THE UNIVERSITY of EDINBURGH

Edinburgh Research Explorer

Lexically-mediated syntactic priming effects in comprehension

Citation for published version:
Tooley, KM, Pickering, M & Traxler, MJ 2019, 'Lexically-mediated syntactic priming effects in comprehension: Sources of facilitation', Quarterly Journal of Experimental Psychology, vol. 72, no. 9, pp. 2176-2196. https://doi.org/10.1177/1747021819834247

Digital Object Identifier (DOI):
10.1177/1747021819834247

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Quarterly Journal of Experimental Psychology

OPEN ACCESS

Running head: LEXICALLY-MEDIATED SYNTACTIC PRIMING

Lexically-Mediated Syntactic Priming Effects in Comprehension: Sources of Facilitation

Kristen M. Tooley

Texas State University

Martin J. Pickering

University of Edinburgh

Matthew J. Traxler

University of California, Davis

Short Title: Syntactic Priming in Comprehension

Address Correspondence To:

Kristen Tooley

Department of Psychology,

Texas State University

601 University Drive

San Marcos, TX 78666

512-245-3153 (fax) 512-245-4384 (phone)

ktooley@txstate.edu

Abstract

The nature of the facilitation occurring when sentences share a verb and syntactic structure (i.e., lexically-mediated syntactic priming) has not been adequately addressed in comprehension. In four eye-tracking experiments, we investigated the degree to which lexical, syntactic, thematic, and verb form repetition contribute to facilitated target sentence processing. Lexically-mediated syntactic priming was observed when primes and targets shared a verb and abstract syntactic structure, regardless of the ambiguity of the prime. Additionally, repeated thematic role assignment resulted in syntactic priming (to a lesser degree), and verb form repetition facilitated lexical rather than structural processing. We conclude that priming in comprehension involves lexically associated abstract syntactic representations, and facilitation of verb form and thematic role processes. The results also indicate that syntactic computation errors during prime processing are not necessary for lexically-mediated priming to occur during target processing. This result is inconsistent with an error-driven learning account of lexically-mediated syntactic priming effects.

Lexically-Mediated Syntactic Priming Effects in Comprehension: Sources of Facilitation

During comprehension, processing even a very challenging target sentence can be facilitated

when a previously comprehended sentence shares aspects of syntactic form with the target (Arai,

van Gompel, & Scheepers, 2007; Branigan, Pickering, & McLean, 2005; Traxler, 2008a, b;

Thothathiri & Snedeker, 2008a, b; see Bock, 1986; Bock & Loebell, 1990, for comparable

effects in sentence production). Because these effects depend on syntactic repetition, rather than

semantic repetition (Tooley, Traxler, & Swaab, 2009), repetition of function words (Carminati,

van Gompel, Scheepers, & Arai, 2008), or processing strategies (Traxler & Tooley, 2008), they

are classified as *syntactic priming* effects. When aspects of structure, but no content words are

shared between prime and target sentences, the resulting facilitation is referred to as *abstract*

syntactic priming. When prime and target sentences share a content word and syntactic structure,

the observed syntactic priming effects tend to be larger/easier to detect (Arai et al., 2007; Cleland

& Pickering, 2003; Ledoux, Traxler, & Swaab, 2007; see Pickering & Branigan, 1998;

Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008 for analogous effects in

sentence production). Thus, this lexically-mediated form of syntactic priming is sometimes

called the "lexical boost" and is the focus of the current study. Specifically, we seek to establish

the sources of facilitation that underlie lexically-meditated syntactic priming during online

sentence comprehension.

Current explanations of syntactic priming effects revolve around two compatible

principles. The first principle relates to the way experience influences syntactic representations

and/or procedures in long-term memory - i.e., adaptively (Chang, Dell, & Bock, 2006, 2012;

Fine & Jaeger, 2013; Fitz et al., 2011). This principle is supported by growing evidence that

abstract syntactic priming effects in production (Bock, Dell, Chang, & Onishi, 2007; Bock &

Griffin, 2000; Branigan, & McLean, 2016; Hartsuiker et al., 2008) and comprehension (Fine, Jaeger, Farmer, & Qian, 2013; Tooley & Traxler, 2018) are driven by a long-lived learning mechanism. This learning mechanism is suggested to be error-driven, such that learning is a consequence of a given structural experience deviating from the expected/predicted structure (based on encountered structural distributions). Thus, abstract priming is affected by the error-signal generated during processing of the prime, with greater priming following a larger error signal (Chang, Janciauskus, & Fitz, 2012; Jaeger & Snider, 2013). This mechanism accurately predicts findings of greater priming for less frequent structures (the inverse frequency effect) (Fine & Jaeger, 2013), and differential priming based on specific verb-structure biases (Bernolet & Hartsuiker, 2010).

The second principle relates to the way lexical and syntactic information is represented and deployed- i.e., interdependently (Boland & Boehm-Jernigan, 1998; Branigan et al., 2000; MacDonald et al., 1994; Vosse & Kempen, 2000, 2009). This principle has received less attention as it relates to syntactic priming. However, it offers insights into the nature of the facilitation underlying the lexical boost. Language production studies have shown that the lexical boost rarely persists across unrelated, intervening sentences (Branigan & McLean, 2016; Hartsuiker et al., 2008). Thus, some have argued that the lexical boost is likely produced by a short-lived (i.e., non-learning-based) mechanism (Bernolet, Collina, & Hartsuiker, 2016; Branigan & McLean, 2016; Hartsuiker et al., 2008; Tooley & Traxler, 2012). This could be a residual activation mechanism (similar to that proposed by Pickering & Branigan, 1998), where links between structural and verb nodes activated during prime processing, retain activation and facilitate processing of a target with that same verb and structure pairing (see Tooley & Traxler, 2012). Another mechanistic account suggests that structural information from the prime

4

sentence (stored in long-term memory) is temporarily linked to the individual words in the prime sentence (stored in working memory) (e.g., Reitter, Keller, & Moore, 2011; see also Chang et al., 2006; Chang et al., 2012). According to this account, when a content word from the prime is re-encountered during target processing, the associated structural information is activated. This information influences structural formulation/interpretation of the target, causing target facilitation.

Findings from comprehension, on the other hand, have shown that lexically-mediated syntactic priming effects can persist across one to three filler sentences (Pickering, Branigan, & MacLean, 2013; Tooley, Swaab, Boudewyn, Zirnstein, & Traxler, 2014). This may indicate that the lexical boost and abstract syntactic priming effects share a common mechanism. Learning models that rely on prediction error (e.g., Jaeger & Snider, 2013) can accommodate a lexical boost effect if they assume that better structural predictions can be made about sentences that utilize the same verb. If this prediction advantage (based on lexical similarity between sentences) is also assumed to decay more quickly than error associated with overall structural predictions, then this account would likewise predict a lexical boost that is more short-lived than abstract priming effects. Importantly, this account does not rely on a short-term/working memory system, which makes it consistent with recent findings that individuals with profound short-term memory deficits produce lexical boost effects that are on par with matched controls (Yan, Martin, & Slevc, 2018).

Another important question about the lexical boost is the nature of the syntactic representation being facilitated. It is unclear whether the syntactic representation being facilitated is highly abstract, reflecting a global constituent structure (but not lexical features within constituent phrases), or one that is based more so on the specific lexical content within

constituent phrases. For example, a reduced-relative clause (such as *The boy pushed by the girl cried*) and a full relative clause (such as *The boy who was pushed by the girl cried*) have identical global abstract structures (noun phrase- relative clause- verb phrase). Yet, they differ within the constituent relative clause phrase in that the full relative contains a relativizer ("who was"), but the reduced-relative does not. It is important to note that all of the major mechanistic accounts of syntactic priming assume priming effects reflect facilitation of an abstract structural representation (Chang et al., 2006; Pickering & Branigan, 1998; Reitter et al., 2011). This assumption is consistent with findings from Bock (1989), who found that priming for prepositional object datives is unaffected by the preposition (to vs. for) used in the prepositional phrase of this structure. It is also consistent with findings from Hsieh (2017) who found evidence for cross-linguistic syntactic priming across Chinese and English sentences that had the same abstract structures but different word orders (and different content words).

However, this assumption may be inconsistent with findings that participants can be primed to produce (or not produce) the word "that" as part of an internal complement clause of a sentence (Ferreira, 2003). Furthermore, this issue has never been investigated specifically for the lexical boost. It may be the case that the lexical boost, which is triggered by word-level information, is sensitive to changes in precise lexical/syntactic matching within constituent phrases. If such lexically-booseted/lexically-mediated syntactic priming effects do reflect facilitation of an abstract structural representation, then one would predict that priming effects will be observed for sentences that have matching abstract structures, even if the prime and target sentences differ in the specific lexical/syntactic content within their respective constituent phrases.

A related question is the degree to which other sources of facilitation (e.g., thematic role

6

Syntactic Priming in Comprehension

assignment) contribute to the observed lexically-mediated syntactic priming effects in comprehension. Intuitively, this seems likely given that sentences that share both structure and a content word may be more similar in meaning than sentences that share only abstract structure. Importantly, such additional sources of facilitation have been investigated with respect to abstract priming effects, specifically in production. For instance, Bock and Loebell (1990) found abstract syntactic priming effects without repetition of thematic roles for the active/passive alternation in production, but there are many studies showing that the order of thematic roles in production can be primed (e.g., Chang, Bock, & Goldberg, 2003; Ziegler & Snedeker, 2018). Analogous investigations for lexically-mediated syntactic priming effects in comprehension are currently lacking. These investigations are necessary given the mechanisms that produce abstract and lexically-mediated syntactic priming effects may differ, and so may be differentially influenced by non-syntactic sources of information.

To this end, the experiments reported in this article provide further evidence regarding the sources of facilitation that contribute to lexically-mediated syntactic priming effects in comprehension. The main goal of the study is to identify how aspects of structural, thematic, and lexical form repetition affect lexically-mediated priming. Clarifying what kinds of repeated features affect this type of priming will help to establish the type of syntactic representation that is being facilitated, identify other (non-syntactic) sources of facilitation that co-occur with syntactic effects, and lead to a better understanding of the mechanism that produces lexically-mediated syntactic priming effects.

For our purposes, the term "lexically-mediated syntactic priming" is preferred over the term "lexical boost" for two reasons. For one, it more accurately reflects the design of these studies which are not intended to compare situations where prime and target share only syntactic

structure to situations where they share both structure and a content word (allowing identification

of a boost in effect size). Secondly, the term "lexical boost" could imply an increase in the

magnitude of the abstract priming effect, rather than a lexically driven effect in addition to an

abstract effect. We feel that characterizing these syntactic priming effects as "lexically-

mediated" is more objective in that it only implies what we know: a lexical cue leads to some

sort of facilitation in syntactic processing.

Overview of the Experiments

Four experiments investigated the manipulated relationship between reading prime and target

expressions. These manipulations allowed us to test the following hypotheses:

1. Does a prime sentence need to be syntactically ambiguous for lexically-mediated

syntactic priming in comprehension to occur? Importantly, an error-driven learning mechanism,

which has been found to account for abstract structural priming effects, would predict priming

only when the prime structure involved a structural error signal. This is unlikely to be the case

for unambiguous relative clause prime sentences. Thus, priming in prior studies involving

reduced relatives may have occurred solely because syntactic reanalysis processes took place

when readers processed the prime sentence. If syntactic reanalysis processes are necessary for

syntactic priming effects during target processing, then little or no priming should occur when

the prime sentence is syntactically unambiguous. Experiment 1 contrasted the magnitude of

priming for target sentences (2) following temporarily ambiguous sentences, such as (1a), and

unambiguous sentences, such as (1b) below.

2. (target sentence): The contestant selected by the judge did not deserve to win.

1a. (*ambiguous* prime):   The customer selected by the security guard was not a thief.

1b. (*unambiguous* prime): The customer who was selected by the security guard was

not a thief.

Equivalent priming caused by 1a and 1b would indicate that syntactic misanalysis and reanalysis during processing of the prime sentence is not required for priming during processing of the target.

2. Is exact repetition of lexical elements within constituents required for lexically-mediated priming to occur? Or, does lexically-mediated syntactic priming reflect facilitation for an abstract structural representation, like abstract priming effects (Bock, 1989)? At an abstract level of representation, sentences (1a) and (1b) have the same structure such that the initial noun phrase (NP) is made up of the noun and a relative clause (RC), which specifies something about that noun (NP => NP + RC). At a less abstract level of representation where the string of lexical items within the relative clause is taken into account, the two sentences have different structures. This is because the internal structures of the relative clauses are different: the relative clause in sentence (1a) contains no relativizer (relative pronoun *who* in *who was*), but the relative clause in (1b) does, which unambiguously marks it as a relative clause [Relative Clause in sentence (1a) = Verb + Prepositional Phrase vs. Relative Clause in sentence (1b) = Relativizer + Auxiliary Verb + Verb + Prepositional Phrase]. If we consider the relationship between a passive voice sentence and a sentence with a reduced relative clause, parts of both types of sentence can have identical sequences of syntactic elements at a less abstract level, while having very different overall abstract structures.   Experiments 1-3 manipulate syntactic repetition at greater and lesser degrees of abstractness. If precise matching for the string of lexical elements is a necessary condition for lexically-mediated priming, then only those conditions with exact matching within constituents should produce priming.   If, instead, the repeated lexical item cues syntactic information/structure-building processes in comprehension at a globally abstract level of

9

representation, then equivalent priming should occur whether there is exact matching within constituents or not [e.g., (1b) should prime readers' response to (2) just as much as 1a does].

Likewise, *short relatives* such as (1c) should be effective primes:

1c. (*short relative prime*): The customer who was selected was not a thief.

3. Does facilitation of non-syntactic information account for, or contribute to, the observed lexically-mediated priming effects? Facilitation of a reduced-relative target sentence when it follows a reduced-relative prime sentence containing the same verb may reflect greater ease in syntactic processing. However, it is also possible that the observed priming reflects facilitation of thematic role assignment, or interpretation of a past-tense verb. In the reduced relative structure, the by-phrase in the relative clause introduces an agent other than the subject. It is possible that this object of the prepositional phrase, which takes on an agent role, facilitates processing of the reduced-relative target, which also contains a prepositional phrase-object in an agent role. Experiment 3 addresses this possibility by including a prime condition that also refers to an agent in prepositional-object position. If repetition of role assignment contributes to lexically-mediated priming effects then passive sentences such as 1d should prime processing of reduced-relative target sentences:

1d. (*passive prime*): The customer was selected by the security guard but was not a thief.

If passive sentences are not found to prime reduced-relatives, then this would imply that thematic role assignment is not a source of facilitation of lexically-mediated syntactic priming effects.

Experiment 4 tests the additional possibility that lexical interpretation of the verb may contribute to lexically-mediated syntactic priming effects. The local ambiguity inherent to the reduced-relative structure stems from the initial verb in these sentences (e.g., *selected* in 1a) being ambiguous between a past-tense verb and a past participle. It is therefore possible that

10

there is persistence of assigning this word as a past participle, rather than any sort of structural

facilitation. If this is true, then pluperfect sentences like (1e) should be effective primes for

reduced-relative clause sentences, because the first verb is a past participle but the overall

structure is more similar to a main clause sentence:

1e. (*pluperfect prime*): The customer had selected the jacket but was not a thief.

However, if pluperfect sentences (like 1e) are not found to prime reduced-relative clause

sentences, then this would imply that lexical interpretation processes are not a source of

facilitation that contribute to observed lexically-mediated priming effects in comprehension.

Experiment 1

Experiment 1 investigated whether the processing of reduced relatives can be facilitated

by prior comprehension of full (or unreduced) relatives, such as *The defendant who was*

examined by the lawyer was unreliable. Note that *The defendant who was examined* does not

contain a local syntactic ambiguity, because the relativizer (*who was*) unambiguously indicates

the presence of a relative clause and thereby rules out a main clause interpretation. Since the full

relatives do not require syntactic reanalysis, priming should not occur if syntactic reanalysis

during prime processing causes all of the observed facilitation. However, if syntactic structure

information/structure-building processes are being facilitated, then we would expect full relative

primes to facilitate processing of reduced-relative targets due to their shared syntactic elements.

Experiment 1 also offers some initial insight into the representation of syntactic

information that is being facilitated when there is structural and lexical overlap between primes

and targets. Full relatives include the words *who was*, and therefore differ within their respective

relative clauses from reduced relatives. While both full and reduced relatives have a relative

clause, only full relatives have a relativizer and auxiliary verb. Thus, Experiment 1 can suggest

whether abstract syntactic matching is sufficient to produce priming, or whether exact lexical

matching within the relative clause is necessary for priming to occur.

Experiment 1 used four types of primes. One condition involved a main-clause prime

sentence with the same verb as the target sentence; a second condition involved a reduced-

relative prime sentence with the same verb as the target sentence. The third condition was the

full-relative clause, same verb condition. The fourth condition involved a reduced-relative prime

with a different verb from the target sentence. This final condition serves as a manipulation

check to verify our assumption that priming is larger with lexical repetition.

As our concern was with effects of different types of primes on the processing of

reduced-relative sentences, the targets were always reduced-relatives. In our analyses, we treat

the reduced-relative prime condition with the same verb (as the target) as the *baseline condition*,

as previous on-line comprehension studies have done (Tooley et al., 2009; 2014). This is

warranted because the set of prime sentences in this condition were the same as the set of target

sentences (and of course these sentences were preceded filler sentences which did not have the

same verb or structure as the prime).

Method

Participants. 37 participants from UC Davis took part in return for credit towards a course

requirement. All participants who signed up to participate were allowed to do so, though this led

to a slight deviation from the planned participant sample size (32). Data was not excluded on the

basis of maintaining the planned sample size.

Stimuli. Each participant read 24 reduced relative target sentences (such as 3). Each target

sentence was yoked to 4 different prime sentences to create 4 different types of prime-target

Syntactic Priming in Comprehension

pairs. The prime sentences (3a-d) consisted of sentences containing a reduced relative with the

same verb as the target (*RR-same* condition, 3a), a full (unreduced) relative with the same verb as

the target (*FR-same* condition, 3b), a reduced relative with a different verb from the target (*RR-*

different condition, 3c), and a main-clause construction with the same verb as the target (*MC-*

same condition, 3d). The target sentences were all reduced relatives, such as (3). The prime and

target sentences appeared one at a time on the screen, and were immediately adjacent to one

another.

The stimuli were rotated across 8 lists of items such that an equal number of each type of

trial appeared on each list, so that no participant saw more than one version of each item, and

that every reduced-relative prime sentence (from one list) served as a target sentence (on a

different list). Each participant was randomly assigned to one stimuli list. Critically, this

counterbalancing of items across sentence position (prime vs. target) allows us to use processing

behaviors associated with the prime sentences as our baseline to which we compare processing

behaviors on the targets. Essentially, we are comparing the same set of sentences to each other,

the only difference being whether the sentences were processed as a prime (*not* primed by a

previous sentence) or a target (primed by a previous sentence).

The experimental sentences were presented along with 72 fillers of various types. At

least one filler sentence appeared between each prime-target pair.

(3) The contestant selected by the judge did not deserve to win. (RRC target)

(3a) The customer selected by the security guard was not a thief. (RRC-Same prime)

(3b) The customer who was selected by the security guard was not a thief. (FRC-Same

prime)

(3c) The personal trainer wanted by the athlete was very busy. (RRC-Different prime)

(3d) The customer selected the jacket but was not a thief. (MC-Same prime)

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.

We report results for three regions of the target sentences. The *verb region* consists of the initial verb or past participle (e.g., *selected* in sentence 3e). The *disambiguating region* consists of the prepositional phrase that followed the verb (e.g., *by the judge*). The *post-disambiguating region* consists of the two words immediately following the disambiguating

14

region.[i] 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. *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 6.2% of the data. Means for all four measures

across all three scoring regions are presented in the online Supplementary Material.

Statistical Analyses. Each of the four dependent measures were analyzed at each of the three

sentence locations using linear mixed-effects models (for the duration measures) or logit mixed

models (for the first-pass regressions measure) (Baayen, Davidson, & Bates, 2008; Jaeger,

2008). Analyses were carried out in R (R Development Core Team, 2008) using the lmer

function (lme4 package), and the four different prime types were included as fixed effects

(compared to the prime sentence baseline via dummy coding). These models estimated crossed

random effects for participants and items, and the fully maximal version of each model (based on

design) was used. If this resulted in non-convergence, random effects were removed based on the

size of their variance components (smaller effects were removed first) until the model reached

convergence. All effects were considered significant at α = 0.05.

Results and Discussion.

Figure 1 presents mean values of the four dependent measures by region and condition

for the reduced relative prime sentence that had the same critical verb as the target (the *baseline*

condition; e.g., 3a), and for target sentences following each of the four prime types. Results from

the multi-level models are presented in Table 1, below.

--- Insert Figure 1 about here ---

--- Insert Table 1 about here ---

Verb Region. Model results revealed a significant difference between the Baseline

condition and the Full Relative Clause condition in the total time measure ($p < 0.05$). Participants

spent less total time fixating the verb region of the reduced-relative clause target sentences that

were preceded by primes having the same verb (as the prime) and the full relative clause

structure, than they did fixating the verb region of the prime reduced-relative clause sentences.

Disambiguating Region. Significant differences between the Baseline condition and the

Full Relative Clause condition were observed in models of the total time measure and first-pass

regressions (p's < 0.05). Participants spent less total time fixating, and produced proportionately

fewer first-pass regressions from the disambiguating region of the reduced-relative targets that

followed full relative clause prime sentences, compared to that of prime reduced-relative clause

16

Syntactic Priming in Comprehension

sentences.

Post-disambiguating region. Model results also revealed a significant difference between the Baseline and Reduced-Relative Clause-same conditions in first-pass regressions ($p < 0.05$). Participants made proportionately fewer first-pass regressions from the post-disambiguating region of the reduced-relative target sentences that followed reduced-relative prime sentences with the same verb, compared to these measures while reading the reduced-relative clause prime sentences.

The results of Experiment 1 replicate past findings that reduced-relative target processing is facilitated following reading of a reduced-relative prime sentence with the same verb (Ledoux, Traxler, & Swaab, 2007; Tooley et al., 2009; Tooley & Traxler, 2018). Interestingly, this effect was reliably observed only in first-pass regression behavior, whereas previous studies have observed this effect in the total time measure (Tooley et al., 2009; Tooley & Traxler, 2018). We include the Reduced-Relative Clause-Same verb condition and larger sample sizes in Experiments 2-4, which will allow us to address whether the lack of effect in total time was a failure of detection in Experiment 1.

In Experiment 1, we found no evidence that the processing of reduced-relative sentences was facilitated by prior comprehension of a reduced-relative sentence with a different verb, or by a main clause sentence with the same verb. Repeating a verb, in and of itself, did not result in detectably faster processing of the disambiguating region of the target sentences in this study. Nor was repetition of syntax alone sufficient to produce observable structural facilitation effects. These null results should be interpreted with caution. However, failure to show structural facilitation with only lexical overlap (in the absence of structural overlap) has been reported in several previous studies (Ledoux et al., 2007; Tooley et al., 2009; Traxler, 2008a), which makes

17

a lack of detectability less plausible for this effect. Furthermore, this condition is included in Experiments 2-4, which will shed light on the replicability of this null result.

The absence of an abstract priming effect is much more difficult to interpret. The current result is consistent with some previous studies that have failed to detect abstract priming effects in comprehension (e.g., Arai et al., 2007; Carminati et al., 2008; Tooley et al., 2009) and inconsistent with others that have observed these effects (Kim, Carbary, & Tanenhaus, 2014; Pickering, Branigan, & MacLean, 2013; Thothathiri & Snedeker, 2008a,b; Tooley & Bock, 2014; Traxler, 2008a). As abstract priming effects are not the focus of the current study, we do not examine this issue extensively. Suffice it to say that facilitation effects in Experiment 1 were observable when there was both structural and verb overlap (as predicted), and methodological differences across studies such as depth of processing inherent to the task demands and lexical biases associated with the tested structure likely affect the detectability of abstract syntactic priming effects in comprehension.

Experiment 1 is the first study to demonstrate that processing of reduced-relative clause sentences can be facilitated by prior reading of full relative clause sentences with the same verb. Compared to the prime baseline, targets following full relative clause primes had decreased total fixation times at the verb and disambiguating regions as well as few first-pass regressions from the disambiguating region. This finding suggests that lexically-mediated priming does not depend on a locally ambiguous prime sentence. Facilitation in this condition cannot be explained by participants improving at recovering from a garden-path effect. Rather, our results suggest that lexically-mediated priming observed for locally ambiguous structures reflect facilitated structural processing. This structural facilitation is unlikely to be produced by an error-driven learning mechanism, as this mechanistic account is difficult to reconcile with

18

Syntactic Priming in Comprehension

finding priming with little to no error signal generated during prime sentence processing.

Reduced- and full-relative sentences are syntactically quite similar at an abstract level of representation (though they differ in explicit lexical elements within the relative clause). They both involve the use of a relative clause to modify a noun, with the full relative including additional nodes that dominate the words *who was*. Note that some accounts do assume qualitative differences between full- and reduced relative sentences (e.g., McKoon & Ratcliff, 2003). The fact that both reduced-relatives and full relatives led to speeded processing of reduced relative targets may suggest that the two types of sentences share some components of form representation. However, the fact that facilitation effects did not emerge in all the same regions/measures for these two different types of primes could also point to representational differences. The next experiment also includes a full relative clause condition to address this discrepancy, and includes a short relative clause condition to further test the hypotheses that lexically-mediated syntactic priming survives changes in relative clause wording/structure.

Experiment 2

Experiment 2 included the main-clause, reduced-relative, and full-relative conditions in which prime and target involved the same initial verb. These conditions allow for a replication of those conditions of Experiment 1. Experiment 2 also included a new *short relative* condition in which there was no *by*-phrase, as in *The customer who was selected was not a thief*. This condition is further removed from the reduced-relative target sentence in terms of precise constituent form overlap, as it involves the extra words *who was* and does not include the *by*-phrase. Assuming that the representation of the relative clause structure is abstract enough to include variants that differ in such cues, the absence of the *by*-phrase should not matter. Priming should occur based

19

on facilitated computation of or access to the abstract relative clause structure [e.g., NP => NP + RC], even though the prime does not explicitly mention an agent that belongs to the relative-clause verb. Additionally, since the short relative has an overt relative pronoun relativizer (*who*), syntactic misanalysis should not occur during prime processing. Hence, any priming effects observed in the target sentence would not be attributable to error correction.

Method

Participants. 51 participants from UC Davis took part under the same terms as in Experiment 1. All participants who signed up to participate were allowed to do so, though this led to a slight deviation from the planned participant sample size (48). Data was not excluded on the basis of maintaining the planned sample size.

Stimuli. These consisted of 24 sets of items comprised of a prime and target sentence (such as 4, below). All prime sentences involved the same verb as the target sentence (hence we do not include *same* in the condition names). The prime sentences (4a-d) consisted of sentences containing a reduced relative (*RR* condition, 4a), a full (unreduced) relative (*FR* condition, 4b), a short (full) relative without the prepositional phrase (*SR* condition, 4c), and a main-clause construction (*MC* condition, 4d). The target sentences were all reduced relatives, such as (4). The stimuli were rotated across 8 lists of items such that an equal number of each type appeared on each list, so that no participant saw more than one version of each item, and, most critically, so that every reduced-relative prime sentence (from one list) served as a target sentence (on a different list). Each participant was randomly assigned to one stimuli list.

(4) The contestant selected by the judge did not deserve to win. (RRC target)

  (4a) The customer selected by the security guard was not a thief. (RRC prime)

  (4b) The customer who was selected by the security guard was not a thief. (FRC prime).

Syntactic Priming in Comprehension

(4c) The customer who was selected was not a thief. (SRC prime)

(4d) The customer selected the jacket but was not a thief. (MC prime)

Procedure and Analyses. The procedure and analyses were identical to those used in

Experiment 1.

Results and Discussion

Figure 2 presents mean values of the four dependent measures by region and condition for the

reduced relative prime sentence that had the same critical verb as the target (the baseline

condition), and for target sentences following each of the four prime types. 6.0% of the data

were excluded based on the same outlier criteria used in Experiment 1. Results from the multi-

level models are presented in Table 2, below.

--- Insert Figure 2 about here ---

--- Insert Table 2 about here ---

Verb Region. Model results revealed a significant difference between the Baseline

condition and the Short Relative Clause and Reduced-Relative Clause conditions in the total time

measure (p's < 0.05). The full RC was also marginally different from the baseline condition in

the total time measure. Participants spent less total time fixating the verb region of the reduced-

relative clause target sentences that were preceded by primes having the same verb (as the prime)

and any type of relative clause structure, compared to processing of the reduced-relative clause

prime sentences.

Disambiguating Region. Data from the disambiguating region showed that all of the

21

prime types except for main clause primes led to facilitated processing of the Reduced-Relative Clause target sentences. Proportions of first-pass fixations were significantly decreased relative to the baseline condition for the Short Relative Clause, Reduced-Relative Clause, and Full Relative Clause conditions (all p's < 0.05). Regression path times were also decreased relative to the baseline condition for the Full Relative Clause, Short Relative Clause, and Reduced-Relative Clause conditions (all p's < 0.05). Analyses of total reading times revealed significant differences from baseline for the Short Relative Clause and Reduced-Relative Clause conditions (p's < 0.05). Participants spent less time reading and had fewer first-pass regressions for target reduced-relative clause sentences that were preceded by primes sentences with one of the three types of relative clause (full, short, or reduced) structures, compared to processing of the reduced-relative clause prime sentences.

Post-Disambiguating Region. Analyses of the four dependent measures from the post-disambiguating region failed to reveal any significant effects (all p's > 0.05).

Experiment 2 showed significant priming effects in the short, full, and reduced relative clause conditions, while no priming effects were observed for the main clause condition, even though it contained the same initial verb as the target. These findings replicate those from the previous experiment, and reveal priming effects for the Reduced-Relative Clause condition in total time as well as regression measures. Also consistent with findings from Experiment 1, priming effects in Experiment 2 were reliable following unambiguous primes (full and short relatives) as well as temporarily ambiguous primes (reduced relatives). This reinforces our previous conclusions that error correction during prime processing is not necessary for facilitated target structure processing due to structure and verb overlap.

In addition to replicating findings from Experiment 1, Experiment 2 revealed that the

Syntactic Priming in Comprehension

short relative clause condition produced priming, despite substantial differences in precise lexical

elements present in the relative clauses of short and reduced relative sentences. These results

indicate further that lexically-mediated syntactic priming reflects facilitation of abstract syntactic

structures. Target sentences were primed even when the prime lacked an overt by-phrase (in the

Short Relative Clause condition). Hence, facilitated processing of the disambiguating region in

the target sentence does not require function word repetition. Overall, lexically-mediated

syntactic priming effects do not emerge with verb repetition alone and likely reflect facilitation

for abstract syntactic representations, rather than from parallelism between the string of explicit

lexical elements within constituents, or function word repetition.

Experiment 3

Full relatives and short relatives both involve relative clauses, just as reduced relatives do, so

similarity at this level of abstract structure may be driving the priming effects. However, it is

possible that other types of prime-target relationships may also contribute to priming. For

example, the by-phrase in the relative clauses introduces an agent (and short relatives have an

implied agent; Mauner et al., 1995). It may be the presence of this prepositional object in an

agent role that facilitates processing and interpretation of the reduced relative target sentences,

which also contain a prepositional-object as an agent. To test this hypothesis, we included prime

sentences that also mentioned an agent in prepositional-object position. These primes were

passive-voice sentences like (5b), below. Because the abstract syntactic form of the passives is

very different from that of the reduced relative, and does not entail any major syntactic

ambiguity, finding facilitation of reduced relatives from passives would indicate that aspects of

the prime sentence beyond strictly abstract syntactic repetition can produce priming.

Method

Participants. 69 further participants from UC Davis took part. All participants who signed up to

participate were allowed to do so, though this led to a slight deviation from the planned

participant sample size (66). Data was not excluded on the basis of maintaining the planned

sample size.

Stimuli. Items consisted of 48 sets of sentences (such as 5, below). All of the target sentences

were reduced relatives (5). In addition to reduced relative primes (5a), there were passive

primes, as in (5b), and main clause primes, as in (5c).

(5) The contestant selected by the judge did not deserve to win. (RRC target)

    (5a) The customer selected by the security guard was not a thief. (RRC prime)

    (5b) The customer was selected by the security guard but was not a thief. (Passive prime)

    (5c) The customer selected the jacket but was not a thief. (MC prime)

Test sentences were randomly assigned to one of 6 lists, such that each participant saw only one

version of each sentence, so that they read an equal number of prime-target pairs from each

condition, and so that each target sentence (on one list) served as a prime sentence (on another

list). Each participant was randomly assigned to one stimuli list. We used the same scoring

regions as the preceding experiments. We computed the same four dependent measures for each

scoring region.

Procedure and Analyses. The procedure and analyses were the same as in the previous two

experiments.

Results and Discussion

Mean first pass, first-pass regressions, regression-path time, and total time by region and

condition are presented in Figure 3. 5.5% of the data were excluded based on the same outlier

24

Syntactic Priming in Comprehension

criteria as in the preceding experiments. Model output results from the analyses of these regions

and measures are presented in Table 3, below.

--- Insert Figure 3 about here ---

--- Insert Table 3 about here ---

Verb Region. Analyses revealed significant decreases in first-pass, regression path, and

total target fixation times for the Reduced-Relative Clause condition compared to the prime

baseline condition (all p's < 0.05). A significant decrease in the proportion of first-pass fixations

for the Passive condition relative to the baseline condition was also observed ($p < 0.05$).

Participants spent less time reading the verb region of the reduced-relative clause targets when

they were preceded by reduced-relative clause primes with the same verb than when reading a

reduced-relative prime. Participants also made fewer first-pass regressions from this region after

reading a Passive prime with the same verb than when reading a reduced-relative prime sentence.

Disambiguating Region. Results in the disambiguating region indicated that priming

effects occurred when the prime sentences were reduced relatives and when the prime sentences

were passives. Model results revealed significant decreases in all four dependent measures for

the Reduced-Relative Clause condition relative to the baseline condition (all p's < 0.05). These

models also revealed significant decreases in regression path and total time measures for the

Passive condition relative to the baseline condition (p's < 0.05). Follow-up comparisons between

the Reduced-Relative Clause and Passive conditions at this region yielded a marginally

significant difference in regression path time ($t > 1.9$) and a non-significant difference in total

time. This suggests there was marginally greater facilitation in regression path time (and

numerically greater facilitation in total time) for the Reduced-Relative Clause condition

25

compared to the Passive condition. Participants spent less time reading and had fewer first-pass regressions from the disambiguating region of targets sentences that were preceded by reduced-relative primes than when reading reduced-relative primes. This advantage was also observed for targets following passive primes, but to a lesser degree and in fewer reading time measures.

Post-Disambiguating Region. Model results revealed significant decreases in regression path and total time measures for the Reduced-Relative Clause condition relative to the baseline condition (p's < 0.05). Participants tended to spend less time reading the post-disambiguating region of target sentences that were preceded by reduced-relative prime sentences with the same verb than when reading reduced relative prime sentences.

Experiment 3 again revealed that participants found reduced relatives easier to process following other reduced relatives with the same verb. There was also evidence that participants found reduced relatives easier to process following passive sentences, though this facilitation was less robust than that observed for the reduced relative primes (in that evidence for priming emerged later and was marginally smaller in the passive prime condition compared to the reduced relative condition). Priming in the Passive condition would seem to indicate that a non-syntactic source of priming contributes to observed lexically-mediated syntactic priming effects. One possibility is that the presence of a prepositional-object agent in the prime facilitated mapping of the same surface element (pp-object) to the same thematic role during target sentence processing. Passive primes may also have facilitated mapping of the subject of the sentence to thematic patient/experiencer/theme roles. Effects in targets following passive primes might also reflect facilitated construction of a 'local' syntactic constituent. In this case, that would be a verb-prepositional phrase combination.

Syntactic Priming in Comprehension

Experiment 4

Experiment 4 evaluated an alternative hypothesis explaining facilitated target processing. Preceding experiments support connections between lexical entries and abstract syntactic structure representations. However, the results are in fact compatible with an alternative account, in which priming results from a tendency to interpret words in the same way rather than having anything to do with syntactic structure. The form *examined* is ambiguous between the simple past tense (or preterite) and the past participle. Indeed, many irregular verbs in English distinguish these two forms of the verb (e.g., *chose* vs. *chosen*). Rather than prime people to adopt the reduced relative analysis of sentences, we may have primed people to interpret ambiguous verb forms as past participles.

It is, however, possible to distinguish this *word-form* account from the syntactic account. *Pluperfect* sentences such as *The defendant had examined the glove* use the past-participle form (cf. *The defendant had chosen the glove*) but are actives, so that the first noun phrase (*The defendant*) is the agent and the second noun phrase (*the glove*) is the patient. On the verb-form account, pluperfect sentences should prime participants to adopt the reduced-relative analysis of an ambiguous target sentence (so long as the verb is repeated). They should therefore have similar effects as reduced-relative prime sentences. Moreover, they should differ from main-clause prime sentences such as *The defendant examined the glove*, because *examined* is a simple past-tense verb form (cf. *The defendant chose the glove*). In contrast, the syntactic account predicts that pluperfect sentences should not prime participants to adopt the reduced-relative analysis of an ambiguous target sentence, because main clause and reduced relative syntactic structures differ. Instead, they should behave like main-clause prime sentences.

Method

Participants. 50 further participants from UC Davis took part. All participants who signed up to participate were allowed to do so, though this led to a slight deviation from the planned participant sample size (48). Data was not excluded on the basis of maintaining the planned sample size.

Stimuli. The items were adapted from the previous experiment. We generated 24 sets of items such as (6) below. The prime sentences consisted of sentences containing reduced relatives (*RR prime*, 6a), pluperfect verbs (*pluperfect prime,* 6b), and main clauses (*MC prime,* 6c). The target sentences (6) were always reduced relatives and always had the same past participle as the preceding prime sentence (or verb, in the case of sentences in the main clause and pluperfect conditions). The stimuli were rotated across 6 lists of items such that an equal number of each type appeared on each list, so that no participant saw more than one version of each item, and, most critically, so that every reduced-relative prime sentence (from one list) served as a target sentence (on a different list). Each participant was randomly assigned to one stimuli list.

(6) The contestant selected by the judge did not deserve to win. (RRC target)

   (6a) The customer selected by the security guard was not a thief. (RR prime)

   (6b) The customer had selected the jacket during the shopping trip. (Pluperfect prime)

   (6c) The customer selected the jacket but was not a thief. (MC prime)

Procedure and Analyses. The procedure and analyses were identical to those used in the previous three experiments.

Results and Discussion

Figure 4 presents mean values for the four dependent variables by region and condition for Experiment 4. 4.9% of the data were removed as outliers based on the same criteria used in

Syntactic Priming in Comprehension

the preceding experiments. As in the previous experiments, we analyzed data from the *verb*,

disambiguating, and *post-disambiguating* regions. Model output results from the analyses of

these regions and measures are presented in Table 4, below.

--- Insert Figure 4 about here ---

--- Insert Table 4 about here ---

Verb Region. Analyses revealed a significant decrease in first-pass and total fixation

times for the Pluperfect condition relative to the baseline condition (p's < 0.05). Additionally,

there was a significant decrease in first-pass fixations for the Main Clause condition relative to

the baseline condition ($p < 0.05$). Participants tended to spend less time reading the verb region

of target sentences that were preceded by pluperfect primes and made fewer first-pass

regressions for targets preceded by main clause primes than when reading reduced-relative prime

sentences.

Disambiguating Region. Model results revealed a significant decrease in total fixation

time for the Reduced-Relative Clause condition relative to the baseline condition ($p < 0.05$).

Participants spent less time reading the disambiguating region of target sentences that were

preceded by reduced-relative prime sentences with the same verb than when reading reduced-

relative prime sentences.

Post-Disambiguating Region. Model results revealed a significant decrease in first-pass

regressions for the Reduced-Relative Clause and Pluperfect conditions relative to the baseline

(p's < 0.05). Participants were less likely to reread a previous region after a first-pass fixation in

the post-disambiguating region for targets following reduced-relative or pluperfect primes

compared to reduced-relative primes.

Experiment 4 showed that reduced relative structural processing is facilitated following

previous exposure to a reduced relative with the same verb, thus replicating the lexically-mediated priming effects observed in the previous three experiments. The Pluperfect condition was also found to affect reduced-relative target processing, but these effects were restricted to the verb and the post-disambiguating regions. In the post-disambiguating region, reductions in first-pass regressions should be associated with a decrease in total fixation times on an earlier sentence region (as there were fewer eye movements back to those regions). For the Pluperfect condition, the verb region is the most likely candidate for this decrease in re-fixations, as total fixation times on this region were found to be significantly decreased relative to baseline. In contrast, the disambiguating region of targets following reduced-relative clause primes showed significant reductions in total fixation times relative to baseline. This likely indicates that structural processing was receiving the bulk of the facilitation in the Reduced-Relative Clause condition, whereas lexical processing was receiving the majority of the facilitation in the Pluperfect condition. These findings are easily interpretable insofar as the reduced-relative and pluperfect structures share word-form interpretation of the verb, but not global aspects of abstract structure. Therefore, the most parsimonious explanation is that repetition of verb form facilitates interpretation of the verb, whereas repetition of structure and verb-form facilitate syntactic processing.

General Discussion

In four experiments, we used eye-tracking to investigate the conditions under which fixation times and regressions can be affected by the form and verb of an immediately preceding sentence. The overall pattern of results from four experiments demonstrate that a single instance of repetition of an initial verb and abstract syntactic form *can* facilitate comprehension processes, which replicates previous findings (Tooley et al., 2009; Tooley & Traxler, 2018). Importantly,

this facilitation was not contingent on ambiguity resolution processes of the prime sentence, which would be predicted by an error-driven learning mechanism. In addition to these lexically-mediated syntactic priming effects, we also found evidence for non-syntactic sources of facilitation, such as thematic role assignment and word-form interpretation. This suggests that multiple sources of facilitation affect interpretive processing when verb and structure are constant across prime and target sentences. However, repetition of the verb within an unrelated main clause structure never resulted in facilitation of the reduced-relative structure, suggesting simple lexical repetition contributes little to lexically-mediated syntactic priming.

What Mechanism Produces Lexically-Mediated Syntactic Priming?

Abstract syntactic priming effects have been attributed to an error-driven learning mechanism whereby the degree of priming at the target can be predicted by the degree of error experienced during processing of the prime (Fine, Jaeger, Farmer, & Qian, 2013; Fine & Jaeger, 2013; Jaeger & Snider, 2013). If lexically-mediated priming effects are likewise modulated by an error-signal during reanalysis processing of the prime, then they should appear only when the prime sentences themselves required syntactic reanalysis (or be notably larger in these instances). Since Experiment 2 yielded observable priming across a range of reading measures for both ambiguous primes (reduced relatives) and unambiguous primes (full relatives and short relatives), which involve different degrees of syntactic revision (with reduced relative primes triggering the greatest amount of syntactic revision), it is unlikely that facilitated target processing is based on repeating the same syntactic reanalysis, or based on an error signal. Relatedly, if the observed priming effects reflected only facilitated syntactic revision processes, then one would expect them to appear only in measures of "late" processing, such as total time. Instead, robust priming effects were observed in first pass and first-pass regressions measures.

Our results are therefore most consistent with an account where prime sentences temporarily activate an abstract relative clause structure (NP => NP + RC; RC => Participle + PP(NP)) in long-term memory, to which constituents from the target can be readily mapped or bound. This structural representation may be activated via a working memory mechanism (e.g., Reitter et al., 2011; see also Chang et al., 2006; Chang et al., 2012). Under this type of account, the words from the prime are stored in working memory and are temporarily bound to a given structural representation in long-term memory. When the verb is re-encountered in the target sentence, this cues retrieval of structural information from long-term memory. However, this account is challenged by recent evidence that individuals with severe short-term memory impairments nevertheless show lexically-mediated syntactic priming effects in production (Yan, Martin, & Slevc, 2018).

It therefore seems more likely that the structural representation is primed via residual activation for a link between a specific verb node and structural node within a lexicalist framework in long-term memory (see Tooley & Traxler, 2012). This is similar to the residual activation mechanism proposed by Pickering and Branigan (1998), but it lacks shared structural nodes for different verbs and does not assume that residual activation at the structural node itself is the source of abstract syntactic priming effects. This dual mechanism account posits that error-based learning produces abstract syntactic priming effects while the residual activation mechanism yields lexically-mediated priming effects. Such an account can most straightforwardly account for the lexically-mediated priming effects observed in the current study as well as abstract syntactic priming effects, including cumulative priming effects, observed in previous comprehension studies (e.g., Fine & Jaeger, 2013; Tooley & Traxler, 2018).

Syntactic Priming in Comprehension

What Comprehension Processes are Facilitated During Lexically-Mediated Priming?

Conceptually, there are two kinds of processing 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. 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 that we report here indicates that both processes may have contributed.

For instance, many of the priming effects showed up relatively quickly during target sentence processing, appearing in first-pass reading of the disambiguating region or first-pass regressions. This may indicate that reading the prime sentence affected the likelihood that readers considered the reduced relative analysis during early syntactic processing, thus eliminating the garden-path effect common to this structure. However, because we did not test unambiguous (e.g., full relative) target sentences, we do not have a direct comparison that would allow us to determine if processing a primed reduced-relative target was still more difficult than a full relative clause target. 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 responses to the reduced relative targets equivalent to unambiguous relative clause sentences.

Two of the results point towards a separate thematic contribution to the observed comprehension priming effects, which is consistent with findings in production that thematic

roles can be primed separately from syntactic structure (Chang, Bock, & Goldberg, 2003; Ziegler & Snedeker, 2018). First, passive prime sentences led to facilitated target processing. Passive prime sentences do not share syntactic form with the reduced relative targets apart from having a by-phrase following the initial verb. Nonetheless, reduced relatives appeared to be primed following passive sentences. This is less likely to reflect priming from the by-phrase (by phrases did not prime reduced relatives in the different verb condition in Experiment 1) and more likely to reflect facilitated mapping of the by-phrase object as agent and the subject of the sentence as patient or experiencer. However, having a by-phrase agent explicitly represented in the prime sentence is not necessary for facilitated target processing, as shown in the conditions involving short relatives (*The defendant who was examined was guilty*). It is possible that reading a short relative prime causes comprehenders to insert an implicit agent (Mauner et al., 1995), which might be sufficient for thematic priming to occur. Further experimentation will be required to establish abstract thematic roles, or perhaps the surface ordering of thematic roles, as a major contributor to priming effects in comprehension.

Finally, there was also evidence that repetition of verb form across primes and targets led to facilitated lexical processing at the verb. Participants spent less time fixating and had fewer first-pass regressions back to the verb region of the reduced relative target sentences following pluperfect prime sentences, relative to processing of reduced-relative baseline sentences. Interestingly, there was scant evidence that the pluperfect primes affected processing at the critical disambiguating sentence region, which would indicate facilitated syntactic processing. This result is easily interpreted in light of the common features shared between the reduced-relative and pluperfect structures. Namely, these structures share verb-form interpretation but not syntactic form. It therefore appears that when adjacent sentences share a common verb form

34

Syntactic Priming in Comprehension

interpretation there is facilitated lexical processing at the verb, but this facilitation is manifestly

different from the syntactic facilitation that occurs when they share a verb form and abstract

syntactic structure.

Limitations

While priming for the Reduced-Relative Prime Condition (with the same verb) was

observed in all four experiments, it was noticeably less robust in Experiment 1 (and somewhat

less so in Experiment 4). While this does not change the overall conclusions that can be drawn

from this set of experiments, it does point to some potential limitations of this type of

comprehension research. Most obviously, that these effects vary across participant samples, and

so planned sample sizes may need to be sufficiently large to detect small overall effect sizes.

This is supported by our greater ability to detect priming effects in Experiments 2-4 which had

larger sample sizes than Experiment 1. Our ability to detect trial-to-trial (prime-to-target)

priming effects may also be hindered by overall implicit learning of structure that can take place

throughout the course of an experimental session (Fine et al., 2013; Tooley & Traxler, 2018). If

participants are gradually learning the reduced-relative structure, then trial-to-trial priming

effects may appear weaker in the latter parts of experiment, thus decreasing the overall,

experiment-wide size of effects. This implies that future studies of trial-to-trial priming effects in

comprehension may be better served by using larger sample sizes, rather than adding more

items/trials to increase the number of observations from each individual participant, as this may

lead to greater overall learning of the investigated structure and a decreased ability to detect trial-

to-trial priming. Whenever possible, researchers should take these considerations into account

before data collection, and endeavor to determine appropriate sample sizes a priori.

A further limitation on the interpretation of the current results is that this study does not

speak directly to the precise nature of lexical versus syntactic representations. A full treatment

of this issue is beyond the scope of this paper (for book length treatments see, e.g., Carnie et al.,

2014; Jackendoff, 1998). We have assumed a distinction between syntactic representation (qua

phrase structure) and lexical/semantic representations (qua thematic roles), and have

hypothesized that repeated syntactic form can have effects that are independent of lexical (word)

repetition or thematic role (agent, patient, instrument, etc.) repetition. In truth, because the

expressed forms that go with different thematic role configurations also may also differ in form

within constituent phrases, further work may be required before strong conclusions can be drawn

about the degree to which "pure" syntactic form repetition effects can be separated from "pure"

thematic role repetition in comprehension. However, in language production, syntactic structure

can be primed in the absence of thematic role repetition (Bock & Loebell, 1990), thematic roles

can be primed separately from syntactic structure (Chang, Bock, & Goldberg, 2003) and a

specific thematic role can be primed (e.g., recipient) while another thematic role (e.g.,

destination) that shares a syntactic position with the former is not primed (Ziegler & Snedeker,

2018). Assuming a shared-representational account between comprehension and production

(e.g., Branigan & Pickering, 2017), there is good reason to expect similar distinctions between

syntactic structure and thematic roles to be present during comprehension processes.

Conclusions

The experiments reported here indicate that lexically-mediated syntactic priming in

comprehension is the result of lexical and abstract structural repetition across sentences. This

type of facilitation likely does not derive from an error-signal generated during prime reanalysis,

nor is it solely a reflection of facilitated reanalysis processing. Additionally, repetition of verb

and structure across sentences also leads to facilitated lexical and thematic processing. Hence,

Syntactic Priming in Comprehension

we favor an account under which repeated lexical and syntactic forms ease verb form

interpretation and thematic role assignment while also cueing abstract syntactic representations

in long-term memory. Together, these processing outcomes make the dis-preferred analyses of a

sentence more salient or accessible, leading to the observed priming effects.

[ii] The post-disambiguating region is reported largely for the sake of completeness. Syntactic manipulations sometimes produce "spillover effects" (see, e.g., Rayner, 1998; Rayner & Pollatsek, 1989). In terms of syntactic structure-building and syntactic reanalysis processes, most or all accounts would predict that effects would arise in the disambiguating region itself, and this is what previous studies have shown (see, e.g., Trueswell et al., 1994; Clifton et al., 2003; Ledoux et al., 2007; Tooley et al., 2009).

Running head: LEXICALLY-MEDIATED SYNTACTIC PRIMING

Author notes

Syntactic Priming in Comprehension

Supplementary Material

The Supplementary Material is available at: qjep.sagepub.com

References

Arai, M., Van Gompel, R.P.G., & Scheepers, C. (2007). Priming ditransitive structures in comprehension. *Cognitive Psychology, 54*, 218-250.

Bernolet, S., Collina, S., & Hartsuiker, R. J. (2016). The persistence of syntactic priming revisited. *Journal of Memory and Language*, *91*, 99-116.

Bernolet, S., & Hartsuiker, R. J. (2010). Does verb bias modulate syntactic priming?. *Cognition*, *114*(3), 455-461.

Bock, J.K. (1986). Syntactic persistence in language production. *Cognitive Psychology, 18*, 355-387.

Bock, K. (1989). Closed-class immanence in sentence production. Cognition, 31(2), 163–186.

Bock, K., Dell, G. S., Chang, F., & Onishi, K. H. (2007). Persistent structural priming from language comprehension to language production. *Cognition*, *104*(3), 437-458.

Bock, K., & Griffin, Z. M. (2000). The persistence of structural priming: Transient activation or implicit learning? *Journal of Experimental: General, 129,* 177-192.

Bock, J.K., & Levelt, W.J.M. (1994). Language production: Grammatical encoding. In M.A. Gernsbacher (Ed.), *The Handbook of Psycholinguistics* (pp. 945-983). San Diego, CA: Academic Press.

Bock, J.K., & Loebell, H. (1990). Framing sentences. *Cognition*, **35**, 1-39.

Boland, J.E., & Blodgett, A. (2006). Argument status and PP-attachment. *Journal of Psycholinguistic Research*, **35**, 385-403.

Boland, J.E., & Boehm-Jernigan, H. (1998). Lexical constraints and prepositional phrase attachment. *Journal of Memory and Language*, **39**, 684-719.

Boudewyn, M.A., Zirnstein, M., Swaab, T.Y., & Traxler, M.J. (in press). Priming

   prepositional phrase attachment: Evidence from eye-tracking and ERPs. *Quarterly*

   Journal of Experimental Psychology.

Branigan, H. P. & Pickering, M. J. (2017). An experimental approach to linguistic

   representation. *Behavioral and Brain Sciences, 40*, 1-61.

Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic coordination in

   dialogue. *Cognition, 75*, B13-B25.

Branigan, H.P., Pickering, M.J., & McLean, J.F. (2005). Priming prepositional-phrase

   attachment during language comprehension. *Journal of Experimental Psychology:*

   Learning, Memory, and Cognition, 31, 468-481.

Branigan, H.P., Pickering, M.J., McLean, J.F., & Cleland, A.A. (2007). Participant role

   and syntactic alignment in dialogue. *Cognition*, **104**, 163-197.

Carminati, M.N., van Gompel, R.P.G., Scheepers, C., & Arai, M. (2008). Syntactic

   priming in comprehension: The role of argument order and animacy. *Journal of*

   Experimental Psychology: Learning, Memory, and Cognition, 34, 1098-1110.

Carnie, A., Siddiqi, D., & Sato, Y. (Eds.). (2014). *The Routledge handbook of syntax*.

   Routledge.

Chang, F., Bock, J. K., & Goldberg, A. (2003). Can thematic roles leave traces of their

   places? *Cognition, 90*, 29-49.

Chang, F., Dell, G.S., & Bock, K. (2006). Becoming syntactic. *Psychological Review*, **113**, 234-

   272.

Chang, F., Dell, G.S., Bock, K., & Griffin, Z.M. (2000). Structural priming as implicit learning:

   A comparison of models of sentence production. *Journal of Psycholinguistic Research*, **29,**

   217-229.

Chang, F., Janciauskas, M., & Fitz, H. (2012). Language adaptation and learning: Getting

explicit about implicit learning. *Language and Linguistics Compass*, **6**, 259-278.

Chomsky, N. (1995). *The Minimalist Program*. Cambridge, MA: MIT Press.

Clifton, C., Jr., Traxler, M.J., Mohammed, M.T., Williams, R.S., Morris, R.K., & Rayner,

K. (2003). The use of thematic role information in parsing: Syntactic processing

autonomy revisited. *Journal of Memory and Language, 49,* 317-334.

Dell, G.S. (1986). A spreading-activation theory of retrieval in sentence production.

Psychological Review, **93**, 283-321.

Elman, J.L. (2004). An alternative view of the mental lexicon. *Trends in Cognitive

Sciences*, **8**, 301-306.

Ferreira, V. S. (2003). The persistence of optional complementizer production: Why

saying "that" is not saying "that" at all. *Journal of Memory and Language*, *48*(2), 379-

398.

Fine, A. B., & Florian Jaeger, T. (2013). Evidence for implicit learning in syntactic

comprehension. *Cognitive Science*, *37*, 578-591.

Fine, A. B., Jaeger, T. F., Farmer, T. A., & Qian, T. (2013). Rapid expectation adaptation

during syntactic comprehension. *PloS one*, *8*(10), e77661.

Fitz, H., Chang, F., & Christiansen, M.H. (2011). A connectionist account of the

acquisition and processing of relative clauses. In E. Kidd (Ed.), *The Acquisition of

Relative Clauses: Processing, Typology, and Function* (pp. 39-60). Amsterdam, The

Netherlands: John Benjamins.

Fodor, J.A. (1983). *Modularity of Mind*. Cambridge, MA: MIT Press.

Ford, M., Bresnan, J., & Kaplan, R.M. (1982). A competence-based theory of syntactic

closure. In J. Bresnan (Ed.), *The Mental Representation of Grammatical Relations*

Syntactic Priming in Comprehension

(pp. 727-796). Cambridge, MA: MIT Press.

Frazier, L. (1979). *On Comprehending Sentences: Syntactic Parsing Strategies*. Ph.D.

dissertation, University of Connecticut. West Bend, IN: Indiana University

Linguistics Club.

Garnsey, S.M., Pearlmutter, N.J., Myers, E., & Lotocky, M.A. (1997). The contributions

of verb bias and plausibility to the comprehension of temporarily ambiguous sentences.

Journal of Memory and Language, **37**, 58-93.

Hale, J.T. (2011). What a rational parser would do. *Cognitive Science*, **35**, 399-443.

Hartsuiker, R.J., Bernolet, S., Schoonbaert, S., Speybroeck, S., & Vanderelst, D. (2008).

Syntactic priming persists while the lexical boost decays: Evidence from written and

spoken dialogue. *Journal of Memory and Language*, **58,** 214-238.

Hsieh, Y. (2017). Structural priming during sentence comprehension in Chinese–English

bilinguals. *Applied Psycholinguistics*, *38*(3), 657-678.

Jackendoff, R. (2002). Foundations of language: Brain, meaning, grammar, evolution.

Jaeger, T.F., & Tily, H. (2010). On language 'utility': Processing complexity and

communicative efficiency. *Wiley WIRES: Cognitive Science*, **2**, 323-335.

Jaeger, T. F., & Snider, N. E. (2013). Alignment as a consequence of expectation

adaptation: Syntactic priming is affected by the prime's prediction error given both

prior and recent experience. *Cognition*, *127*(1), 57-83.

Kim, C. S., Carbary, K. M., & Tanenhaus, M. K. (2014). Syntactic priming without

lexical overlap in reading comprehension. *Language and Speech*, *57*(2), 181-195.

Ledoux, K. Traxler, M.J, & Swaab, T.Y. (2007). Syntactic priming in comprehension:

Evidence from event-related potentials. *Psychological Science, 18*, 135-143.

Levelt, W.J.M. (1989). *Speaking*. Cambridge, MA: MIT Press.

Levelt, W.J.M., & Kelter, S. (1982). Surface form and memory in question answering. *Cognitive Psychology*, **14**, 78-106.

Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, **106**, 1126-1177.

MacDonald, M.C., Pearlmutter, N.J., & Seidenberg, M.S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101*, 676-703.

Mauner, G., Tanenhaus, M.K., & Carlson, G.N. (1995). Implicit arguments in sentence processing. *Journal of Memory and Language, 34,* 357–38.

McKoon, G., & Ratcliff, R. (2003). Meaning through syntax: Language comprehension and the reduced relative clause construction. *Psychological Review, 110,* 490-525.

Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language, 39,* 633-651.

Pickering, M.J., & Ferreira, V.S. (2008). Structural priming: A critical review. *Psychological Bulletin, 134*, 427-459.

Pickering, M. J., McLean, J. F., & Branigan, H. P. (2013). Persistent structural priming and frequency effects during comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(3), 890.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading.* New York: Prentice-Hall.

Reitter, D., Keller, F., & Moore, J. D. (2011). A computational cognitive model of syntactic priming. *Cognitive Science*, *35*, 587-637.

Roelofs, A. (2000). WEAVER++ and other computational models of lemma retrieval

Syntactic Priming in Comprehension

and word-form encoding. In L. Wheeldon (Ed.), *Aspects of Language Production* (pp.

71-114). Sussex, UK: Psychology Press.

Sag, I.A., Wasow, T., & Bender, E.M. (2003). *Syntactic Theory: A Formal Introduction.*

Palo Alto, CA: Center for the Study of Language and Information.

Sedivy, J.C. (2002). Invoking discourse-based contrast sets and resolving syntactic

ambiguities. *Journal of Memory and Language*, **46**, 341-370.

Sturt, P., Keller, F., & Dubey, A. (2010). Syntactic priming in comprehension:

Parallelism effects with and without coordination. *Journal of Memory and Language,*

62, 333-351.

Thothathiri, M., & Snedeker, J. (2008a). Give and take: Syntactic priming during

spoken language comprehension. *Cognition*, 108, 51-68.

Thothathiri, M., & Snedeker, J. (2008b). Syntactic priming during comprehension in

three and four-year old children. *Journal of Memory and Language*, 58, 188-213.

Tooley, K. M., & Traxler, M. J. (2018). Implicit learning of structure occurs in parallel

with lexically-mediated syntactic priming effects in sentence comprehension. *Journal*

of Memory and Language, 98, 59-76.

Tooley, K.M., & Bock, J.K. (2014). On the equivalence of structural priming in language

comprehension and production. *Cognition, 132*, 101-136.

Tooley, K.M., Swaab, T.Y., Boudewyn, M.A., Zirnstein, M., & Traxler, M.J. (2014).

Evidence for priming across intervening sentences during on-line sentence

comprehension. *Language, Cognition and Neuroscience, 29*(3), 289-311.

Tooley, K.M., & Traxler, M.J. (2012). Syntactic priming in comprehension: A dual

mechanism account. In R. Mishra (Ed.), *The Relationship between Language and*

Thought. Munich, Germany: Lincom Europa.

Tooley, K.M., Traxler, M.J., & Swaab, T.Y. (2009). Electrophysiological and behavioral

evidence of syntactic priming in sentence comprehension. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 35, 19-45.

Traxler, M.J. (2008a). Lexically independent priming in online sentence comprehension.

Psychonomic Bulletin & Review, 15, 149-155.

Traxler, M.J. (2008b). Structural priming among prepositional phrases: Evidence from

eye-movements. *Memory & Cognition, 36*, 659-674.

Traxler, M.J., & Tooley, K.M. (2007). Lexical mediation and context effects in parsing.

Brain Research, **1146**, 59-74.

Traxler, M.J., & Tooley, K.M. (2008). Priming in sentence comprehension: Strategic or

syntactic? *Language and Cognitive Processes*, 23, 609-645.

Traxler, M.J., Tooley, K.M., & Pickering, M.J. (2014). Syntactic priming during

sentence comprehension: Evidence for the lexical boost. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 40(4), 905-918.

Trueswell, J.C., Tanenhaus, M.K., Kello, C. (1993). Verb-specific constraints in

sentence processing: Separating effects of lexical preference from garden-paths.

Journal of Experimental Psychology: Learning, Memory, and Cognition, **19**, 528-553.

Trueswell, J.C., & Kim, A.E. (1998). How to prune a garden path by nipping it in the

bud: Fast priming of verb argument structure. *Journal of Memory and Language, 39,*

102-123.

Trueswell, J.C., Tanenhaus, M.K., & Garnsey, S.M. (1994). Semantic influences on

parsing: Use of thematic role information in syntactic disambiguation. *Journal of*

Syntactic Priming in Comprehension

Memory and Language, 33, 285-318.

Vosse, T., & Kempen, G. (2000). Syntactic structure assembly in human parsing: A

computational model based on competitive inhibition and lexicalist grammar.

Cognition, **75**, 105-143.

Vosse, T., & Kempen, G. (2009). The Unification Space implemented as a localist neural

net: Predictions and error-tolerance in a constraint-based parser. *Cognitive*

Neurodynamics, **3**, 331-346.

Wells, J.B., Christiansen, M.H., Race, D.S., Acheson, D.J., & MacDonald, M.C. (2009).

Experience and sentence processing: Statistical learning and relative clause

comprehension. *Cognitive Psychology*, **58**, 250-271.

Yan, H., Martin, R. C., & Slevc, L. R. (2018). Lexical overlap increases syntactic

priming in aphasia independently of short-term memory abilities: Evidence against the

explicit memory account of the lexical boost. *Journal of Neurolinguistics*.

Ziegler, J. & Snedeker, J. (2018). How broad are thematic roles? Evidence from

structural priming. *Cognition, 179*, 221-240.

Figure Captions

Figure 1. Experiment 1 mean reading time measures (a. first-pass time, b. first-pass regressions, c. total time, and d. regression path time) for the verb, disambiguating (past-participle), and post-disambiguating (spillover) regions. Error bars represent standard errors.

Figure 2. Experiment 2 mean reading time measures (a. first-pass time, b. first-pass regressions, c. total time, and d. regression path time) for the verb, disambiguating (past-participle), and post-disambiguating (spillover) regions. Error bars represent standard errors.

Figure 3. Experiment 3 mean reading time measures (a. first-pass time, b. first-pass regressions, c. total time, and d. regression path time) for the verb, disambiguating (past-participle), and post-disambiguating (spillover) regions. Error bars represent standard errors.

Figure 4. Experiment 4 mean reading time measures (a. first-pass time, b. first-pass regressions, c. total time, and d. regression path time) for the verb, disambiguating (past-participle), and post-disambiguating (spillover) regions. Error bars represent standard errors.

Table 1. Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include fixed effects of the four priming conditions (Full Relative Clause- same verb, Main Clause-same verb, Reduced-Relative Clause-same verb, and Reduced-Relative Clause-different verb) relative to the Reduced-Relative Clause Prime sentence Baseline condition (Intercept). Modifications to the fully maximal random-effects structure (allowing for convergence) are reported for each model.

Sentence Region	First-Pass Time			Regression Path Time			Regressions			Total Time		
Verb	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	360.52	14.38	25.08*	455.49	29.42	15.48*	-2.65	0.32	-8.26*	581.82	31.14	18.69*
Full RC-same verb	-21.12	15.65	-1.35	-27.24	30.85	-0.88	0.18	0.39	0.48	-101.79	34.94	-2.91*
MC-same verb	-7.93	15.36	-0.52	-50.60	30.59	-1.65	-0.32	0.36	-0.91	-64.96	37.41	-1.74
RR-same verb	9.89	17.77	0.56	-10.80	34.82	-0.31	0.45	0.35	1.29	-56.11	31.88	-1.76
RR-different verb	7.59	17.45	0.44	-28.40	31.36	-0.91	0.021	0.37	0.057	-60.45	36.46	-1.66
modified Random effects	*Subjects random slope removed*			*Subjects random slope removed*			*Items random slope removed*			*Items random slope removed*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	608.89	31.29	19.46*	792.51	46.35	17.10*	-1.70	0.25	-6.83	872.99	49.03	17.81*
Full RC-same verb	-25.84	28.15	-0.92	-95.71	51.27	-1.87	-0.86	0.37	-2.33*	-125.87	49.37	-2.55*
MC-same verb	25.03	28.16	0.89	-24.22	50.06	-0.48	-0.31	0.33	-0.95	-13.94	50.91	-0.27
RR-same verb	-36.09	29.03	-1.24	-90.25	53.76	-1.68	-0.38	0.33	-1.14	-87.20	56.06	-1.56
RR-different verb	14.37	27.84	0.52	-36.47	47.12	-0.77	-0.23	0.33	-0.68	-35.17	51.44	-0.68
modified Random effects	*Items random slope removed*			*None- fully maximal*			*Items random slope removed*			*Subjects random slope removed*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Post-Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	454.80	25.15	18.09*	589.20	41.07	14.35*	-1.91	0.21	-9.27*	596.62	34.58	17.25*
Full RC-same verb	-43.81	30.48	-1.44	-76.72	52.95	-1.45	-0.20	0.31	-0.63	-46.46	40.74	-1.14
MC-same verb	-20.16	31.75	-0.64	-3.40	56.43	-0.06	-0.43	0.37	-1.14	15.33	47.24	0.33
RR-same verb	-24.31	32.8	-0.74	-51.51	56.67	-0.91	-0.85	0.40	-2.14*	-0.62	47.32	-0.013
RR-different verb	-17.01	34.44	-0.49	-36.14	55.51	-0.65	-0.55	0.38	-1.45	-1.89	39.82	-0.047
modified Random effects	*None- fully maximal*			*Subjects random slope removed*			*Items random slope removed*			*Subjects random slope removed*		

* indicates *t* > 2

Table 2. Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include fixed effects of the four priming conditions (Full Relative Clause- same verb, Main Clause-same verb, Reduced-Relative Clause-same verb, and Short-Relative Clause-same verb) relative to the Reduced-Relative Clause Prime sentence Baseline condition (Intercept). Modifications to the fully maximal random-effects structure (allowing for convergence) are reported for each model.

Sentence Region	First-Pass Time			Regression Path Time			Regressions			Total Time		
Verb	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	373.11	13.7	27.23*	427.99	16.54	25.87*	-2.30	.21	-11.08*	556.73	30.10	18.5*
Short RC-same verb	-21.07	15.19	-1.39	-22.92	23.75	-0.97	-0.45	0.33	-1.36	-68.86	31.01	-2.22*
Full RC-same verb	-17.16	14.97	-1.15	-2.77	23.58	-0.12	-0.33	0.30	-1.11	-59.65	31.77	-1.88
RR-same verb	-15.54	14.96	-1.04	-8.31	24.76	-0.34	-0.34	0.32	-1.06	-65.72	30.00	-2.19*
MC-same verb	1.43	17.15	0.083	18.97	28.06	0.68	0.023	0.27	0.085	-8.74	29.99	-0.29
Modified random effects	*subjects random slope removed*			*None- fully maximal*			*subjects random slope removed*			*None- fully maximal*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	548.78	20.58	26.66*	742.82	43.33	17.14*	-1.54	0.20	-7.65*	807.13	54.15	14.91*
Short RC-same verb	-3.79	23.48	-0.16	-110.0	40.39	-2.72*	-0.84	0.25	-3.36*	-97.35	43.24	-2.25*
Full RC-same verb	11.05	29.87	0.37	-91.85	45.43	-2.02*	-1.14	0.27	-4.31*	-76.59	48.49	-1.58
RR-same verb	-22.94	23.98	-0.96	-91.77	43.57	-2.11*	-0.87	0.26	-3.34*	-87.01	41.35	-2.10*
MC-same verb	2.28	26.59	0.086	-27.53	46.53	-0.59	-0.17	0.22	-0.78	-8.70	53.64	-0.16
Modified random effects	*None- fully maximal*			*None- fully maximal*			*subjects random slope removed*			*None- fully maximal*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Post-Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	437.57	21.12	20.72*	618.16	47.39	13.04*	-1.92	0.26	-7.44*	611.32	33.55	18.22*
Short RC-same verb	4.88	29.95	0.16	-74.25	61.68	-1.20	-0.52	0.36	-1.45	-50.60	40.87	-1.24
Full RC-same verb	-5.56	28.12	-0.20	-77.17	55.30	-1.40	-0.41	0.35	-1.15	-26.13	41.68	-0.63
RR-same verb	-27.43	28.83	-0.95	-59.41	54.65	-1.09	-0.22	0.32	-0.70	-54.37	37.13	-1.46
MC-same verb	25.58	35.61	0.718	-7.24	61.67	-0.12	0-27	0.30	0.88	-0.044	44.29	-0.001
Modified random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*None- fully maximal*		

* indicates $t > 2$

Table 3. Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include fixed effects of the three priming conditions (Passive- same verb, Main Clause-same verb, Reduced-Relative Clause-same verb) relative to the Reduced-Relative Clause Prime sentence Baseline condition (Intercept). Modifications to the fully maximal random-effects structure (allowing for convergence) are reported for each model.
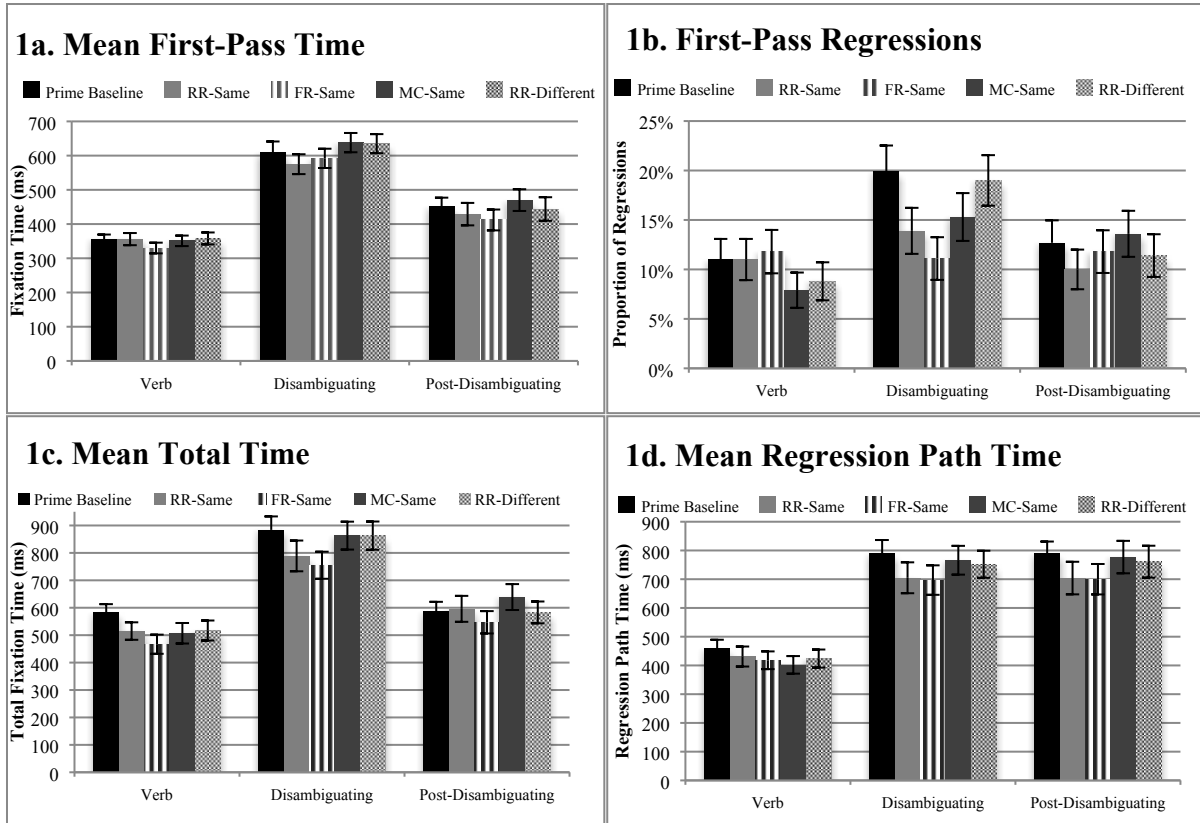
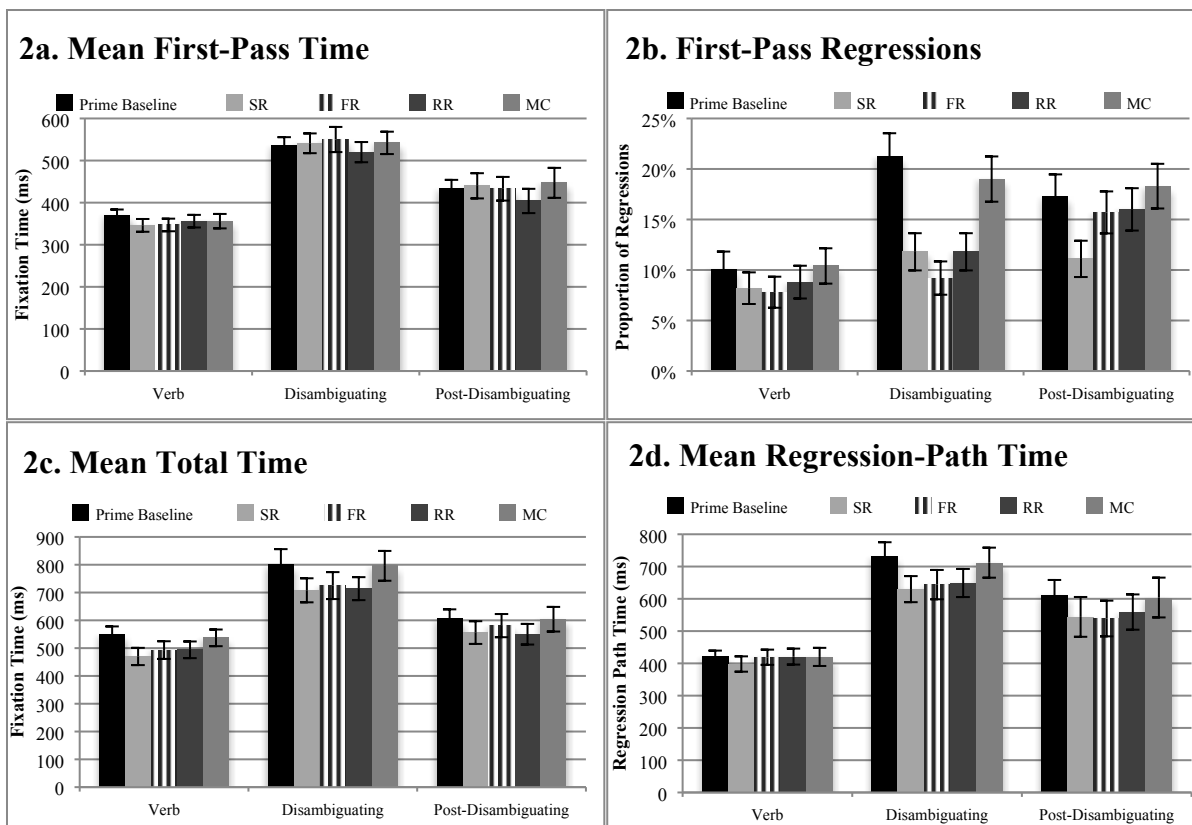| Sentence Region	First-Pass Time			Regression Path Time			Regressions			Total Time		
Verb	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	364.34	9.73	37.44*	400.78	13.18	30.41*	-2.23	0.19	-12.02*	557.55	24.22	23.03*
RR-same verb	-26.39	9.02	-2.93*	-29.81	11.73	-2.54*	-0.24	0.24	-1.03	-62.90	18.29	-3.44*
Passive-same verb	-9.95	10.01	-0.99	-16.60	13.14	-1.26	-0.59	0.23	-2.56*	-33.81	18.09	-1.87
MC-same verb	-11.48	8.56	-1.34	-20.14	11.54	-1.75	-0.21	0.20	-1.04	-21.38	17.84	-1.20
modified Random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*None- fully maximal*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	609.06	23.26	26.19*	670.83	25.05	26.78*	-1.99	0.16	-12.08*	883.26	36.33	24.31*
RR-same verb	-32.04	14.89	-2.15*	-61.63	15.40	-4.00*	-0.56	0.24	-2.32*	-90.72	25.19	-3.60*
Passive-same verb	-17.47	14.64	-1.19	-34.54	14.83	-2.33*	-0.20	0.21	-0.97	-62.86	23.68	-2.66*
MC-same verb	-13.45	16.38	-0.82	-10.69	18.48	-0.58	0.31	0.20	1.54	-8.44	27.67	-0.31
modified Random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*None- fully maximal*		
	First-Pass Time			Regression Path Time			Regressions			Total Time		
Post-Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	535.09	20.40	26.23*	624.05	23.85	26.17*	-0.62	0.18	-3.51*	686.23	27.17	25.26*
RR-same verb	-27.28	14.61	-1.87	-39.93	16.29	-2.45*	-0.11	0.16	-0.69	-37.82	18.17	-2.08*
Passive-same verb	-23.71	15.34	-1.55	-23.02	17.59	-1.31	-0.17	0.17	-1.03	-26.50	20.93	-1.27
MC-same verb	-19.44	15.39	-1.26	-10.04	19.15	-0.52	0.15	0.14	1.05	-24.08	20.60	-1.17
modified Random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*None- fully maximal*		

* indicates $t > 2$

Table 4. Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include fixed effects of the three priming conditions (Pluperfect- same verb, Main Clause-same verb, Reduced-Relative Clause-same verb) relative to the Reduced-Relative Clause Prime sentence Baseline condition (Intercept). Modifications to the fully maximal random-effects structure (allowing for convergence) are reported for each model.

Sentence Region	First-Pass Time			Regression Path Time			Regressions			Total Time		
Verb	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	397.53	12.59	31.57*	485.18	20.43	23.75*	-2.07	0.18	-11.23*	566.26	27.92	20.28*
RR-same verb	-24.02	15.21	-1.58	-37.63	25.04	-1.50	-0.40	0.27	-1.48	-54.85	28.42	-1.93
Pluperfect -same verb	-35.72	15.81	-2.26*	-41.68	24.67	-1.69	-0.11	0.24	-0.44	-86.89	27.27	-3.19*
MC-same verb	-26.76	14.09	-1.90	-25.25	28.99	-0.87	-0.65	0.30	-2.15*	-45.71	30.64	-1.49
modified Random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*None- fully maximal*		

	First-Pass Time			Regression Path Time			Regressions			Total Time		
Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	612.29	21.67	28.26*	758.80	38.74	19.59	-1.88	0.16	-11.41*	823.05	38.78	21.22*
RR-same verb	-33.48	21.88	-1.53	-72.70	40.03	-1.81	-0.37	0.23	-1.59	-96.20	37.35	-2.58*
Pluperfect -same verb	-9.98	20.26	-0.49	-58.49	38.99	-1.50	-0.32	0.22	-1.45	-66.00	37.38	-1.77
MC-same verb	-6.63	24.26	-0.27	-50.19	44.66	-1.12	-0.29	0.22	-1.29	-38.60	37.31	-1.04
modified Random effects	*None- fully maximal*			*None- fully maximal*			*Items random slope removed*			*Items and subjects random slopes removed*		

	First-Pass Time			Regression Path Time			Regressions			Total Time		
Post-Disambig.	Estimate	Std. error	t-value	Estimate	Std. error	t-value	Estimate	Std. error	z-value	Estimate	Std. error	t-value
Intercept	511.50	26.28	19.47*	698.69	38.84	17.99*	-1.43	0.18	-8.07*	676.58	33.74	20.05*
RR-same verb	6.83	34.85	0.20	-41.46	54.91	-0.76	-0.56	0.25	-2.26*	-29.79	39.57	-0.75
Pluperfect -same verb	28.76	33.44	0.86	-26.09	52.30	-0.50	-0.57	0.24	-2.40*	-4.60	39.63	-0.12
MC-same verb	18.79	31.50	0.60	-10.18	51.79	-0.20	-0.35	0.23	-1.47	-24.62	39.52	-0.62
modified Random effects	*None- fully maximal*			*None- fully maximal*			*None- fully maximal*			*Items and subjects random slopes removed*		

* indicates $t > 2$

1a. Mean First-Pass Time

1b. First-Pass Regressions

1c. Mean Total Time

1d. Mean Regression Path Time

2a. Mean First-Pass Time

2b. First-Pass Regressions

2c. Mean Total Time

2d. Mean Regression-Path Time

3a. Mean First-Pass Time

3b. First-Pass Regressions

3c. Mean Total Time

3d. Mean Regression-Path Time

4a. Mean First-Pass Time

4b. First-Pass Regressions

4c. Mean Total Time

4d. Mean Regression-Path Time