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Contrasting mechanistic accounts of the lexical boost

Kristen M. Tooley[1]

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Abstract
While many recent studies focused on abstract syntactic priming effects have implicated an error-based learning mechanism, there is little consensus on the most likely mechanism underlying the lexical boost. The current study aimed at refining understanding of the mechanism that leads to this priming effect. In two eye-tracking during reading experiments, the nature of the lexical boost was investigated by comparing predictions from competing accounts in terms of decay and the requirement of structural overlap between primes and targets. Experiment 1 revealed facilitation of target structure processing for shorter relative to longer primes, when there were fewer intervening words between prime and target verbs. In Experiment 2, significant lexically boosted priming effects were observed, but only when the target structure also appeared in the prime, and not when the prime had a different structure but a high degree of lexical overlap with the target. Overall, these results are most consistent with a short-lived mechanistic account rather than an error-based learning account of the lexical boost. Furthermore, these results align with dual-mechanism accounts of syntactic priming whereby different mechanisms are claimed to produce abstract syntactic priming effects and the lexical boost.

Keywords Syntactic priming · Comprehension · Lexical boost

Introduction

Over the past several decades, research on structural priming and persistence has informed theoretical accounts of the underlying mental representation of grammatical structure (e.g., Bock, 1986; Branigan, Pickering, & Cleland, 2000; Pickering & Branigan, 1998), and pointed to the malleability of those representations in the face of a dynamic language environment (e.g., Bock & Griffin, 2000; Kaschak & Glenberg, 2004). Investigations of this phenomenon have also yielded new paradigms that offer language researchers more objective probes of syntactic knowledge than previous methods like grammaticality judgments (Branigan & Pickering, 2017). Despite these substantial contributions, the underlying mechanism(s) that produce syntactic priming effects have yet to be firmly established. Lacking an empirically supported understanding of the likely causes of these effects means the theoretical conclusions that can be drawn from such studies will necessarily be weakened. The current study aims to address this issue by providing evidence that rules out two possible mechanistic accounts of lexically mediated syntactic priming effects (i.e., the lexical boost).

✉ Kristen M. Tooley
ktooley@txstate.edu

[1] Department of Psychology, Texas State University, 601 University Drive, San Marcos, TX 78666, USA

Syntactic priming (also known as syntactic or structural persistence) refers to a processing advantage for grammatical/syntactic structure information that has been previously processed. In language production, this phenomenon manifests as a given structure being more likely to be used (compared to an equally plausible alternative structure), when that structure was recently heard or said (Bock, 1986; see Pickering & Ferreira, 2008, for a review of these effects). For example, if someone hears or says the passive sentence "The boy was scratched by the cat," they are then more likely to describe a pictured transitive event using a passive structure (than if they had originally said an active-voice sentence like "The cat scratched the boy"). In language comprehension, these effects manifest as a recently encountered structure becoming easier to understand or more predictable (than before this exposure) (e.g., Thothathiri & Snedeker, 2008; Traxler, 2008; see Tooley & Traxler, 2010, for a review of these effects). For example, if someone reads the sentence "The chemist poured the fluid in the beaker into the flask earlier" they show a processing advantage (shorter fixation times and fewer regressive eye movements at critical sentence regions) if they have just read a sentence with the same structure, relative to initially reading a sentence with a different structure (Traxler, 2008).

Interestingly, structural facilitation varies based on the lexical items that appear in the prime sentence. Specifically, syntactic priming effects are larger in magnitude when a particular content word (especially a verb) appears in both the initial exposure (the prime), and the subsequent use of (or exposure to) the structure (i.e., the target) (Mahowald, James, Futrell, & Gibson, 2016; Pickering & Branigan, 1998; Segaert, Kempen, Petersson, & Hagoort, 2013). For example, Pickering and Branigan (1998) found an increase in the proportion of producing a sentence structure when it matched (vs. mismatched) that of a previous sentence (by roughly .04–.05). However, the magnitude of structural persistence increased (to roughly .16-.18) when the sentences shared a verb as well as had a structural match. This increase in syntactic priming for cases of lexical and structural overlap has been termed the "lexical boost," and the robustness of this effect has been verified in a recent meta-analysis of syntactic priming studies in production (Mahowald et al., 2016). Analogous increases in syntactic priming for cases of lexical and structural overlap have also been observed in online measures of language comprehension (e.g., Segaert et al., 2013; Traxler, Tooley, & Pickering, 2014).

Understanding the mechanisms that produce syntactic priming (both abstract priming and lexically boosted priming) is essential for utilizing and interpreting these effects in investigations of syntactic acquisition, representation, and use. Thus, there have been several attempts to characterize or model the mechanism(s) underlying syntactic priming and persistence. Pickering and Branigan (1998) initially described a unitary mechanism that could account for both abstract priming and the lexical boost. This mechanism relied on a lexicalist framework of linguistic knowledge in long-term memory, based on Levelt's (1993) model of language production. This framework assumes lexical information is stored in nodes that are linked to the structures in which they participate via structural (combinatorial) nodes. During prime sentence processing, the structure and verb nodes associated with the prime are activated and residual activation for these nodes, and for the link between them, remains active during target formulation. This biases structural decisions towards the recently processed structure, especially when the verb is used in both the prime and the target (as in these cases there is residual activation not only for the structural node but also the link with the specific verb node).

However, this residual activation mechanism cannot easily reconcile subsequent findings that abstract priming effects persist across a sizeable number of intervening sentences (Bock & Griffin, 2000; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008), and accumulate with increased structural exposure (Fine, Jaeger, Farmer, & Qian, 2013; Kaschak, Kutta, & Jones, 2011). Residual activation in long-term memory is conceived of as being transient, and is expected to decay with time or be washed out by activation associated with subsequent language processing. In light of the longevity of abstract priming, several researchers have suggested that abstract priming effects are better characterized as implicit learning for abstract syntactic representations (Bock & Griffin, 2000; Branigan & McLean, 2016; Chang, Dell, Bock, & Griffin, 2000; Chang, Dell, & Bock, 2006; Hartsuiker et al., 2008; Tooley & Traxler, 2018). This learning mechanism is suggested to be error based (Fine & Jaeger, 2013; Jaeger & Snider, 2013), such that the degree of learning from a given structural exposure is determined by the size of the error signal associated with that structure; the more unexpected the structure, the larger the error signal and greater the structural learning. The error-based implicit learning account accurately predicts persistent and cumulative priming effects as well as greater priming for less frequent structures (i.e., the inverse frequency effect) (Fine, Jaeger, Farmer, & Qian, 2013; Fraundorf & Jaeger, 2016; Jaeger & Snider, 2013).

Unlike abstract priming effects, the lexical boost has been shown to be more short lived (Hartsuiker et al., 2008), with any amount of intervening language material between prime and target structures leading to a dramatic decrease in effect size (Mahowald et al., 2016). Two important inferences are often drawn from differences in longevity for abstract and lexically boosted priming effects: (1) the lexical boost is unlikely to reflect learning (such as for a specific structure-verb pairing), and (2) abstract syntactic priming and the lexical boost are unlikely to be caused by the same mechanism. Thus, dual-mechanism accounts have been proposed by several researchers in recent years (Branigan & McLean, 2016; Hartsuiker et al., 2008; Reitter, Keller, & Moore, 2011; Tooley & Traxler, 2010, 2018). These accounts largely agree about the nature of abstract priming effects; the body of evidence strongly supports an implicit learning mechanism. However, little agreement exists under these accounts in terms of the mechanism that produces the lexical boost. A better understanding of the nature of the mechanism underlying the lexical boost is a necessary next step in this line of inquiry, and is the focus of the current study.

It is worth noting that there have been some studies that have observed lexically boosted priming effects that persist across a few intervening sentences (Pickering, McLean, & Branigan, 2013; Tooley, Swaab, Boudewyn, Zirnstein, & Traxler, 2014). Furthermore, there are learning models that can accommodate different longevities of the lexical boost and abstract priming effects (e.g., Jaeger & Snider, 2013; Malhotra, Pickering, Branigan, & Bednar, 2008). Such models would need to assume that the prediction error (driven by lexical similarity between sentences) is weighted differently than prediction error associated with global syntactic predictions, but are plausible. Therefore, before embracing the conclusion that the lexical boost *cannot* be caused by a learning mechanism, evidence for decay of lexically boosted syntactic priming effects with *no* intervening sentences between primes and targets was sought.

Experiment 1 investigated the question of whether the lexical boost shows signs of decay in situations where the primes and targets are adjacent sentences, and where the priming conditions should produce equal "error signals." Previous research has shown that reading a reduced-relative clause (RRC) sentence (like 3, below) can be facilitated by first reading another reduced-relative with the same verb (like 1 or 2, below) (Ledoux, Traxler, & Swaab, 2007; Tooley, Traxler, & Swaab, 2009).

1) The woman pushed by the man was going to the front of the line. (RRC Long Prime)
2) The woman pushed by the man was going home. (RRC Short Prime)
3) The boy pushed by the girl made a sexist remark. (RRC Target Sentence)

Similarly, Experiment 1 used adjacent RRC prime and target sentences with the same initial verb. Importantly, the same RRC prime sentences, that varied the in length, were used across conditions. This created two priming conditions (Short and Long, like sentences 1 and 2, above) that only differed in the number of words required to process the prime before re-encountering the verb in the target sentence structure. Otherwise, these primes were the same, and so should lead to equivalent verb and structure error signals, and thus equivalent magnitudes of priming according to an error-based learning account. This prediction holds even for an error-based learning account that predicts a more short-lived lexical boost, as it still requires that at least one structure intervene between prime and target to adjust the prediction error associated with the predicted verb and structure pairing. A transient, short-term mechanism, on the other hand, relies on activation that decays with time/additional lexical processing, and so would predict a decreased lexically boosted priming effect for the Long relative to the Short condition. If decreased structural facilitation is observed for targets following long primes relative to those following short primes, then this would suggest that a more short-lived, non-learning mechanism produces the lexical boost.

The current set of experiments also addresses the possibility that the lexical boost derives primarily from short-term, explicit memory for the wording of the prime sentence. An explicit memory account of the lexical boost was first proposed to reconcile the lexically based nature of this effect relative to abstract priming effects (Bock & Griffin, 2000; Ferreira & Bock, 2006), as well as computational, implicit learning models' inability to reproduce this effect (Chang et al., 2006). According to this account, language users explicitly remember the content words (such as the verb) used in the prime. When that verb is re-encountered in the target, it acts as a cue to upcoming lexical or phrasal information, which biases target sentence processing. Consistent with the observed time course of the lexical boost, this account predicts that the additional degree of structural priming due to having a repeated verb across prime and target sentences will only persist as long as that explicit memory trace does. That is to say, not long; certainly not across multiple intervening sentences.

Importantly, this account, as has been explained in the published literature, could be interpreted in more than one way, each predicting a lexical boost that will decay as the explicit memory trace does. A deep processing view of this account would mean that the repeated lexical cue (stored in short-term, explicit memory) is temporarily linked to a structural representation (stored in long-term memory), and the global abstract structure of the prime is recalled with the explicit memory trace of the repeated verb (Chang, Janciauskas, & Fitz, 2012). However, a shallow processing view of this account is also possible. Under such an account, a verbatim, word-based representation of the prime sentence remains active in short-term, explicit memory. When the verb from the prime sentence is re-encountered in the target, the words following the verb in the prime bias processing of the target. Though verbatim memory for sentences has been shown to be rather fragile (Potter & Lombardi, 1990), such a possibility is warranted given findings of "good enough parsing" for comprehension of complex structures (e.g., Ferreira, Bailey, & Ferraro, 2002). In such cases, readers have been shown to endorse propositional interpretations of word strings in sentences that are inconsistent with the global structure/interpretation of that sentence. Additionally, classic findings of locatives priming passive sentences (e.g., Bock & Loebell, 1990) regardless of function word overlap, have been called into question by more recent findings that these effects only emerge when the function word *by* is present in the locative prime (Ziegler, Bencini, Goldberg, & Snedeker, 2019). In light of such findings, it is prudent to test the possibility that shallow explicit memory for prime wording drives the lexical boost.

The two different explicit memory possibilities outlined above, make different predictions as they relate to the lexical boost. Specifically, Experiment 2 tests the shallow explicit memory prediction that surface-level overlap between primes and targets (without structural overlap) will be sufficient to produce lexically boosted syntactic priming effects. In contrast, accounts that rely on access to structural information that is stored in long-term memory (i.e., the residual activation and deep explicit memory accounts) predict that encountering the target structure in the prime will be necessary for structural facilitation to occur. Findings from this experiment, coupled with that from Experiment 1, will serve to narrow down the plausible mechanistic accounts of the lexical boost. This in turn will lead to a better understanding of the nature of syntactic priming effects as a whole. Specifically, whether a single mechanism can account for both abstract priming effects and the lexical boost, or whether dual mechanism accounts of syntactic priming effects are most viable.

Experiment 1

The assumption that a short-lived mechanistic account of the lexical boost is more tenable than an error-based learning account rests largely on the observation that the lexical boost rarely persists across intervening sentences (e.g., Hartsuiker, et al., 2008). However, there are some studies that have shown that this effect can persist across a few unrelated sentences (Pickering et al., 2013; Tooley et al., 2014), and versions of a learning-based mechanism that predict shorter-lived priming effects for the lexical boost relative to abstract priming effects (e.g., Jaeger & Snider, 2013). Thus, the lexical boost may have a time course that is felicitous with a learning mechanism. However, it may also be the case that the lexical boost is caused by a short-lived, non-learning mechanism. Experiment 1 contrasts these competing accounts by comparing priming effects at RRC target sentences immediately following RRC prime sentences that were either shorter or longer in length. A short-lived mechanism predicts that having less (relative to more) intervening lexical material between encountering the verb in the prime structure and re-encountering the verb in the target will result in decreases in processing times. However, with no intervening structure to cause a change in error-signal for the verb and structure pairing, the learning-based account would predict no difference in target processing. Thus, finding increased facilitation for targets preceded by the shorter primes, relative to the longer primes, would support a mechanism that decays over a short time-span rather than a learning-based mechanism.

Method

Participants

Fifty-four undergraduates from Texas State University participated in this study. All participants gave informed consent to participate, were native English speakers with normal (or corrected-to-normal) 20/20 vision, and were compensated with course credit.

Stimuli and design

The experimental stimuli consisted of 36 pairs of yoked, prime and target sentences. These sentence pairs were adapted from those used by Tooley and Traxler (2018), because they have been shown to effectively elicit lexically mediated syntactic priming effects for the RRC structure. The target sentences were always reduced-relative clauses (such as *The architect selected by the firm had years of experience*). The primes were either main clause sentences (baseline condition: *The group selected the speaker who gave a…*) or reduced-relatives that had the same initial verb as the target. The reduced-relative primes appeared in either a “short” or “long” version (Short: *The speaker selected by the group gave a presentation*. Long: *The speaker selected by the group gave a wonderful presentation at the conference*.) The short version was created to have as few words as possible after the by-phrase (2–4) and the long version was created by adding 4–7 words *after* the spillover region of the short version. Thus, the two versions were identical through the spillover region but varied in the number of words after this region. Across versions, this created a decreased (short version) or increased (long version) lexical processing demand between the two exposures to the verb, from prime to target sentences. Half of the main clause (baseline) sentences took a long form and half took a short form in order to balance out effects of length in this condition.

Each participant saw each of the 36 item pairs only once, in one of the three conditions, and was exposed to each of the conditions on 12 of the prime-target pairs. Prime sentence condition was counterbalanced across participants using six separate experimental lists (see Appendix for a full list of stimuli). Target sentences always immediately followed prime sentences, and one filler sentence intervened between pairs of primes and targets. There were 55 filler sentences in total, and these fillers took on a variety of structures including relative clauses, main clauses, passives, reduced-relatives, etc. The independent variable in this experiment was the prime sentence condition (Baseline, Short RRC or Long RRC). The dependent variables consisted of the same reading measures (detailed below) collected via eye tracking during reading of the *target* sentences. As the set of target sentences remained the same for all participants, we can measure reading behavior associated with these sentences and then estimate whether this reading behavior differed based on the condition of the previous, prime sentence.

Apparatus/procedure

An EyeLink 1000 Plus Desktop Mount Eye Tracker (SR Research) monitored participants' eye movements during reading of the sentence stimuli. The eye tracker has an average accuracy of 0.25–0.5° and a resolution of 0.01°. The gaze location of only one eye (usually the right eye) was monitored. A PC running Experiment Builder software was used to display sentences on an LCD monitor located approximately 75 cm from participants' eyes. The sentences were presented in Times New Roman 20-pt font. The location of participants' gaze was sampled every millisecond and was recorded by the software to establish the sequence of eye fixations and saccades, including their start and finish times.

At the start of the study, the participant is seated in front of the eye tracker and is asked to place his or her head on the chin rest. The researcher then helps the participant adjust the chair and chin rest to make the participant as comfortable as possible. The participant's chair is adjustable in two dimensions and the chin rest is padded for extra comfort. After explaining the task to the participant, the researcher aligns and then calibrates the tracker to the participant's eyes by having him or her fixate on a dot on the screen that moves through a 9-pt grid configuration. After calibration, a validation procedure allows the researcher to determine whether the calibration is precise enough (with an average error of no more than 0.5°). Once adequate calibration has been achieved, the participant begins the experiment. The actual experiment consisted of an initial four filler sentences followed by the experimental prime-target pairs that were separated by one filler. These sentences were presented in the manner described below.

On each trial of the experiment, one (left-justified) sentence was presented on the screen, roughly half-way between the top and bottom of the screen. The participants were instructed to silently read each sentence such that they understood the meaning of the sentence. When they were finished reading the sentence, they were instructed to fixate on a small blue rectangle in the bottom right-hand corner of the screen. This indicated to the researcher that they were ready to advance to the next sentence. After every target sentence and roughly half of the filler sentences, a comprehension question was displayed on the screen. These were all forced-choice questions with two options displayed underneath the question. Participants indicated their answers to these questions by pressing one of two buttons on a keyboard, positioned on the table in front of them. On trials that were not followed by a comprehension question, a prompt appeared instructing participants to press a particular button (one of two) on the keyboard to move on to the next sentence. After this question or prompt, a drift correction screen was displayed containing a small box on the left-hand side of the screen. Participants were instructed to look at this box when they were ready to see the next sentence. This allowed the researcher to check the calibration of the eye tracker after every trial. If the calibration was off, the researcher re-calibrated the eye tracker before moving on to the next trial. This drift correction screen also ensured that the participant had a stable fixation near the first word of the sentence before that next sentence was displayed.

Data analysis

Data from all 54 participants were included in the analyses. The data were "cleaned" prior to calculation of reading time measures. This cleaning process merged fixations that were less than 50 ms and within 0.5° of each other, as well as deleted individual fixations that were less than 80 ms or greater than 1,000 ms. From this data, four reading time measures were calculated: first-pass time, regression-path time, total time, and regressions out. *First-pass time* includes all fixations within a specified region before the eyes crossed either the right- or left-hand boundary of that region, and reflects early processing of that region. *Regression path time* includes all fixations in a region before the eyes crossed the right-hand boundary of that region. This includes first-pass fixations in a region as well as subsequent fixations in that region after the participant has gone back to an earlier region in the sentence. Regression-path time offers a measure of understanding of the sentence up until the point of that particular region. *Total time* includes all time spent fixating in a region. This measure reflects overall processing of a region and is a summation of first-pass fixations and re-fixations to a region after either going back to an earlier region or moving forward to a subsequent region. *Regressions out* is a binary measure that captures whether or not a regression was made from a given region to a previous region in the sentence. Regressions out provides a measure of whether or not the reader decided he or she needed to re-read an earlier part of the sentence, possibly to understand the current region.

These reading time measures were calculated over three sentence regions of the reduced-relative clause target sentences: the verb region, the by-phrase region, and the spillover (or post-by-phrase region). The *verb region* includes the initial past tense verb in the sentence (i.e., "pushed" in example 2, above), which is technically a past participle in the reduced-relative structure. The *by-phrase region* includes the word "by" and its following article and noun (i.e., "by the girl" in example 2, above). This region tends to be difficult for readers as it is where the reduced-relative structure is disambiguated from the main clause structure, and is typically where syntactic priming effects are most readily observable (Tooley & Traxler, 2018). The *spillover region* includes the two words immediately following the by-phrase region (i.e., "made a" in example 2, above). This region is interesting to consider because syntactic priming is sometimes observed a little downstream of the by-phrase region in this structure.

Prior to analyses, each region was subjected to data trimming for outliers such that trials with total fixation times of less than 180 ms or more than 3,000 ms were removed. This trimming resulted in a loss of less than 2% of the data. Each of the four dependent measures (first-pass time, regression-path time, total time, and regressions out) were analyzed at each of the three sentence regions (verb, by-phrase, and spillover) using linear mixed-effects models (for the duration measures) or logit mixed models (for the regressions measure) (Baayen, Davidson, & Bates, 2008; Jaeger, 2008). Analyses were carried out in R (R Development Core Team, 2008) using the lmer or glmer functions, with the Prime Condition variable included as a fixed effect. This fixed effect was contrast coded, and included two contrasts: targets preceded by a main clause prime (baseline) were compared to primes preceded by reduced-relative clause primes (Long and Short Conditions combined) and targets preceded by the Long reduced-relative clauses were compared to primes preceded by the Short reduced-relative clauses. The first contrast tested whether facilitated processing of the RRC structure took place (i.e., lexically mediated priming occurred in the experiment), and the second contrast tested whether that priming differed based on the length of the prime sentence. 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 $\alpha = 0.05$ (test statistic value > 2).

Results and discussion

Figure 1 presents mean values of the four dependent measures by region and condition for the targets following Main Clause, Long RRC, and Short RRC prime sentences. Results from the multi-level models are presented in Table 1.

Verb region

Model results revealed a significant difference in first-pass fixation times between the baseline condition and the RRC primes ($p < 0.05$) at the verb region. Here, participants spent less time initially fixating the verb of the RRC target sentence when it was preceded by a main clause prime sentence relative to an RRC prime sentence. No other significant effects were observed at this region.

By-phrase region

At the by-phrase region, model results revealed a significant difference in total time between the baseline condition and the RRC primes, as well as between the Long and Short RRC prime conditions ($ps < 0.05$). Participants spent less total time fixating the critical by-phrase region of a reduced-relative clause target sentence when they had just read another reduced-relative clause (relative to a main clause baseline),

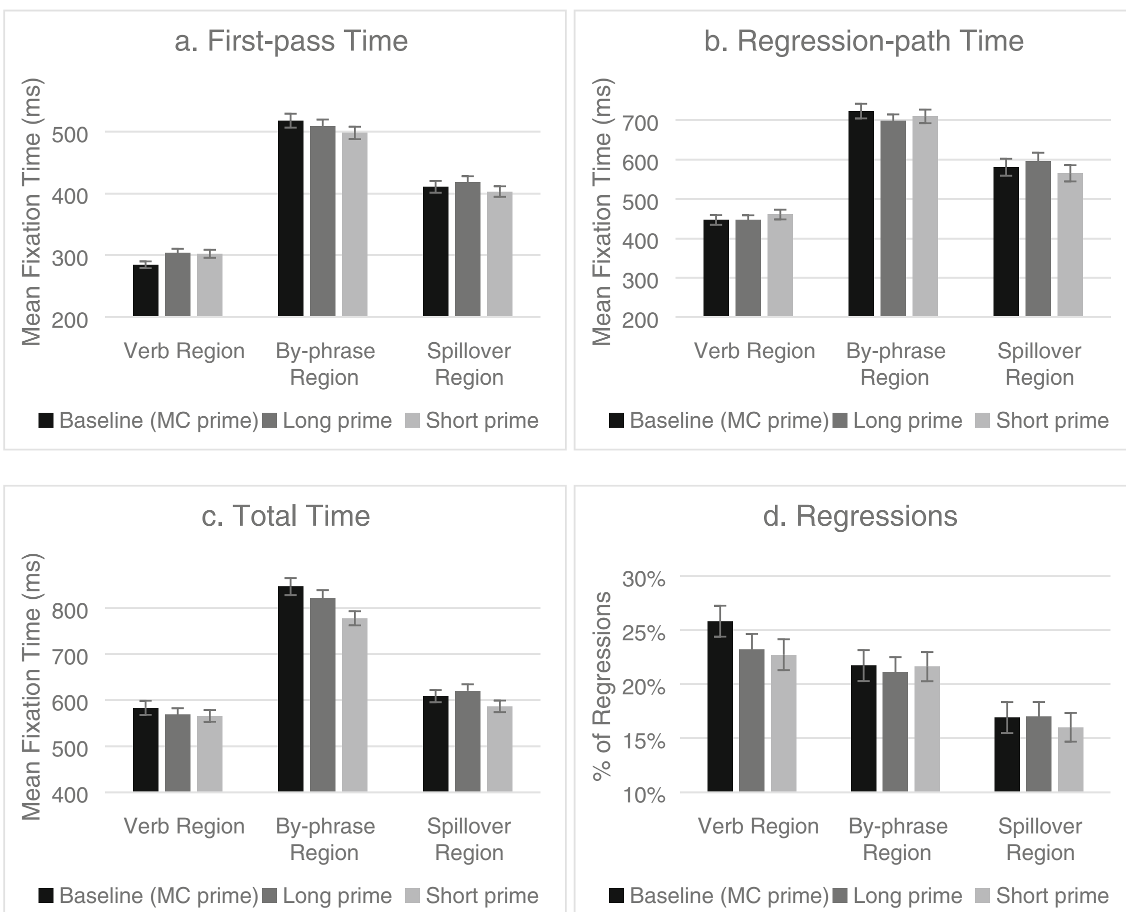

Fig. 1 Experiment 1 mean reading time measures (**a** first-pass time, **b** regression path time, **c** total time, and **d** regressions out) for the verb, by-phrase, and spillover (post by-phrase) regions. Error bars represent standard errors

Table 1 Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include the fixed effects of the Prime Sentence Condition (contrast coded to compare the baseline to the RRC prime conditions and the Long and Short RRC prime conditions). The random-effects structure (allowing for convergence) is reported for each model

Verb region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept	294.5	8.7	33.7*	445.9	20.8	21.4*	565.4	24.9	22.7*	-1.3	0.12	-10.7*
MC vs. RRC prime	18.9	7.0	2.7*	7.7	13.4	0.6	-15.5	15.2	-1.02	-0.2	0.12	-1.4
Long vs. Short prime	-1.9	8.1	-0.2	15.7	15.6	1.01	0.02	17.6	0.001	-0.02	0.14	-0.2
Random effects	By-participant and by-item random intercepts			By-participant and by-item random intercepts			By-participant and by-item random intercepts			By-participant and by-item random intercepts		
By-phrase region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept	506.4	22.1	22.9*	708.6	32.5	21.8*	813.2	34.9	23.3*	-1.5	0.15	-10.3*
MC vs. RRC prime	-15.5	13.3	-1.2	-19.7	18.9	-1.04	-47.9	17.7	-2.7*	-0.03	0.12	-0.2
Long vs. Short prime	-10.3	13.1	-0.8	12.2	21.8	0.56	-42.0	20.5	-2.1*	0.04	0.14	0.3
Random effects	By-participant and by-item random intercepts; by-participant random slopes			By-participant and by-item random intercepts			By-participant and by-item random intercepts			By-participant and by-item random intercepts		
Spillover region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept	405.1	19.7	20.6*	574.5	34.9	16.5*	597.0	26.0	22.9*	-1.9	0.18	-10.8*
MC vs. RRC prime	-1.1	9.7	-0.1	-0.2	24.0	-0.01	-7.1	14.1	-0.5	-0.03	0.14	-0.2
Long vs. Short prime	-15.7	11.2	-1.4	-31.8	27.7	-1.1	-35.4	16.3	-2.2*	-0.09	0.16	-0.6
Random effects	By-participant and by-item random intercepts			By-participant and by-item random intercepts			By-participant and by-item random intercepts			By-participant and by-item random intercepts		

and this difference was significantly smaller following a long RRC prime.

Spillover region

Model results for the spillover region revealed a significant difference in total fixation times between the Long RRC and Short RRC conditions ($p < 0.05$). Participants spent less total time fixating the region right after the by-phrase region of the RRC target sentences when the preceding prime RRC sentence had fewer words after the spillover region. The difference in total fixation times between the baseline and RRC primes was not significant, nor were any other effects, at this region (*p*s > 0.05).

Comprehension question performance

Participants correctly answered comprehension questions on 93% of all trials with questions. For comprehension questions that followed the reduced-relative target sentences, participants answered correctly 85% of the time.

In Experiment 1, lexically mediated priming for the reduced-relative clause structure was observed. This effect was indicated by shorter total fixation times at the critical by-phrase region of reduced-relative target sentences following reduced-relative primes with the same initial verb. This result is consistent with several previous studies investigating this type of priming using reduced-relative clause stimuli (e.g., Tooley & Traxler, 2018; Tooley, Traxler, & Swaab, 2009). One slight oddity in the observed pattern of results was that first-pass fixation times at the verb of the targets were actually shorter when the prime was a main clause, and so had a different structure than that of the target. However, the recent exposure to a simpler structure may have led readers to (initially) believe the target sentence was another main clause, and so anticipated an easier structure. While this is speculative, it is consistent with the observed reversal of this numeric trend in later reading time measures for this region, and in the numerically greater regressive eye movements from this region for the main clause/baseline condition relative to the other priming conditions.

Interestingly, the eye-movement behavior associated with comprehending a reduced-relative target sentence was also found to differ depending on the length of the preceding prime sentence. Specifically, total fixation time measures on the critical by-phrase and spillover regions of the targets were significantly reduced when the prime sentence was shorter compared to when it was longer. Notably, the primes and targets were adjacent and the prime types in this experiment did not differ in a way that would systematically alter the respective error signals associated with processing them; Long and Short primes had the same structure and verb and were actually identical through the point at which their structure could be disambiguated from a main clause. Thus, an error-driven learning mechanism would not predict that they would differ in terms of how they affect processing of a subsequent RRC target sentence. However, because these prime types did differ in the number of lexical items between encountering the verb in the prime and then re-encountering it in the target, a short-lived mechanism would predict the observed pattern of facilitated processing for the RRC targets preceded by short (relative to long) prime sentences.

The results from Experiment 1 are therefore more easily explained by a short-lived mechanistic account of the lexical boost, rather than an error-driven learning account. The current findings are also consistent with those observed in language production (e.g., Hartsuiker et al., 2008; Mahowald et al., 2016), where the lexical boost is found to decay with intervening material, on a relatively short-lived timescale.

The next important question to address is whether a short-lived mechanism that relies on shallow, explicit memory for the wording of the prime is sufficient to account for the observed lexical boost. Past evidence of good enough parsing for comprehension of complex syntactic structures (e.g., Ferreira et al., 2002) as well as recent evidence that repetition of a function word *can* elicit syntactic priming in production (Ziegler et al., 2019) makes this a plausible explanation that deserves attention. Experiment 2 was designed to test whether, in the absence of structural overlap, surface-level lexical repetition following a repeated verb is sufficient to produce a lexical boost. Such a result would be consistent with a shallow explicit memory account of the lexical boost, whereby memory for the wording of the prime guides target sentence processing without accessing a stored structural representation.

Relying on the basic priming methodology used in Experiment 1, this shallow explicit memory account would predict that a surface-level memory cue should lead to facilitated processing of an RRC target, even if the prime sentence does not have the same RRC structure as the prime. A locative prime sentence (such as 4, below), has the same verb followed by a "by-phrase," but does not have a relative-clause structure. Rather, this sentence uses a particle verb (pushed by) as a main verb of the sentence. Thus, if a surface-level memory cue is sufficient for the lexical boost to occur, sentence 4 should lead to structural facilitation of an RRC target, as the RRC Primes (sentences 1 and 2, above) do. This is because the verb acts as a cue that makes it easier to predict that a "by-phrase" will occur again (rather than a direct object of the verb) after re-encountering that particular verb in the target.

4) The woman pushed by the man to get to the front of the line. (Locative Prime)

However, an account of the lexical boost that postulates a linkage between the repeated verb in the prime and its structure, would predict that first reading sentence 4 would *not* lead to structural facilitation of the RRC target sentence. This is because the RRC representation will not be active in long-term memory. Both a deep processing explicit memory account and a residual activation account, which rely on a repeated word cueing a stored structural representation, would make such a prediction. Therefore, if syntactic priming is only found for the RRC targets that were preceded by RRC primes then this would implicate an account of the lexical boost that depends on accessing a stored structural representation from long-term memory.

Experiment 2

Experiment 2 was designed to investigate whether comprehending a reduced-relative target structure (e.g., *The boy pushed by the girl made a sexist remark*) could be facilitated by previous (prime) processing of a locative sentence with a "by-phrase" and the same verb as the target (e.g., *The woman pushed by the man to get to the front of the line*). Importantly, these sentences rely on different structural representations, but have a high degree of surface-level lexical overlap. If this type of prime processing experience leads to facilitation of the target, this would imply that the lexical boost is driven (at least in part) by shallow explicit memory cues from prime sentence wording. If this prime processing experience does not lead to facilitation for comprehending a reduced-relative target, this would imply that the lexical boost is instead likely caused by a mechanism that guides access to a structural representation in long-term memory. The target sentences in this experiment were always reduced-relatives and the prime sentence that preceded each target had varying degrees of structural and lexical overlap.

Method

Participants

Sixty-five undergraduates from Texas State University participated in this study. All participants gave informed consent to participate, were native English speakers with normal (or corrected-to-normal) 20/20 vision, and were compensated with course credit.

Stimuli and design

The experimental stimuli consisted of 48 pairs of yoked, prime and target sentences. The target sentences were always reduced-relative clauses (RRC), such as sentence 2, below. The prime sentences took on one of four forms: (1) a locative sentence with a by-phrase and the same initial verb that appears in the subsequent target sentence, (2) a reduced-relative clause with the same initial verb that appears in the target sentence, (3) a reduced-relative clause with a different initial verb than the target sentence, or (4) a main clause sentence with a different verb from that which appears in the subsequent target sentence (see sentences 1a–d, below).

1) Prime Sentence Condition:
    a) Locative, same verb: The child pushed by the man to get to the front of the line.
    b) RR, same verb: The child pushed by the man was going to the front of the line.
    c) RR, different verb: The child noticed by the man was going to the front of the line.
    d) Main clause, different verb: The child noticed the man who was going to the front of the line.
2) Target Sentence (always RR): The boy pushed by the girl made a sexist remark.

Each participant saw each of the 48 item pairs only once, in one of the four conditions, and was exposed to each of the four conditions on 12 of the prime-target pairs. Prime sentence condition was counterbalanced across participants using four separate experimental lists (see Appendix for a full list of stimuli). Target sentences always immediately followed prime sentences, and two to three filler sentences intervened between pairs of primes and targets. There were 120 filler sentences in total, and these fillers were always either main clauses (60) or locatives with a by-phrase (60). This was done to balance out the experiment-wide distribution of structures: combining fillers and experimental sentences, there were 72 main clause, 72 reduced-relative clause, and 72 locative sentences in this experiment. The verbs that appeared in the filler sentences never appeared in the experimental sentences. It has been previously shown that implicit learning of structure occurs during priming studies of this nature, and that these learning effects may make the learned structure more predictable, thus making priming effects harder to detect (Fine, et al., 2013). By balancing out the distribution of structures within our experiment, we help to ensure that one of these structures is not more predictable on any given trial, bettering our chances of detecting possible priming effects.

Twelve verbs were chosen for the experimental target sentences that could take either the reduced-relative or locative structure (pushed, squeezed, stopped, shoved, moved, bumped, elbowed, skipped, raced, nudged, hustled, and hurried). Each of these 12 verbs appeared in four prime-target pairs (once in each of the four conditions). For same-verb conditions, the verb appeared twice within the prime-target pair, and for different-verb conditions, the verb appeared in the target sentence, with a novel verb appearing in the prime sentence.

The independent variable in this experiment was the prime sentence condition (which had four levels: Locative same verb, RRC same verb, RRC different verb, MC different verb). The dependent variables consisted of various reading measures (detailed in Experiment 1) collected via eye tracking during reading of the *target* sentences. As the set of target sentences remained the same for all participants, we can measure reading behavior associated with these sentences and then model whether this reading behavior differed based on the condition of the previous, prime sentence.

Apparatus/procedure

The eye-tracking methodology and procedure was identical to that used in Experiment 1.

Data analysis

Data from seven participants could not be used because (1) the researcher was unable to obtain and/or maintain an acceptable level of calibration, (2) the participant dropped out of the study before completing all trials, or (3) technical malfunction prevented data collection. All analyses are based on the remaining 58 participants. Data cleaning and trimming procedures were identical to those reported in Experiment 1. This trimming resulted in a loss of approximately 3% of the total data.

The same regions and measures used in Experiment 1 were used for Experiment 2. 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 regressions measure) (Baayen, Davidson, & Bates, 2008; Jaeger, 2008). The spillover region is of particular interest in this experiment because this is where the reduced-relative clause structure is disambiguated from the locative structure. Analyses were carried out in R (R Development Core Team, 2008) With the Prime Condition variable included as a fixed effect. This fixed effect was dummy-coded such that the (baseline) MC different verb condition was compared to the three different prime type conditions. 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 $\alpha = 0.05$ (test statistic value > 2).

Results and discussion

Figure 2 presents mean values of the four dependent measures by region and condition for the targets following main clause prime sentences that had a different verb than the target (the *baseline* condition), and for target sentences following each of the other prime types (locative-same verb, RR-different verb, and RR-same verb). Results from the multi-level models are presented in Table 2.

Verb region

Model results revealed a significant difference between the baseline (MC different verb) condition and the RR same verb condition in regression-path time and total time at the verb region (ps < 0.05). Participants spent less accumulated time fixating the verb region of the target sentence when the preceding prime sentence had the same initial verb and syntactic structure compared to when it had a different verb and structure.

By-phrase region

At the critical by-phrase region, there was a significant difference between the baseline condition and the RR same verb condition in both regression-path time and total fixation time (ps < 0.05). Participants spent significantly less accumulated time fixating the by-phrase region of the target sentences when those sentences were preceded by a sentence with the same verb and structure relative to when they were preceded by a main clause sentence with a different verb. There was also a significant difference in regression-path time for the comparison of the baseline condition and the locative condition ($p < 0.05$) at this region. Participants spent less time reading the by-phrase region of target sentences, before moving on to later parts of the sentence, when the prime sentence had the same verb and a by-phrase versus when it had a different verb and no by-phrase.

Spillover region

Model results revealed a significant difference between the baseline condition and the RR different verb condition in the total time measure of the spillover region ($p < 0.05$). A similar numeric trend in the total time measure (that did not reach statistical significance) was also present for the RR same verb condition. Participants in this study spent less time fixating the post by-phrase, spillover region of the reduced relative target sentences when the prime sentence also had a reduced-relative structure.

The post by-phrase, spillover region is the point at which the reduced-relative structure is disambiguated from the locative structure (that contains a *by* phrase). By this point in the sentence, the main clause interpretation has likely already been ruled out. Thus, it is informative to directly compare the processing of target sentences that were preceded by locative primes to targets that were preceded by reduced-relative

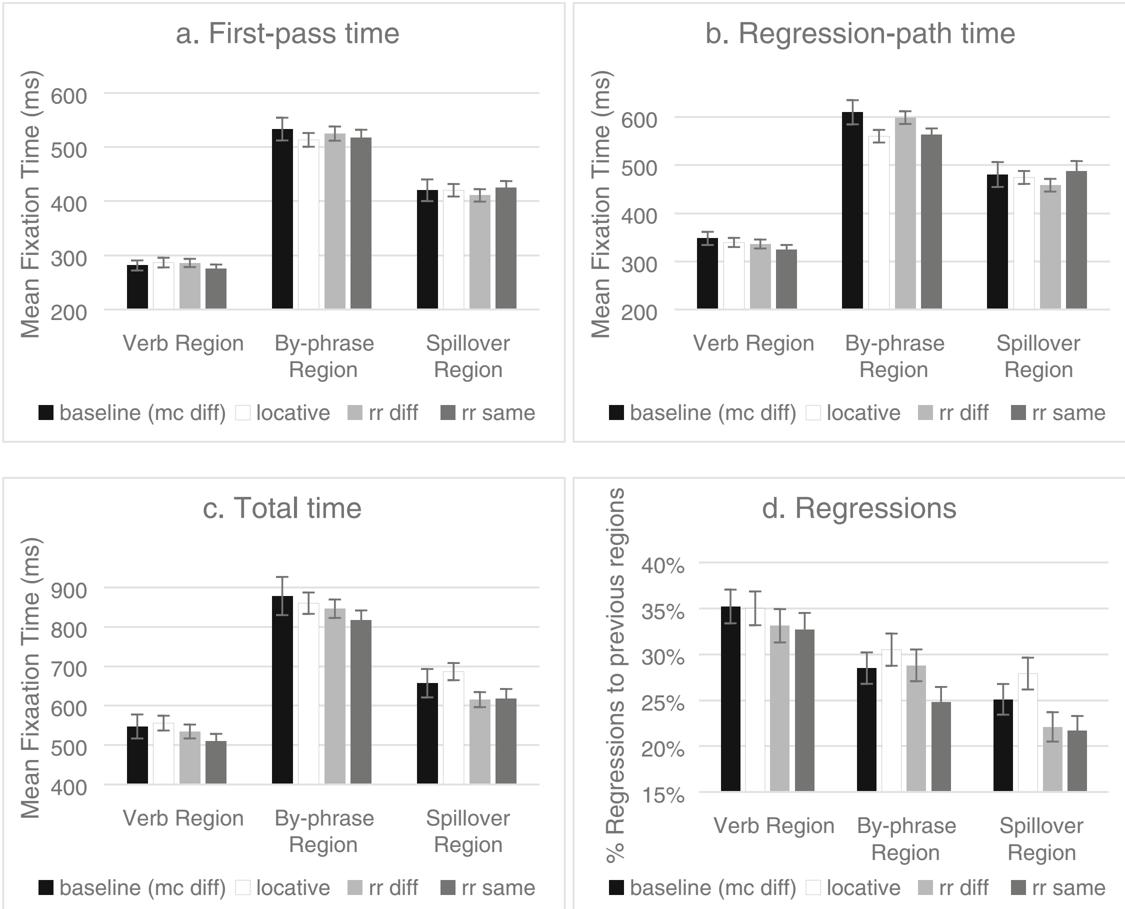

Fig. 2 Experiment 2 mean reading time measures (**a** first-pass time, **b** regression path time, **c** total time, and **d** regressions out) for the verb, by-phrase, and spillover (post by-phrase) regions. Error bars represent standard errors

primes. To accomplish this, additional models were run at the spillover region that contrasted (via dummy coding) the locative same verb condition to the RR same verb condition and to the RR different verb condition (see Table 3 for model output). These models revealed significant differences between the locative same verb condition and the RR same verb condition, and the locative same verb condition and the RR different verb condition in both total time and regressions to previous regions ($p < 0.05$). At the point in the reduced-relative target sentences where the this structure is disambiguated from the locative structure, participants spent less total time reading and were less likely to go back to an earlier part of the sentence when they had just read a sentence with a reduced-relative structure (regardless of verb overlap) compared to when they had just read a prime with a locative structure.

Comprehension question performance

Average accuracy on all comprehension questions was approximately 87%, indicating that participants were engaging in the task and reading for understanding. On average, participants correctly answered comprehension questions that followed the reduced-relative target sentences 78% of the time. This is well above chance (50%), but is consistent with the difficult nature of the reduced-relative structure. This accuracy varied little based on the condition of the prime that preceded the reduced-relative target sentence (MC = 77%, Locative = 78%, RR different verb = 79%, RR same verb = 79%).

The results from Experiment 2 indicate that processing a reduced-relative target sentence was facilitated when a previous prime sentence had the same verb and structure as the target. This finding is consistent with previous research investigating syntactic priming with lexical overlap using this structure (Ledoux, et al., 2007; Tooley et al., 2009; Tooley & Traxler, 2018). Facilitated processing of RRC targets was also observed when the prime sentence had the same RRC structure, but a different verb, though this facilitation was statistically reliable in fewer and later regions and time measures than in the RRC Same Verb condition. The more extensive priming effect when primes and targets had both lexical and structural overlap compared to when they had just structural overlap suggests that both lexically boosted and abstract syntactic priming effects were observed in this experiment.

Table 2 Analyses of the four eye-tracking dependent measures at each of the three sentence regions. The models include the fixed effects of the Prime Sentence Condition (dummy-coded to contrast the MC different verb baseline condition (Intercept) to the locative same verb, RR different verb, and RR same verb conditions). Modifications to the fully maximal random-effects structure (allowing for convergence) are reported for each model

Verb region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept (baseline)	280.6	9.3	30.3*	346.2	13.7	25.2*	542.7	30.5	17.8*	-0.71	0.14	-5.1*
Locative	4.7	8.9	0.5	-9.4	9.6	-0.99	6.2	18.8	0.3	-0.01	0.12	-0.12
RR different verb	4.6	7.7	0.6	-11.1	9.3	-1.2	-11.0	17.5	-0.6	-0.09	0.12	-0.78
RR same verb	-5.9	7.9	-0.8	-23.1	10.1	-2.3*	-36.3	18.2	-2.0*	-0.13	0.12	-1.08
Random effects	By-participant and by-item random intercepts; by-participant random slopes			By-participant and by-item random intercepts; by-participant random slopes			Fully Maximal (by-participant and by-item random intercepts and slopes)			By-participant and by-item random intercepts		
By-phrase region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept (baseline)	533.9	21.0	25.4*	610.6	25.1	24.4*	879.7	48.6	18.1*	-1.12	0.17	-6.8*
Locative	-21.0	12.7	-1.7	-51.4	13.2	-3.9*	-21.1	27.1	-0.8	0.13	0.13	0.99
RR different verb	-9.5	13.1	-0.7	-12.4	13.2	-0.9	-31.0	23.4	-1.3	0.04	0.13	0.32
RR same verb	-16.7	14.9	-1.1	-47.6	13.2	-3.6*	-61.3	24.5	-2.5*	-0.21	0.13	-1.61
Random effects	Fully Maximal (by-participant and by-item random intercepts and slopes)			By-participant and by-item random intercepts			Fully Maximal (by-participant and by-item random intercepts and slopes)			By-participant and by-item random intercepts		
Spillover region	First-pass time			Regression-path time			Total time			Regressions out		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	z-value
Intercept (baseline)	418.9	20.1	20.8*	478.8	25.8	18.6*	654.2	36.0	18.2*	-1.29	0.17	-7.71*
Locative	-2.1	11.6	-0.2	-8.6	13.4	-0.6	21.6	21.8	1.0	0.10	0.14	0.70
RR different verb	-10.6	11.5	-0.9	-24.1	13.3	-1.8	-44.6	19.1	-2.3*	-0.24	0.15	-1.63
RR same verb	4.8	12.0	0.4	10.0	20.7	0.5	-37.4	24.7	-1.5	-0.25	0.15	-1.63
Random effects	Fully Maximal (by-participant and by-item random intercepts and slopes)			Fully Maximal (by-participant and by-item random intercepts and slopes)			Fully Maximal (by-participant and by-item random intercepts and slopes)			By-participant and by-item random intercepts; by-participant random slopes		

Table 3 Analyses of the four eye-tracking dependent measures at the spillover region. The models include the fixed effects of the Prime Sentence Condition (dummy-coded to contrast the locative same verb condition (Intercept) to the RR different verb, and RR same verb conditions). The random-effects structure (allowing for convergence) is reported for each model

Spillover region	First-pass Time			Regression-path Time			Total Time			Regressions		
Fixed Effect	estimate	S.E.	t-value	estimate	S.E.	t-value	estimate	S.E.	t-value	Estimate	S.E.	z-value
Intercept (locative)	416.9	22.1	18.9*	470.3	25.1	18.8*	675.8	42.0	16.1*	-1.16	0.17	-6.81*
RR different verb	-8.8	11.2	-0.8	-15.4	13.6	-1.1	-66.2	21.5	-3.1*	-0.36	0.14	-2.64*
RR same verb	6.9	11.2	0.6	18.7	23.6	0.8	-59.0	24.6	-2.4*	-0.37	0.14	-2.72*
Random effects	By-participant and by-item random intercepts			Fully Maximal (by-participant and by-item random intercepts and slopes)			Fully Maximal (by-participant and by-item random intercepts and slopes)			By-participant and by-item random intercepts		

Results from this experiment therefore add to the growing body of studies that have observed trial-to-trial abstract priming effects in online measures of language comprehension (e.g., Thothathiri & Snedeker, 2008; Tooley & Bock, 2014; Traxler, 2008).

While the results from Experiment 2 do provide some evidence for facilitated processing of RRC targets following locative primes (with the same verb), this facilitation was restricted to earlier regions and time measures, before the RRC structure could be disambiguated from the locative structure. This means that the locative prime could have led participants to parse the target as another locative. If this was the case, then facilitated processing at the by-phrase would be expected (as was observed), but only in early processing measures (such as first-pass and regression-path time) because these do not reflect processing of information from regions after the by-phrase, where the two structures diverge. Indeed, once the target structure was disambiguated as an RRC rather than a locative, there was no observable facilitation in the Locative condition. In fact, the trend in fixation times and regressive eye movements was actually in the opposite direction (longer fixation times and more regressions), which is consistent with the idea that participants may have mis-parsed the RRC targets as locatives and had to revise their structural assumptions after the locative structure had been ruled out. Therefore, facilitated processing of the RRC structure only occurred for conditions where the prime and target shared the same structure (with or without lexical overlap). Together these results suggest that a locative prime sentence (with verb overlap and a following by-phrase) is not sufficient to produce facilitated processing of an RRC target structure.

The residual activation account and deep explicit memory account predict the lexical boost will only occur when the prime and target sentences share both a verb and structural representation. However, the shallow explicit memory account predicts lexically boosted priming will occur as long as there is a valid lexical cue to upcoming words in the target sentence. Finding significant lexically boosted syntactic priming for RRC primes, but not locative primes, is therefore much more consistent with an account that relies on a linkage between the repeated verb and the structure in which it recently appeared. In the case of the residual activation account, this comes from linked lexical and structural representations in long-term memory, whereas in the case of the deep explicit memory account, this comes from the temporary binding between the explicit memory trace for the repeated verb and the long-term memory representation for the structure in which it appeared. It is worth pointing out, however, that these results are not directly inconsistent with an error-driven learning account of the lexical boost. The error-driven learning account predicts that facilitation due to learning a structure and verb pairing would require that the prime processing experience include the same structure and verb pairing that is encountered in the target sentence. This is consistent with what was observed in Experiment 2, however not consistent with the results of Experiment 1, which support a non-learning-based mechanism.

General discussion

Results from two experiments suggest that the mechanism that produces the lexical boost is likely to be short lived and based on facilitation for a transient lexical and structural pairing- either in long-term memory (i.e., residual activation), or between explicit and long-term memory (i.e., deep explicit memory account). The first of these implications is consistent with findings from previous production studies that have shown the lexical boost does not persist across many intervening sentences (Hartsuiker et al., 2008; Mahowald et al., 2016). It is also consistent with recent comprehension studies that have shown the lexical boost does not accumulate with increased exposure (Fine & Jaeger, 2016; Tooley & Traxler, 2018), nor is it sensitive to differences in error-signals generated during prime processing (Tooley, Pickering, & Traxler, under review). The findings from Experiment 1 coupled with the existing literature therefore make an error-driven learning account of the lexical boost fairly untenable. A more parsimonious explanation is that while error-driven learning produces abstract priming effects, a more short-lived mechanism produces the lexical boost. This conclusion straightforwardly supports a dual-mechanism account of abstract and lexically boosted syntactic priming effects (e.g., Branigan & McLean, 2016; Hartsuiker et al., 2008; Tooley & Traxler, 2018).

The second implication from this study helps pare down which short-term mechanistic account of the lexical boost is currently most plausible. In Experiment 2, facilitated processing of the RRC structure was only observed when the prime also had an RRC structure. Notably, no target structural facilitation was observed when the prime and target shared a repeated verb and by-phrase, without also sharing a structural representation (i.e., the locative condition). These results suggest that the lexical boost does not primarily arise from shallow explicit memory cues relating to the specific wording of the prime sentence. Nor can the lexical boost in this experiment be attributed to repetition of the word *by*, or the by-phrase, as has been found for abstract priming effects in production (Ziegler et al., 2019). It is worth noting, however, that the current results are not inconsistent with the Ziegler et al. (2019) findings. In that study, structural priming arose from the repetition of the word *by* when it acted as the head of adjunct in both structures. That is not the case in the current study – the *by* phrase is part of a past participle in the RRC structure and a consequence of the particle verb in the locative structure. Therefore, our results actually bolster the Ziegler account in that they don't implicate structure-less function words leading to facilitation of abstract structure.

Instead, these results are more consistent with an account that suggests the lexical boost arises from lexically mediated access to a structural representation in long-term memory. This could be reflective of activation changes for coupled verb and structural representations in long-term memory, as in the residual activation account (Pickering & Branigan, 1998). While a residual activation account (à la Pickering and Branigan, 1998) has difficulty explaining persistent abstract priming effects, it is not inconsistent with the shorter time course of lexically boosted syntactic priming effects. However, the mechanism proposed in this model would need to be restricted to residual activation for the link between (or combination of) a verb node and structural/combinatorial node, rather than activation for an isolated combinatorial node. These results could also be reflective of a temporary binding between the explicit memory trace for the prime verb and it structural representation in long-term memory (e.g., Bock & Griffin, 2000; Chang, Dell, & Bock, 2006), as well as a similar account (Reitter et al., 2011) that suggests the words in the prime (stored in working memory) are temporarily linked to structural information (stored in long-term memory). The current findings do not directly support one of these accounts over another. Future research is therefore needed that can creatively contrast these competing accounts.

Of particular interest will be future research that can instantiate these different mechanistic possibilities in computational models, especially those that can model both the implicit learning mechanism (e.g., Chang et al., 2006) to account for abstract priming effects and the separate, short-lived mechanism to account for the lexical boost. Such dual-mechanism computational models would need to be able to account for findings in both production and comprehension. Currently, the Reitter et al. (2011) model only models production processes. Development and testing of these dual-mechanism models would allow researchers to model a wider range of the observed syntactic priming effects, both within and across studies, and may also generate additional predictions that can be tested empirically. Ideally, this would lead to refined mechanistic accounts of both abstract and lexically boosted priming effects, and more precise interpretation of these effects in relation to measures of grammatical learning/knowledge.

Beyond mechanistic accounts, conceptualizing the lexical boost as short lived and not a learning effect has important implications for interpreting studies that utilize these priming effects as indicators of syntactic learning/knowledge. For instance, some studies have attempted to use the lexical boost as a marker for learning new verb and structure regularities (e.g., Rowland, Chang, Ambridge, Pine, & Lieven, 2012). However, this rests on the assumption that the lexical boost reflects a learning mechanism for such pairings. If the lexical boost instead reflects short-term pairings of verb and structural information, it is not a good indicator of this sort of learning. On the other hand, investigations of the lexical boost likely would still be informative as to existing structural constraints represented for particular verbs (see Coyle & Kaschak, 2008; Thothathiri & Snedeker, 2008b). This consideration is relevant to studies of both children and adults, and should be applied to future studies that use syntactic priming paradigms (with lexical overlap) to investigate grammatical learning/knowledge.

Conclusions

The experiments reported here indicate that lexically boosted syntactic priming effects are most likely caused by a short-lived mechanism whereby linked verb and structural pairings bias target sentence processing. This type of facilitation likely does not reflect shallow explicit memory cues from the exact wording of the prime sentence. Importantly, the mechanism that produces the lexical boost is assumed to be qualitatively different from the error-based learning mechanism that produces abstract priming effects. Thus, a dual-mechanistic account of syntactic priming effects is implicated by the results of this study.

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Appendix: Experimental Stimuli

Experiment 1: Targets were preceded by one of three prime types (a. Main Clause (baseline) Prime: same verb; b. Long Prime: same verb and RRC structure, but with 4-7 additional words after post-by-phrase region; c. Short Prime: same verb and RRC structure) across experimental lists.

1. Target: The architect selected by the firm had years of experience.

   a. The group selected the speaker who gave a great presentation.
   b. The speaker selected by the group gave a great presentation at the conference.
   c. The speaker selected by the group gave a great presentation.

2. Target: The mouse watched by the cat ate some delicious cheese.

   a. The cop watched the junkie who walked very slowly down the empty street.
   b. The junkie watched by the cop walked very slowly down the empty street.
   c. The junkie watched by the cop walked very slowly.

3. Target: The singer loved by the fan married a movie star.

   a. The class loved the teacher who smiled a lot.
   b. The teacher loved by the class smiled a lot and was a great listener.
   c. The teacher loved by the class smiled a lot.

4. Target: The chef graded by the panel used lots of butter.

   a. The professor graded the student who received high marks.
   b. The student graded by the professor received high marks relative to the rest of his peers.
   c. The student graded by the professor received high marks.

5. Target: The secretary appreciated by the accountant kept things very organized.

   a. The principal appreciated the teacher who organized a fundraiser to support the new library.
   b. The teacher appreciated by the principal organized a fundraiser to support the new library.
   c. The teacher appreciated by the principal organized a fundraiser.

6. Target: The victim identified by the doctor was in bad shape.

   a. The driver identified the suspect who fled the scene before the police arrived.
   b. The suspect identified by the driver fled the scene before the police arrived.
   c. The suspect identified by the driver fled the scene.

7. Target: The governor excited by the liberals called a press conference.

   a. The politician excited the protestors who chanted loudly.
   b. The protesters excited by the politician chanted loudly and cheered when the speech was over.
   c. The protesters excited by the politician chanted loudly.

8. Target: A driver stopped by the policeman was drinking and driving.

   a. The lifeguard stopped the child who was running near the pool.
   b. The child stopped by the lifeguard was running near the side of the pool.
   c. The child stopped by the lifeguard was running.

9. Target: The consumer convinced by the salesman bought the new stove.

   a. The mayor convinced the voters who reelected him by a wide margin.
   b. The voters convinced by the mayor reelected him by a very wide margin.
   c. The voters convinced by the mayor reelected him.

10. Target: The passengers injured by the reckless driver needed medical attention.

   a. The Labrador injured the child who cried loudly for his mother.
   b. The child injured by the Labrador cried loudly and called for his mother.
   c. The child injured by the Labrador cried.

11. Target: The dog located by the hunter had an injured paw.

a. The scientist located the bird that was endangered.
b. The bird located by the scientist was endangered due to habitat destruction and poaching.
c. The bird located by the scientist was endangered.

12. Target: The man scolded by the security guard was heavily intoxicated.

a. The babysitter scolded the child who went to bed.
b. The child scolded by the babysitter went to bed early without having any dessert.
c. The child scolded by the babysitter went to bed.

13. Target: A spy caught by the FBI agent went to prison.

a. The detective caught the imposter who started to panic.
b. The imposter caught by the detective started to panic and asked to call his lawyer.
c. The imposter caught by the detective started to panic.

14. Target: The homeowner frightened by a loud noise called the police.

a. The coyote frightened a horse that galloped away.
b. A horse frightened by the coyote galloped away toward the safety of the barn.
c. A horse frightened by the coyote galloped away.

15. Target: The toddler fascinated by the parrot fed him many peanuts.

a. The monkey fascinated the girl who giggled as she played with him.
b. The girl fascinated by the monkey giggled as she played games with him.
c. The girl fascinated by the monkey giggled.

16. Target: The tutor offended by the delinquent refused to teach him.

a. The duke offended the countess who told her husband about the rude behavior.
b. The countess offended by the duke told her husband about the rude behavior.
c. The countess offended by the duke told her husband.

17. Target: The campers stalked by the cougar were in grave danger.

a. The owl stalked the chipmunk that scurried away under a large bush.
b. The chipmunk stalked by the owl scurried away and hid under a large bush.
c. The chipmunk stalked by the owl scurried away.

18. Target: The student helped by a counselor chose a new major.

a. The nurses helped the surgeons who operated all night.
b. The surgeons helped by the nurses operated all night on one critical patient.
c. The surgeons helped by the nurses operated all night.

19. Target: The man rescued by the sailor was wet and cold.

a. The paramedics rescued the miners who recovered slowly from their experience.
b. The miners rescued by the paramedics recovered slowly from their harrowing experience.
c. The miners rescued by the paramedics recovered slowly.

20. Target: The butler questioned by the widow lied about his actions.

a. The inspector questioned the carpenter who acted nervous.
b. The carpenter questioned by the inspector acted nervous and unsure about his answers.
c. The carpenter questioned by the inspector acted nervous.

21. Target: A child grabbed by the guard had wandered into traffic.

a. An eagle grabbed the mouse that squeaked and managed to squirm itself free.
b. The mouse grabbed by an eagle squeaked and managed to squirm itself free.
c. The mouse grabbed by an eagle squeaked.

22. Target: A hobo ignored by the conductor snuck aboard the train.

a. The salesman ignored the customers who were impatient.
b. The customers ignored by the salesman were impatient to the point of leaving the store.
c. The customers ignored by the salesman were impatient.

23. Target: The juror accused by the judge was held in contempt.

a. The supervisor accused the employee who got fired from his job.
b. The employee accused by the supervisor got fired from his job at the credit union.
c. The employee accused by the supervisor got fired.

24. Target: The king pleased by the jester pardoned the accused thief.

a. A puppy pleased the baby who stopped crying.
b. The baby pleased by a puppy stopped crying and reached out to touch it.
c. The baby pleased by a puppy stopped crying.

25. Target: A man astounded by the astronaut read his new book.

a. The magician astounded the woman who applauded after each trick.
b. The woman astounded by the magician applauded and whistled after each trick.
c. The woman astounded by the magician applauded.

26. Target: The monkey lifted by the trainer begged for a treat.

a. The elephant lifted the man who held on tightly.
b. The man lifted by the elephant held on tightly and yelled for someone to help him.
c. The man lifted by the elephant held on tightly.

27. Target: The woman shoved by the thief screamed for the police.

a. The referee shoved the player who missed the goal.
b. The player shoved by the referee missed the goal and the game ended in a tie.
c. The player shoved by the referee missed the goal.

28. Target: The girl pulled by her father begged to play longer.

a. Some playmates pulled the boy who struggled.
b. The boy pulled by some playmates struggled and asked them to leave him alone.
c. The boy pulled by some playmates struggled.

29. Target: The man rejected by the woman bought himself a drink.

a. The fraternity rejected the nerd who had no friends.
b. The nerd rejected by the fraternity had no friends to teach him the ropes.
c. The nerd rejected by the fraternity had no friends.

30. Target: The Girl Scout startled by the woman dropped her cookies.

a. The intruder startled the dog that barked and growled.
b. The dog startled by the intruder barked and gave a long, threatening growl.
c. The dog startled by the intruder barked.

31. Target: The pitcher replaced by the coach got the big win.

a. The director replaced the actor who filed a lawsuit.
b. The actor replaced by the director filed a lawsuit for unlawful termination.
c. The actor replaced by the director filed a lawsuit.

32. Target: The victim cheated by the insurance agency had medical bills.

a. The employer cheated the aide who lost his pay.
b. The aide cheated by the employer lost his pay and had to borrow money.
c. The aide cheated by the employer lost his pay.

33. Target: The pupil praised by the academic counselor studied extra hard.

a. The scout praised the player who received a scholarship.
b. The player praised by the scout received a scholarship for tuition, room, and board.
c. The player praised by the scout received a scholarship.

34. Target: The woman tired by the children needed a short break.

a. The coach tired the swimmer who hated the backstroke.
b. The swimmer tired by the coach hated the backstroke and long training sessions.
c. The swimmer tired by the coach hated the backstroke.

35. Target: The policeman fooled by the suspect released him from custody.

a. The deejay fooled the contestant who received no prize.
b. The contestant fooled by the deejay received no prize for calling into the radio show.
c. The contestant fooled by the deejay received no prize.

36. Target: A first-grader skipped by the bus driver walked to school.

a. The stewardess skipped the passenger who got no peanuts.
b. The passenger skipped by the stewardess got no peanuts or an in-flight beverage.
c. The passenger skipped by the stewardess got no peanuts.

Experiment 2: Targets were preceded by one of four prime types (a. Locative Prime: same verb and by-phrase wording, but different structure; b. RRC Same Verb Prime: same verb and structure; c. RRC Different Verb Prime: different verb but same structure; d. MC Baseline Prime: different verb and structure) across experimental lists.

1. Target: The secretary pushed by the burglar called for help.

    a. The girl pushed by the man to get to the front of the line.
    b. The girl pushed by the man was going to the front of the line.
    c. The girl noticed by the man was going to the front of the line.
    d. The girl noticed the man who was going to the front of the line.

2. Target: The child pushed by the dog cried for his parents.

    a. The sheriff pushed by the bystanders to get a look at the crime scene.
    b. The sheriff pushed by the bystanders tried to get a look at the crime scene.
    c. The sheriff blocked by the bystanders tried to get a look at the crime scene.
    d. The sheriff blocked the bystanders who tried to get a look at the crime scene.

3. Target: A boy pushed by a bully decided to transfer schools.

    a. The president pushed by the aid in order to talk to the reporters.
    b. The president pushed by the aid was trying to talk to the reporters.
    c. The president appreciated by the aide was trying to talk to the reporters.
    d. The president appreciated the aide who was trying to talk to the reporters.

4. Target: A comic pushed by the audience member told many offensive jokes.

    a. The teller pushed by the manager so that he could get to his desk.
    b. The teller pushed by the manager was trying to get to his desk.
    c. The teller insulted by the manager was trying to get to his desk.
    d. The teller insulted the manager who was trying to get to his desk.

5. Target: The girl squeezed by the relative was shy of strangers.

    a. The messenger squeezed by the security guard to deliver a letter.
    b. The messenger squeezed by the security guard was trying to deliver a letter.
    c. The messenger approached by the security guard was trying to deliver a letter.
    d. The messenger approached the security guard who was trying to deliver a letter.

6. Target: The lifeguard squeezed by the child was trying to get her to safety.

    a. A runner squeezed by the official on his way to the starting line.
    b. A runner squeezed by the official was on his way to the starting line.
    c. A runner questioned by the official was on his way to the starting line.
    d. A runner questioned the official who was on his way to the starting line.

7. Target: The boy squeezed by his parents was not excited to attend summer camp.

    a. The lady squeezed by the border agent to get back to her car.
    b. The lady squeezed by the border agent was trying to get back to her car.
    c. The lady insulted by the border agent was trying to get back to her car.
    d. The lady insulted the border agent who was trying to get back to her car.

8. Target: A boy squeezed by the teacher was not paying attention in class.

    a. The teenager squeezed by the performers when heading backstage.
    b. The teenager squeezed by the performers was heading backstage.
    c. The teenager disliked by the performers was heading backstage.
    d. The teenager disliked the performers who were heading backstage.

9. Target: The man stopped by the sheriff was driving faster than the speed limit.

   a. The student stopped by the class to pick up her belongings.
   b. The student stopped by the class was going to pick up her belongings.
   c. The student appreciated by the class was going to pick up her belongings.
   d. The student appreciated the class who were going to pick up her belongings.

10. Target: A woman stopped by the salesman was trying to shoplift.

   a. The waitress stopped by the table to clear some dirty plates.
   b. The waitress stopped by the table needed to clear some dirty plates.
   c. The waitress questioned by the table needed to clear some dirty plates.
   d. The waitress questioned the table about the need to clear some dirty plates.

11. Target: The driver stopped by the cyclist was asked to provide help.

   a. A deliveryman stopped by the shop on his way to make a delivery.
   b. A deliveryman stopped by the shop was on his way to make a delivery.
   c. A deliveryman noticed by the shop was on his way to make a delivery.
   d. A deliveryman noticed the shop while on his way to make a delivery.

12. Target: An astronaut stopped by the engineer needing briefing on the mission.

   a. The farmer stopped by the wholesaler to pick up some pig feed.
   b. The farmer stopped by the wholesaler was picking up some pig feed.
   c. The farmer challenged by the wholesaler was picking up some pig feed.
   d. The farmer challenged the wholesaler who was picking up some pig feed.

13. Target: The lady shoved by the officer filed a complaint at the station.

   a. A man shoved by the protestor to get inside the building.
   b. A man shoved by the protestor was trying to get inside the building.
   c. A man insulted by the protestor was trying to get inside the building.
   d. A man insulted the protestor who was trying to get inside the building.

14. Target: A waiter shoved by the manager was three hours late for his shift.

   a. The patient shoved by the doctor on her way to get a drink of water.
   b. The patient shoved by the doctor was on her way to get a drink of water.
   c. The patient disliked by the doctor was on her way to get a drink of water.
   d. The patient disliked the doctor who was on her way to get a drink of water.

15. Target: The prince shoved by the peasant was not liked by commoners.

   a. Someone shoved by the bouncer so they could steal the guest list.
   b. Someone shoved by the bouncer was trying to steal the guest list.
   c. Someone approached by the bouncer was trying to steal the guest list.
   d. Someone approached the bouncer who was trying to steal the guest list.

16. Target: A girl shoved by her mother was standing in the way of traffic.

   a. A man shoved by the guard to get a picture of the famous artist.
   b. A man shoved by the guard was taking a picture of the famous artist.
   c. A man approached by the guard was taking a picture of the famous artist.
   d. A man approached the guard who was taking a picture of the famous artist.

17. Target: The toddler moved by the babysitter was covered in sand.

   a. The waitress moved by the patrons to grab the stack of menus.
   b. The waitress moved by the patrons grabbed the stack of menus.
   c. The waitress questioned by the patrons grabbed the stack of menus.

d. The waitress questioned the patrons who grabbed the stack on menus.

18. Target: The juggler moved by the clown dropped his balls.

a. A cook moved by the patron when heading through the kitchen entrance.
b. A cook moved by the patron was heading through the kitchen entrance.
c. A cook observed by the patron was heading through the kitchen entrance.
d. A cook observed the patron who was heading through the kitchen entrance.

19. Target: A kitten moved by the cat was getting too far from the rest of the litter.

a. The violinist moved by the cellist to get to her seat.
b. The violinist moved by the cellist lost her seat.
c. The violinist approached by the cellist lost her seat.
d. The violinist approached the cellist who lost her seat.

20. Target: The car moved by the truck had broken down on the highway.

a. The pigeon moved by the old man to get to the breadcrumbs.
b. The pigeon moved by the old man wanted to get to the breadcrumbs.
c. The pigeon delayed by the old man wanted to get to the breadcrumbs.
d. The pigeon delayed the old man who wanted to toss the breadcrumbs.

21. Target: A spectator bumped by the performer was very embarrassed.

a. The stewardess bumped by the passenger to get to the restroom.
b. The stewardess bumped by the passenger was going to the restroom.
c. The stewardess blocked by the passenger was going to the restroom.
d. The stewardess blocked the passenger who was going to the restroom.

22. Target: A sparrow bumped by the crow flew away in fright.

a. The donkey bumped by the horse on his way to the water trough.
b. The donkey bumped by the horse was on his way to the water trough.
c. The donkey delayed by the horse was on his way to the water trough.
d. The donkey delayed the horse that was on his way to the water trough.

23. Target: The father bumped by the dog almost dropped the baby.

a. The welder bumped by the machinist to get to the lunch table.
b. The welder bumped by the machinist wanted to get to the lunch table.
c. The welder dismissed by the machinist wanted to get to the lunch table.
d. The welder dismissed the machinist who wanted to get to the lunch table.

24. Target: The ship bumped by the whale began to sway back and forth.

a. A squirrel bumped by the bird to get the seeds from the birdfeeder.
b. A squirrel bumped by the bird wanted to get the seeds from the birdfeeder.
c. A squirrel watched by the bird wanted to get the seeds from the birdfeeder.
d. A squirrel watched the bird that wanted to get the seeds from the birdfeeder.

25. Target: The chef elbowed by the busboy had a black eye for a week.

a. The fan elbowed by the bouncer to meet the star in person.
b. The fan elbowed by the bouncer wanted to meet the star in person.
c. The fan watched by the bouncer wanted to meet the star in person.
d. The fan watched the bouncer who wanted to meet the star in person.

26. Target: The swimmer elbowed by the opponent was not able to win the race.

a. The teacher elbowed by the parents in order to get to her classroom.
b. The teacher elbowed by the parents was trying to get to her classroom.
c. The teacher noticed by the parents was trying to get to her classroom.
d. The teacher noticed the parents who were trying to get to her classroom.

27. Target: The hiker elbowed by the guide was standing in a dangerous spot.

    a. A contestant elbowed by an audience member on her way to the stage.
    b. A contestant elbowed by an audience member was on her way to the stage.
    c. A contestant challenged by an audience member was on her way to the stage.
    d. A contestant challenged an audience member who was on her way to the stage.

28. Target: A man elbowed by a thug was unable to call for help.

    a. The singer elbowed by the band to get to the stage door.
    b. The singer elbowed by the band was heading to the stage door.
    c. The singer dismissed by the band was heading to the stage door.
    d. The singer dismissed the band that was heading to the stage door.

29. Target: A woman skipped by the attendant did not pay for her entry into the park.

    a. A boy skipped by the teacher on his way to the water fountain.
    b. A boy skipped by the teacher lost his turn at the water fountain.
    c. A boy disliked by the teacher lost his turn at the water fountain.
    d. A boy disliked the teacher who took his turn at the water fountain.

30. Target: A winner skipped by the announcer did not know about her prize.

    a. The patient skipped by the nurse because she did not want a drink.
    b. The patient skipped by the nurse did not receive a drink.
    c. The patient watched by the nurse did not receive a drink.
    d. The patient watched the nurse who did not receive a drink.

31. Target: A worker skipped by the foreman never got his paycheck.

    a. The girl skipped by group so she could get to the new playground.
    b. The girl skipped by the group was going to the new playground.
    c. The girl approached by the group was going to the new playground.
    d. The girl approached the group who was going to the new playground.

32. Target: The miner skipped by the paramedic was already starting to recover.

    a. A model skipped by the photographer on her way to the catwalk.
    b. A model skipped by the photographer was on her way to the catwalk.
    c. A model appreciated by the photographer was on her way to the catwalk.
    d. A model appreciated the photographer who was on her way to the catwalk.

33. Target: The sedan raced by the motorcycle lost by half a mile.

    a. The team raced by the coach to get to the mile marker first.
    b. The team raced by the coach got to the mile marker first.
    c. The team challenged by the coach got to the mile marker first.
    d. The team challenged the coach who got to the mile marker first.

34. Target: The teenager raced by the quarterback got out to an early lead.

    a. The pony raced by the Labrador and continued down the field.
    b. The pony raced by the Labrador was heading down the field.
    c. The pony blocked by the Labrador was heading down the field.
    d. The pony blocked the Labrador that was heading down the field.

35. Target: The pitcher raced by the catcher got to home plate first.

    a. The niece raced by the uncle and went running into the house.
    b. The niece raced by the uncle went running into the house.
    c. The niece insulted by the uncle went running into the house.

d. The niece insulted the uncle who went running into the house.

36. Target: The sprinter raced by the marathoner did not have the stamina to win.

a. A paramedic raced by a nurse to get to the person in need.
b. A paramedic raced by a nurse got to the person in need.
c. A paramedic observed by a nurse got to the person in need.
d. A paramedic observed a nurse who got to the person in need.

37. Target: The boy nudged by the classmate had fallen asleep during the lecture.

a. The cashier nudged by the customer on his way to the checkout stand.
b. The cashier nudged by the customer was on his way to the checkout stand.
c. The cashier observed by the customer was on his way to the checkout stand.
d. The cashier observed the customer who was on his way to the checkout stand.

38. Target: A man nudged by the security guard was trespassing in a restricted area.

a. The pedestrian nudged by the dog-walker to cross the street.
b. The pedestrian nudged by the dog-walker crossed the street.
c. The pedestrian questioned by the dog-walker crossed the street.
d. The pedestrian questioned the dog-walker who crossed the street.

39. Target: A vagrant nudged by the officer was being arrested for loitering.

a. The girl nudged by the adults to get more cookies from the tray.
b. The girl nudged by the adults wanted more cookies from the tray.
c. The girl noticed by the adults wanted more cookies from the tray.
d. The girl noticed the adults who wanted more cookies from the tray.

40. Target: The snorkeler nudged by the turtle swam away quickly.

a. A solicitor nudged by the woman in order to demonstrate his product.
b. A solicitor nudged by the woman wanted to demonstrate his product.
c. A solicitor dismissed by the woman wanted to demonstrate his product.
d. A solicitor dismissed the woman who wanted him to demonstrate his product.

41. Target: The senior hustled by the salesman impulsively decided to buy the product.

a. An actor hustled by the director to get to the audition on time.
b. An actor hustled by the director did not get to the audition on time.
c. An actor delayed by the director did not get to the audition on time.
d. An actor delayed the director who did not get to the audition on time.

42. Target: The man hustled by the trainer wanted to get faster and stronger.

a. A solider hustled by the commander so he could complete the ropes course.
b. A solider hustled by the commander was trying to complete the ropes course.
c. A solider disliked by the commander was trying to complete the ropes course.
d. A solider disliked the commander who was trying to complete the ropes course.

43. Target: The knight hustled by the princess was needed to slay a dragon.

a. A player hustled by the coaches to take his position on the field.
b. A player hustled by the coaches took his position on the field.
c. A player appreciated by the coaches took his position on the field.
d. A player appreciated the coaches who saved his position on the field.

44. Target: The technician hustled by the event planner was in charge of the sound system.

a. An American hustled by the federal agent to get in the customs line.
b. An American hustled by the federal agent was getting in the customs line.

c. An American blocked by the federal agent was getting in the customs line.
d. An American blocked the federal agent who was getting in the customs line.

45. Target: A child hurried by the counselor was taking too long to decide.

a. An architect hurried by the client to avoid telling her the design was flawed.
b. An architect hurried by the client was telling her why the design was flawed.
c. An architect dismissed by the client was telling her why the design was flawed.
d. An architect dismissed the client who was telling her why the design was flawed.

46. Target: A boy hurried by the teacher was running late for lunch.

a. The speaker hurried by the students so that he could avoid questioning.
b. The speaker hurried by the students wanted to avoid questioning.
c. The speaker delayed by the students wanted to avoid questioning.
d. The speaker delayed the students who wanted to avoid questioning.

47. Target: The driver hurried by the passenger would be too late to see the movie.

a. A shopper hurried by the owner because he was in the store past closing.
b. A shopper hurried by the owner was in the store past closing.
c. A shopper watched by the owner was in the store past closing.
d. A shopper watched the owner who was in the store past closing.

48. Target: A performer hurried by the manager was late for another performance.

a. The attendant hurried by the passengers to check on an emergency.
b. The attendant hurried by the passengers went to check on an emergency.
c. The attendant challenged by the passengers went to check on an emergency.
d. The attendant challenged the passengers who went to check on an emergency.

References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of memory and language*, *59*(4), 390-412.

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

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

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

Branigan, H. P., & McLean, J. F. (2016). What children learn from adults' utterances: An ephemeral lexical boost and persistent syntactic priming in adult–child dialogue. *Journal of Memory and Language, 91*, 141-157.

Branigan, H. P., & Pickering, M. J. (2017). An experimental approach to linguistic representation. *Behavioral and Brain Sciences*, *1-61*.

Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic co-ordination in dialogue. *Cognition*, *75*(2), B13-B25.

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*(5), 259-278.

Coyle, J. M., & Kaschak, M. P. (2008). Patterns of experience with verbs affect long-term cumulative structural priming. *Psychonomic Bulletin & Review*, *15*(5), 967-970.

Ferreira, F., Bailey, K. G., & Ferraro, V. (2002). Good-enough representations in language comprehension. *Current Directions in Psychological Science*, *11*(1), 11-15.

Ferreira, V. S., & Bock, K. (2006). The functions of structural priming. *Language and Cognitive Processes*, *21*(7-8), 1011-1029.

Fine, A. B., & Jaeger, T. F. (2013). Evidence for implicit learning in syntactic comprehension. *Cognitive Science*, *37*, 578-591.

Fine, A. B., & Jaeger, T. F. (2016). The role of verb repetition in cumulative structural priming in comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(9), 1362-1376.

Fine, A. B., Jaeger, T. F., Farmer, T. A., & Qian, T. (2013). Rapid expectation adaptation during syntactic comprehension. *PloS one*, *8*(10), e77661.

Fraundorf, S. H., & Jaeger, T. F. (2016). Readers generalize adaptation to newly encountered dialectal structures to other unfamiliar structures. *Journal of Memory and Language, 91*, 28-58.

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.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*(4), 434-446.

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.

Kaschak, M. P., & Glenberg, A. M. (2004). This construction needs learned. *Journal of Experimental Psychology: General*, *133*(3), 450-467.

Kaschak, M. P., Kutta, T. J., & Jones, J. L. (2011). Structural priming as implicit learning: Cumulative priming effects and individual differences. *Psychonomic Bulletin & Review*, *18*, 1133-1139.

Ledoux, K., Traxler, M, & Swaab, T.Y. (2007). Syntactic Priming in Comprehension: Evidence from Event-Related Potentials. *Psychological Science, 18,* 135-143.

Levelt, W. J. (1993). Lexical access in speech production. In *Knowledge and Language* (pp. 241-251). Springer, Dordrecht.

Mahowald, K., James, A., Futrell, R., & Gibson, E. (2016). A meta-analysis of syntactic priming in language production. *Journal of Memory and Language, 91*, 5-27.

Malhotra, G., Pickering, M., Branigan, H., & Bednar, J. A. (2008). On the persistence of structural priming: Mechanisms of decay and influence of word-forms. *Proceedings of the Annual Meeting of the Cognitive Science Society,* pp. (657-662). Cognitive Science Society.

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*, 890-897.

Potter, M. C., & Lombardi, L. (1990). Regeneration in the short-term recall of sentences. *Journal of Memory and Language*, *29*(6), 633-654.

R Development Core Team. (2008). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from www.R-project.org

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

Rowland, C. F., Chang, F., Ambridge, B., Pine, J. M., & Lieven, E. V. (2012). The development of abstract syntax: Evidence from structural priming and the lexical boost. *Cognition*, *125*(1), 49-63.

Segaert, K., Kempen, G., Petersson, K. M., & Hagoort, P. (2013). Syntactic priming and the lexical boost effect during sentence production and sentence comprehension: An fMRI study. *Brain and language*, *124*(2), 174-183.

Thothathiri, M., & Snedeker, J. (2008). Give and take: Syntactic priming during spoken language comprehension. *Cognition, 108*(1), 51-68.

Thothathiri, M., & Snedeker, J. (2008b). Syntactic priming during language comprehension in three-and four-year-old children. *Journal of Memory and Language*, *58*(2), 188-213.

Tooley, K. M., & Bock, K. (2014). On the parity of structural persistence in language production and comprehension. *Cognition*, *132*(2), 101-136.

Tooley, K.M., Pickering, M.J., & Traxler, M.J. (manuscript under review). Lexically mediated syntactic priming effects in comprehension: Sources of facilitation.

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*, 289-311.

Tooley, K. M., & Traxler, M. J. (2010). Syntactic priming effects in comprehension: A critical review. *Language and Linguistics Compass*, *4*(10), 925-937.

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., 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. (2008). Lexically independent syntactic priming of adjunct relations in on-line sentence comprehension. *Psychonomic Bulletin and Review, 15*, 149-155.

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.

Ziegler, J., Bencini, G., Goldberg, A., & Snedeker, J. (2019). How abstract is syntax? Evidence from structural priming. *Cognition*, *193*, 104045.

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