ns*
Prepositional phrase region	Preposition	300–500	3.89	*ns*	4.27	.0508	<1	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
	Determiner	300–500	1.2	*ns*	<1	*ns*	<1	*ns*	1.39	*ns*
		500–800	<1	*ns*	<1	*ns*	<1	*ns*	2.69	*ns*
	Noun	300–500	<1	*ns*	<1	*ns*	<1	*ns*	1.39	*ns*
		500–800	<1	*ns*	2.74	*ns*	<1	*ns*	2.69	*ns*
Postprepositional phrase region	Noun + 1	300–500	3.23	*ns*	1.2	*ns*	<1	*ns*	<1	*ns*
		500–800	**6.11**	**.0217***	<1	*ns*	<1	*ns*	1.06	*ns*
	Noun + 2	300–500	8.3	.0087**	<1	*ns*	<1	*ns*	<1	*ns*
		500–800	5.44	.0292*	<1	*ns*	<1	*ns*	1.33	*ns*

Note: Type: prime versus target. Time windows relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

*$p < .05$.

**$p < .01$.

Table 5.

Main effects of type and interactions with electrode site for the midline column in Experiment 3

			Type		*Type × Electrode*	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(28, 616)***	**p**
Verb region	Verb	300–500	**3.64**	**.069**	2.8	*ns*
		500–800	<1	*ns*	<1	*ns*
	Verb + 1	300–500	<1	*ns*	<1	*ns*
		500–800	1.88	*ns*	<1	*ns*
	Verb + 2	300–500	<1	*ns*	1.47	*ns*
		500–800	<1	*ns*	1.8	*ns*
Prepositional phrase region	Preposition	300–500	1.18	*ns*	<1	*ns*
		500–800	<1	*ns*	2.79	*ns*
	Determiner	300–500	<1	*ns*	**4.56**	**.0174** *
		500–800	1.11	*ns*	**6.34**	**.0039** *
	Noun	300–500	<1	*ns*	**3.66**	**.0338** *
		500–800	2.08	*ns*	2.05	*ns*

Note: Type: prime versus target. Time windows are relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

* $p < .05$.

** $p < .01$.

Table 6.

Main effects of type and interactions with topographic factors for the medial column in Experiment 3

			Type		*Type × Hemisphere*		*Type × Anteriority*		*Type × Hemisphere × Anteriority*	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(1, 22)***	**p**	**F*(2, 44)***	**p**	**F*(2, 44)***	**p**
Verb region	Verb	300–500	1.64	*ns*	<1	*ns*	1.06	*ns*	<1	*ns*
		500–800	<1	*ns*	2.17	*ns*	<1	*ns*	<1	*ns*
	Verb + 1	300–500	<1	*ns*	3.17	*ns*	<1	*ns*	<1	*ns*
		500–800	1.98	*ns*	2.24	*ns*	<1	*ns*	<1	*ns*
	Verb + 2	300–500	<1	*ns*	1.9	*ns*	1.27	*ns*	<1	*ns*
		500–800	<1	*ns*	2.34	*ns*	1.64	*ns*	1.05	*ns*
Prepositional phrase region	Preposition	300–500	1.09	*ns*	<1	*ns*	1.58	*ns*	<1	*ns*
		500–800	<1	*ns*	<1	*ns*	2.64	*ns*	1.14	*ns*
	Determiner	300–500	<1	*ns*	<1	*ns*	**3.93**	**.057**	1.1	*ns*
		500–800	<1	*ns*	<1	*ns*	**7**	**.0026**[*]	<1	*ns*
	Noun	300–500	<1	*ns*	<1	*ns*	2.17	*ns*	<1	*ns*
		500–800	1.14	*ns*	<1	*ns*	1.5	*ns*	<1	*ns*

Note: Type: prime versus target. Time windows relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

[*] $p < .05$.

[**] $p < .01$.

Table 7.

Main effects of type and interactions with topographic factors for the lateral column in Experiment 3

			Type		***Type × Hemisphere***		***Type × Anteriority***		***Type × Hemisphere × Anteriority***	
Region	***Word***	***Epoch (ms)***	**F*(1, 22)***	**p**	**F*(1, 22)***	**p**	**F*(2, 44)***	**p**	**F*(2, 44)***	**p**
Verb region	Verb	300–500	1.88	*ns*	<1	*ns*	4.38	.0196[*]	1.7	*ns*
		500–800	<1	*ns*	1.98	*ns*	2.62	*ns*	**3.26**	**.0477**[*]
	Verb + 1	300–500	<1	*ns*	1.9	*ns*	2.17	*ns*	**3.62**	**.0356**[*]
		500–800	1.53	*ns*	3.17	*ns*	<1	*ns*	2.18	*ns*
	Verb + 2	300–500	<1	*ns*	1.04	*ns*	<1	*ns*	1.75	*ns*
		500–800	<1	*ns*	<1	*ns*	<1	*ns*	2.42	*ns*
Prepositional phrase region	Preposition	300–500	3.27	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
		500–800	1.22	*ns*	<1	*ns*	<1	*ns*	1.08	*ns*
	Determiner	300–500	<1	*ns*	<1	*ns*	1.68	*ns*	2.22	*ns*
		500–800	1.92	*ns*	<1	*ns*	**5.13**	**.0102**[*]	1.2	*ns*
	Noun	300–500	<1	*ns*	<1	*ns*	1.56	*ns*	<1	*ns*
		500–800	**5.88**	**.0235**[*]	<1	*ns*	<1	*ns*	<1	*ns*

Note: Type: prime versus target. Time windows relative to individual critical word onset; all words were time-locked and baselined to the first word in the region. Statistically significant values are printed in bold.

[*] $p < .05$.

[**] $p < .01$.