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The head or the verb: Is the lexical boost restricted to the head verb?

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ABSTRACT

Four structural priming experiments investigated whether the lexical boost is due to the repeated head verb of the primed structure or due to the repetition of any verb, testing structural priming of ditransitive structures (*The hotel owner decided to loan the tourist a tent/a tent to the tourist*). In Experiments 1–3, we manipulated the repetition of the matrix verb (*decided*) that is not the syntactic head in the primed structure. The results showed abstract structural priming of the embedded ditransitive structure but the repetition of the matrix verb did not boost the priming. In addition to manipulating the repetition of the matrix verb, we also manipulated the head verb of the primed structure (*loan*) in Experiment 4. It showed a lexical boost with the repetition of the head verb but no boost with the repetition of the matrix verb. These results are consistent with the residual activation model, which only predicts a boost from the verb that is the head of the primed structure. They do not support models which predict that the repetition of any lexical material in a sentence boosts priming.

Introduction

Language use is said to be creative. Almost all the time when people want to express an idea, they can create a sentence they have never used before; languages enable speakers to construct a large number of different sentences that can be used to express almost any idea (Lyons, 1977). Yet, spontaneous language use in natural settings tends to be highly repetitive. In discourse like everyday conversations, the contributions that the interlocutors make refer to the topic of the conversation. The choice of a topic brings along lexical items that are central to it and speakers often keep repeating these items a number of times (e.g., Asher & Lascarides, 2003; Brennan & Clark, 1996). But speakers do not just repeat words that are central to the topic, they also adopt each other's way of talking about these items (Pickering & Garrod, 2004). This paralleling involves the use of each other's sentence structures. People's tendency to reuse sentence structures with or without repeated lexical items, termed *structural priming*, has been found both in corpus studies of natural discourse and in experimental settings. It has been found in different languages, in children, in non-native speakers and even in speakers suffering from amnesia and aphasia (see Branigan & Pickering, 2017; Pickering & Ferreira, 2008, for reviews).

The use of priming to study syntactic representations was first introduced by Bock (1986). She demonstrated this reuse of sentence structures in a study in which participants first repeated aloud prime

sentences and then described pictures that were lexically unrelated to the prime sentences. Numerous studies (see Pickering & Ferreira, 2008, for a review) have since used structural priming to study different aspects of language production. For example, participants have been found to repeat the voice of the prime sentence (active vs passive), to choose the same verb phrase in ditransitive constructions as in the prime (*The boy gave the girl a card vs The boy gave a card to the girl*), and to assign an antecedent to an ambiguous relative clause (high vs low attachment for *who* in *Someone shot the servant of the actress who was on the balcony*) in the same way as in the prime sentence (e.g., Bock, 1986; Bock & Loebell, 1990; Pickering & Branigan, 1998; Scheepers, 2003).

One important finding from priming studies has been that structural priming from the prime sentence to the target sentence is enhanced if something of the lexical content from the prime is repeated in the target; a phenomenon termed *the lexical boost* (e.g., Arai et al., 2007; Carminati et al., 2019; Cleland & Pickering, 2003; Hartsuiker et al., 2008; Pickering & Branigan, 1998; Scheepers et al., 2017; Van Gompel et al., 2012). This has also been found in corpus-based studies of naturally occurring discourse (e.g., Gries, 2005; Reitter et al., 2011). In experimental studies, the enhanced priming effect, the lexical boost, has been particularly strong when the verb that is the head of the primed structure was repeated in the target. This seems to suggest that abstract syntactic frames are associated with verbs. The models that have been introduced to explain structural priming differ in their assumptions of

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what causes the priming effect. Most notably, they differ in whether the lexical boost is part of the priming effect and associated with the head verbs or whether abstract structural priming and the lexical boost are separate processes. In the current study, we specifically investigated whether the lexical boost is associated with the repeated head verb of the primed structure or whether structural priming is lexically boosted by any repeated verb.

According to the model of Pickering and Branigan (1998), the enhanced priming effect, the lexical boost, is associated with the repetition of the syntactic head of the primed structure. In their sentence completion study, Pickering and Branigan used ditransitive verbs such as *give* that can be used with two different structures that express the same semantic content; a double object structure (DO) with an agent and two subsequent objects (*The boy gave the girl a card*) expressing the recipient (*the girl*) and the theme (*a card*) or a prepositional object structure (PO) with an agent, an object and a prepositional phrase (*The boy gave a card to the girl*) expressing the same semantic roles of the theme and the recipient. They showed that participants were more likely to complete a target fragment (e.g., *The bus driver gave ...*) with a DO structure if the prime had a DO structure than if it had a PO structure and more often with a PO structure if the prime had a PO than if it had a DO structure. When the verb from the prime was repeated in the target, the priming effect was larger, indicating a lexical boost effect.

Pickering and Branigan (1998) explained their results using a *residual activation model*. The model consists of two types of nodes. Lemma nodes that are the lexical items and so-called combinatorial nodes that encode the syntactic structure associated with the lemmas. When a syntactic structure in a prime is comprehended or produced, the lexical items in it are activated in the language users' mental lexicon. The processing of the prime structure also activates the argument structure that is connected to the verb. For example, the lemma node of *give* is connected both to a combinatorial node that encodes a DO structure and a combinatorial node that encodes a PO structure. These syntactic structures are linked to but separated from the meaning representation of the verb itself. These combinatorial nodes do not contain any lexical information and are shared with other verbs (e.g., *lend*, *show*, *sell*) that are the syntactic head of the same alternating DO and PO structures (e.g., *The bus driver lent the tourist a map/The bus driver lent a map to the tourist*). When the participants in Pickering and Branigan's study completed a target fragment after they had completed a prime structure with a DO structure (e.g., *The captain gave the old sailor the life jacket*), the DO-structure that was activated in the prime is assumed to retain some residual activation in the combinatorial node and this lingering activation then prompted the participants to use a DO in the target (e.g., *The bus driver lent the tourist a map*) more often than after a PO prime. When the verb from the prime was repeated in the target fragment, the participants were even more likely to repeat the structure that was used in the prime. According to Pickering and Branigan's model, this lexical boost comes from residual activation of both the combinatorial node and the link between the combinatorial node and the verb lemma.

A different kind of explanation to structural priming and the lexical boost is given in the *implicit learning account* of Chang et al. (2006, 2012). According to this account, structural priming is due to implicit learning. The same mechanisms that are involved in the acquisition of new grammatical structures in language learning are also responsible for the priming of previously learnt structures. When encountering a sentence structure, language users learn the mapping between it and the conceptual representation it expresses and adjust their syntactic production system to that particular structure. Next time when a similar message needs to be expressed, the corresponding syntactic structure is more readily available than alternative structures. The learning account predicts a long-term priming effect. While structural priming is due to long-lasting implicit learning in the model, the lexical boost effect is seen to be fundamentally different from abstract structural priming. The lexical boost is transient, due to an explicit short-term memory trace of the repeated word and the structure in which it occurred in the prime.

Explicit memory of the prime structure should be triggered by the repetition of any content word, not just by a syntactic head such as the ditransitive verb in the structure. A similar claim that structural priming is a form of learning is made by Reitter et al. (2011). In their model, structural priming emerges from two learning mechanisms; base-level learning of individual syntactic structures and spreading activation between these syntactic representations and lexical material. Abstract structural priming is due to the base-level learning, whereas the lexical boost effect is caused by both mechanisms; the association between the syntactic structure and the lexical items is temporarily increased leading to a short-term enhanced priming effect whenever a lexical item is repeated. Both the implicit learning account by Chang et al. and the learning model by Reitter et al. predict a lexical boost whenever lexical material that is meaningful for the contents in the prime, whether it is a head or not, is repeated in the target. This contrasts with the residual activation model by Pickering and Branigan (1998), in which priming is only assumed to increase when a verb that is the head of the primed structure (the combinatorial node that the verb is associated with) is repeated.

While abstract structural priming has frequently been demonstrated between sentences that have nothing else in common except the phrasal structure, the experimental demonstrations of the lexical boost, although numerous, have been less clear about what causes it. The earliest findings of the lexical boost (e.g., Branigan et al., 2000; Corley & Scheepers, 2002; Pickering & Branigan, 1998) come from studies that used ditransitive constructions and head verb repetitions. These studies and many to follow them (see Mahowald et al., 2016, for a metastudy of syntactic priming) are consistent with the residual activation theory (Pickering & Branigan, 1998). In the residual activation account, the connection between the lemma of the recently activated verb and its combinatorial node linked to the structure (e.g., DO or PO) that was used in the prime, retains activation and this activation makes the connection more accessible for the production system and increases the priming effect in comparison to when the verb is not repeated. However, these findings can also be explained by models that assume that the lexical boost occurs with the repetition of any lexical item.

At present, there are only a few studies that have directly tested the claim that the source of the lexical boost is the repetition of the head of the primed structure rather than the repetition of any lexical item. Previous studies have shown no enhanced priming when closed-class words such as prepositions and relative pronouns were repeated (Bock, 1989; Ferreira, 2003; Pickering & Branigan, 1998). Priming was also unaffected by the repetition of functional morphemes such as tense and number inflections or the aspect (*was showing vs showed*) in the verbs (Pickering & Branigan, 1998). Cleland and Pickering (2003) showed structural priming of noun phrases with either a pre-nominal modifier in the noun phrase (*a red book*) or a relative clause as a post-nominal modifier in the noun phrase (*a book that's red*). The tendency to repeat the prime structures increased when the head noun (e.g., *the book*) was repeated in the target. The repetition of the modifier (e.g., *red*) with a different head noun, on the other hand, did not lead to a lexical boost. This finding suggests that the lexical boost is associated with the syntactic head in phrase structures; verbs in verb phrases and nouns in noun phrases. This is consistent with Pickering and Branigan's (1998) residual activation model, in which combinatorial nodes are linked to their syntactic head but not to other words in the sentence but does not fit well with models that assume that the repetition of any content word causes a lexical boost.

On the other hand, McLean et al. (2004) found lexical boosts in a series of experiments where they repeated argument nouns (the theme and the recipient) in ditransitive DO and PO constructions. When they manipulated the number of repeated argument nouns in the target, they found an extensive boost when all three argument nouns (agent, theme, recipient) from the prime were repeated compared to when none of the arguments were repeated in the target. But the repetition manipulations in the study were between experiments, which could have affected the

results. Participants might adopt different strategies if they notice that some words are frequently repeated. Furthermore, McLean et al. did not report any statistical comparisons between the experiments and they did not repeat the head verbs, which might have offered a useful comparison to the argument nouns.

By and large, the key finding in most experimental studies has been that priming is boosted by verb repetition (Mahowald et al., 2016). This view that only the repetition of the head verb boosts structural priming was challenged in Scheepers et al.'s study (2017) of head and non-head priming. Their participants first read a prime sentence with a DO or PO structure (e.g., *The cardinal gave the jury the envelope/the envelope to the jury*) and were then asked to construct a sentence using words from an array of content words where one of the words was marked as the first word in the sentence to be created. Scheepers et al. repeated either the agent (*cardinal*), the verb (*gave*), the recipient (*jury*) or the theme (*envelope*) in different conditions in addition to a condition where none of the lexical items were repeated in the array. They found lexical boosts from the repeated agent, the verb and the recipient whereas the boost was not quite significant from a repeated theme. According to Scheepers et al., these results showed that the verb, albeit being the head of the DO and PO structure, does not enjoy any special role in the lexical boost; the boost from the verb did not differ from the other content words (although the boost was not quite significant from a repeated theme). Scheepers et al. also showed in two other experiments in the study that increasing the number of repeated content words in the target increased the magnitude of structural priming in it. Their conclusion was that the lexical boost is not bound to the verb and thereby to lexically-specific syntactic structures. They argued for separate mechanisms for structural priming and the lexical boost, in line with the implicit learning account (Chang et al., 2006).

However, despite the use of three different methods – including the same method used by Scheepers et al. (2017) – Carminati et al. (2019) failed to replicate the non-head boost with ditransitive structures. They investigated the lexical boost from the agent, theme and recipient nouns as well as the verb. Their results showed in contrast to Scheepers et al. that only the repetition of the verb heading the DO/PO structure (e.g., *give*) led to a lexical boost. No such boost was found when they repeated the argument nouns. Carminati et al. concluded that if there is a non-head boosting effect, it is very small and evanescent and it would then contrast with the lexical boost from the repetition of the head verb which is robust and tends to be larger in size.

One question that remains though is whether a lexical boost occurs with the repetition of *any* verb. In previous studies that showed robust lexical boost effects when the verb was repeated (e.g., Arai et al., 2007; Branigan et al., 2000; Carminati et al., 2019; Cleland & Pickering, 2003; Hartsuiker et al., 2008; Pickering & Branigan, 1998; Scheepers et al., 2017; Schoonbaert et al., 2007; Segaert et al., 2013), the manipulations always concerned the repetition of the head verb. It remains unclear whether this boost is specific and restricted to verbs that are the head of the primed structure (e.g., *give* is the syntactic head of the DO and PO structures *give the girl a card* and *give a card to the girl*) or if it occurs with *any* verb. Thus, in the present study, we tested whether the repetition of a verb that is not the syntactic head in the primed structure resulted in a lexical boost. We embedded the ditransitive structures into an infinitive phrase in a matrix clause as in (1) and manipulated the repetition of the matrix verb (e.g., *decided/refused*). The matrix verb is both semantically and syntactically an important element in the sentence because it expresses the manner of the action in the infinitive phrase (e.g., whether it was decided or refused) and it is the syntactic head of the infinitive phrase that contains the ditransitive structure. Importantly here, the matrix verb is not the head of the DO/PO structure. Instead, the infinitive phrase contains a verb (e.g., *to loan*) that is the syntactic head of the DO/PO ditransitive structure. This experimental design only adds one more lexical item (the matrix verb) to the prime and target sentences in comparison to the previous studies that manipulated the head verb (e.g., *The bus driver loaned the tourist a map* vs *The bus driver decided to loan the*

tourist a map).

1. The hotel owner decided/refused to loan the tourist a tent/ a tent to the tourist.

If only the repetition of the verb that is the head of the primed structure causes a lexical boost, as predicted by the residual activation model (Pickering & Branigan, 1998), the repetition of the matrix verb should have no boosting effect on structural priming and the priming of DO/PO structures should be unaffected by the repetition of the sentence head, the matrix verb. Finding priming of DO/PO structures in the infinitive phrase but no lexical boost from the matrix verb would suggest that structural representations are not associated with all verbs in the sentence. But if a lexical boost occurs when the matrix verb is repeated, this would suggest that structures are also associated with the sentence head; that is, the matrix verb, indicating that they are not only associated with their own syntactic head but also with a hierarchically higher head. Finding a boost when the matrix verb is repeated would be consistent with models that claim that the source of the lexical boost is the repetition of any content word (Chang et al., 2006; Reitter et al., 2011).

Experiment 1

Experiment 1 tested whether repeating a matrix verb in a sentence would lead to a lexical boost of the DO/PO ditransitive structure in the infinitive phrase that is a direct object of the matrix verb. In the experiment, participants read aloud a prime sentence (e.g., 2a-d) and then described pictures by completing a sentence fragment in the target (3). The prime was either a DO (2a, 2c) or PO (2b, 2d) and the matrix verb in the target was either the same as in the prime or different. The ditransitive verb in the infinitive phrase was always different in the prime and the target (e.g., *to loan* and *to pass*).

- 2a. The hotel owner refused to loan the tourist a tent. (DO prime).
- 2b. The hotel owner refused to loan a tent to the tourist. (PO prime).
- 2c. The hotel owner decided to loan the tourist a tent. (DO prime).
- 2d. The hotel owner decided to loan a tent to the tourist. (PO prime).
3. The chef refused to pass ... /The chef decided to pass ... (target).

Method

Participants

Forty students from the University of Dundee participated either for course credit or were paid for their participation. All participants were native speakers of British English and did not report any reading difficulties.

Materials

The experiment contained 48 experimental prime sentences such as in (2a-d). Twenty-three transitive verbs were used as matrix verbs (e.g., *agree, decide, forget, manage, refuse, threaten*) and 20 ditransitive verbs were used in the infinitive phrase (e.g., *feed, give, hand, lend, pass, sell, serve*). The target trials consisted of a picture (Fig. 1) and of a sentence fragment such as in (3) written underneath the picture. Each target picture contained 3 items: an agent that was mentioned in the sentence fragment as a subject of the given matrix verb (a definite noun phrase such as *the chef*), a possible recipient that was always a human (such as *a robber*) and a possible theme that was either a thing or an animal (such as *a knife*). The positions of the items in the pictures were varied so that there would be no bias for a linear order of the recipient and the theme. We counterbalanced the matrix verb in the prime and target (e.g., *refused* or *decided* in 2–3), so that each matrix verb was used both in the repeated and non-repeated conditions. Because this variable was not of theoretical interest, we did not analyse it. The experimental sentences and the target fragments are listed in Appendix A.

In addition to the experimental items, we constructed 144 filler items; 72 written sentences to be read aloud and 72 pictures to be described as in the experimental trials. The verbs in the read-aloud filler

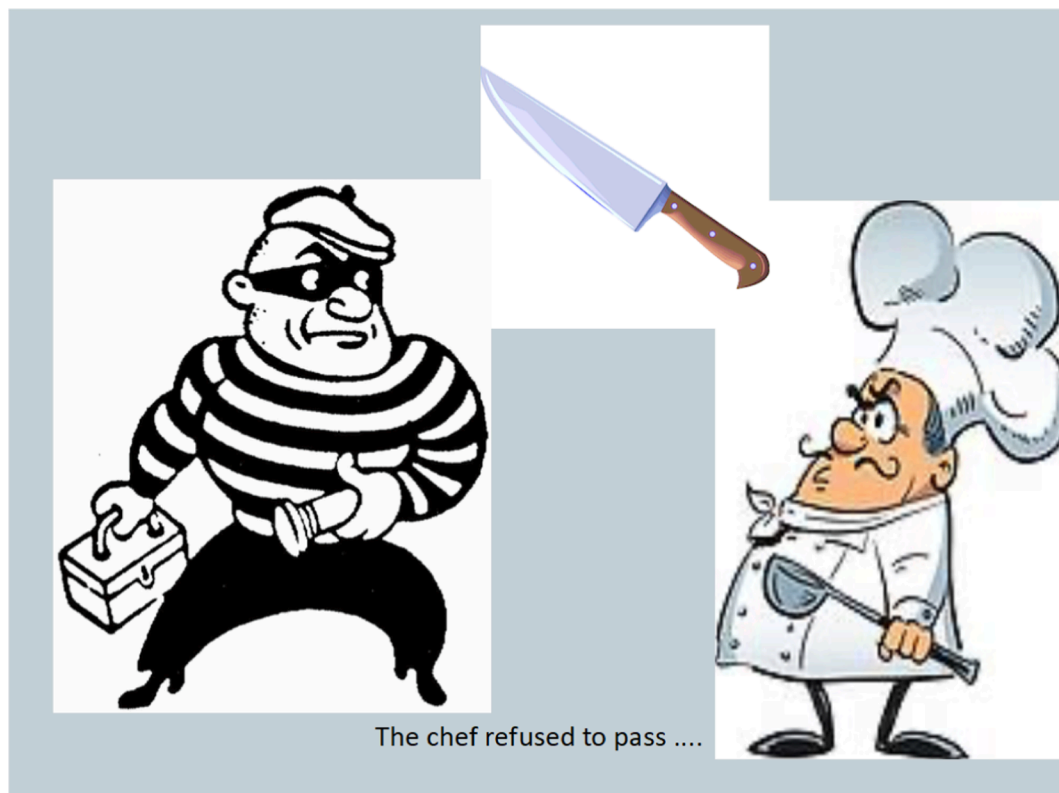


Fig. 1. Example target picture from Experiment 1.

sentences were either transitive or intransitive and they appeared either as the finite and only verbs in their sentences (e.g., *The overworked bus driver fell asleep*) or they were an infinitive preceded by an auxiliary (e.g., *The stuntwoman will probably fall*). The filler pictures depicted humans, animals and things and the number of items in the picture varied from two to four. The verbs in the sentence fragments underneath the filler pictures were varied in a similar way as in the read-aloud sentences. The filler sentences did not contain any ditransitive verbs.

The 48 experimental items occurred in eight experimental versions defined by prime structure (PO vs DO), matrix verb repetition (repeated vs not repeated) and the matrix verb counterbalancing variable. All variables were manipulated both within participants and within items using a factorial design with complete Latin square counterbalancing of all three variables. This resulted in eight lists to which participants were randomly assigned. The experimental items and fillers were placed in the same pseudorandom order in all lists. Between 3 and 6 filler items (both read-aloud sentences and pictures in a random order) appeared between the experimental trials (a prime sentence followed by a target picture).

Procedure

The participants were seated in front of the computer screen and given a description of the experiment before they started a practice session. They were told that they would see both written sentences and pictures that depict different scenarios with humans, animals and things. Their task was to read aloud the written sentences and describe the pictures so that they would start their description with the sentence fragment that was printed underneath the picture and complete it so that their description would correspond to the scene in the picture. In their sentence, they should try to mention all the items depicted in the scene. The participants were shown a written sentence on a paper and a picture of a scene that had a sentence fragment underneath it as examples when the experiment was described to them. After the participants had understood the task, they started a practice session. If the participant had

questions or did not include all the items depicted in the practice session, the instructions were repeated and the participant was given an example of how a picture could be described. When the participants had understood the task, they started the experiment. They were told that they would run the experiment on their own by using the space bar.

The first experimental trial appeared after 9 fillers. Halfway through the experiment, the participants were asked to take a short break. All the experimental sessions were digitally recorded using a table microphone. The experiment lasted about 50 min.

Results

We scored whether participants produced a PO, DO or *other* completion in the target. Completions were scored as PO if the ditransitive verb was first followed by a theme noun phrase and then by a recipient prepositional phrase. They were scored as DO if it was first followed by a recipient noun phrase and then by a theme noun phrase. Only completions that could be reversed into the alternative ditransitive structure were scored as PO or DO. The remaining completions were scored as *other*.

To examine structural priming and the lexical boost, we excluded all *other* responses. Table 1 shows the mean percentages of PO target completions out of all PO and DO completions, together with the numbers of *other* responses. We carried out logit mixed effects analyses using the `glmer` function from the `lme4` Package in R (version 4.2.1; CRAN project; The R Core Team, 2022). The predictor variables prime structure (DO vs PO prime) and matrix verb repetition (repeated vs not repeated) were centered. In all analyses reported in this article, we started with a model that included by-participants and by-items random intercepts and random slopes for all predictor variables (Barr et al., 2013), enforcing zero correlations between random effects in order to avoid overparameterization or false convergence (Bates et al., 2015). However, because the full models either did not converge or resulted in a singular fit, we removed random slopes in a stepwise way, starting by

Table 1
Mean percentages of PO responses out of all PO and DO responses by condition in Experiment 1.

	DO prime	PO prime	Priming effect (PO – DO prime)
Matrix verb not repeated	65.4 (2.3, 9.8)	73.6 (2.1, 7.7)	8.2
Matrix verb repeated	66.1 (2.3, 9.8)	75.8 (2.0, 6.9)	9.7

Note. Standard errors of the means in parentheses, followed by the percentages of *other* responses.

removing the prime structure \times matrix verb repetition interaction, then matrix verb repetition and finally prime structure. Each random slope was first removed by items and then by participants.

The analyses showed an effect of prime structure ($\beta = 0.365$, $SE = .068$, $z = 5.41$, $p < .001$), with more PO target completions after PO than after DO primes. There was no effect of matrix verb repetition ($\beta = -0.056$, $SE = .067$, $z = -0.84$, $p = .399$) and critically, no interaction between prime structure and matrix verb repetition ($\beta = -0.032$, $SE = .067$, $z = -0.48$, $p = .632$). Thus, there was no evidence for a matrix verb boost effect.

In order to provide further evidence for the absence of a lexical boost, we calculated a Bayes factor, comparing the Bayesian information criterion (BIC) of the logit mixed effects model reported above with the BIC of a model that did not include the prime structure \times matrix verb repetition interaction, but that was otherwise identical. The model without interaction was used in the numerator. The resulting Bayes factor, $BF_{01} = 37.53$, provided very strong evidence (Lee & Wagenmakers, 2014) for the null hypothesis that there was no matrix verb boost.

After running the analyses, we discovered that four of the verbs in the experiment (*announce*, *avoid*, *consider*, *insist*) were not listed as permitting non-finite phrases (*to*-infinitives) as direct objects in the active voice in standard British English grammar (e.g., Quirk & Greenbaum, 1976) in the Longman Dictionary of Contemporary English (2003) or in the Oxford Advanced Learner's Dictionary (2000). We therefore also ran the analyses without the items that included these verbs. Like the main analyses, they showed an effect of prime structure ($\beta = 0.344$, $SE = .076$, $z = 4.50$, $p < .001$), but no interaction between prime structure and matrix verb repetition, so there was no evidence for a lexical boost ($\beta = -0.042$, $SE = .076$, $z = -0.55$, $p = .580$). The Bayes factor showed very strong evidence that there was no lexical boost: $BF_{01} = 32.26$.

For completeness, we also analysed the proportions of *other* responses, using the same analysis procedure as before. There was an effect of prime structure ($\beta = -0.252$, $SE = .106$, $z = -2.39$, $p = .017$), with slightly more *other* responses after DO than after PO primes. It is not entirely clear why this effect occurred; possibly, participants produced more *other* responses after DO primes because they are less preferred and may therefore be harder to process. There was no effect of matrix verb repetition or interaction between prime structure and verb repetition ($ps > .5$).

Discussion

Experiment 1 showed a clear structural priming effect with ditransitive DO and PO structures but there was no evidence for elevated priming when the matrix verb was repeated. Finding priming but no lexical boost when the matrix verb was repeated indicates that DO/PO structures in the infinitive phrase were not associated with the matrix verb.

Our results are compatible with the residual activation model (Pickering & Branigan, 1998), in which priming is caused by residual activation of the previously used argument structure. In the model, the boost is restricted to the verb that is the head of the primed structure and the model does not predict any boost from a verb that is not directly associated with DO/PO structures. The results do not support the implicit learning model (Chang et al., 2006), in which the lexical boost is due to an explicit, short-term memory trace of the repeated word and the

structure with which it occurred in the prime. In the same way, they give no support to the learning model of Reitter et al. (2011), in which the lexical boost is due to the association between the lexical items and the syntactic structure that is strengthened when a lexical item is repeated. Both models predict that the repetition of a matrix verb in the target should lead to a lexical boost, but the experiment showed that repeated lexical content between primes and targets did not increase priming. However, the matrix verbs we used in the experiment might not have been effective enough as memory cues for the prime sentence. Therefore, in Experiment 2, we increased the likelihood that the matrix verb would be encoded in explicit memory.

Experiment 2

Memory studies have shown that low-frequency words work as a better retrieval cue for a memory search and are more easily recognised than high-frequency words (e.g., Lohnas & Kahana, 2013; Malmberg & Nelson, 2003; Rugg & Doyle, 1992). In Experiment 1, we used relatively common matrix verbs (such as *decide*, *forget*, *consider*, *refuse*, *manage*), which may not work as a sufficient retrieval cue for the prime sentence structure. In Experiment 2, we therefore used less frequent verbs as matrix verbs than the ones in Experiment 1. The purpose of using less-frequent verbs was to increase the likelihood that the repetition of them would act as an effective memory cue for the previous sentence structure and following the implicit learning model, boost the priming.

Experiment 2 was similar in design to Experiment 1; the participants read aloud prime sentences such as in (4a-d) and then described pictures by completing a sentence fragment in the target (5).

- 4a. The painter hesitated to lend the apprentice the ladder. (DO prime).
 4b. The painter hesitated to lend the ladder to the apprentice. (PO prime).
 4c. The painter vowed to lend the apprentice the ladder. (DO prime).
 4d. The painter vowed to lend the ladder to the apprentice. (PO prime).
 5. The farmer hesitated to show ... /The farmer vowed to show ... (target).

Method

Participants

Fifty-six students from the same population as in Experiment 1 participated in the experiment.

Materials

The materials and the experimental design were similar to those in Experiment 1 apart from the matrix verbs (Appendix B). In addition, some of the target pictures were changed so that the agents mentioned, the facial expressions and body positions of the characters now better corresponded to the matrix verb. Thirty-five less frequent transitive verbs were now used as matrix verbs (e.g., *aspire*, *contrive*, *hasten*, *strive*, *vow*). Their mean lemma frequency per million words in the SUBTLEX-UK corpus was 13.2 and their Zipf value per million was 3.8 (Van Heuven et al., 2014). This was lower than 90.3 per million words and a Zipf value of 4.7 in Experiment 1. Nineteen ditransitive verbs were used in the infinitive phrase (e.g., *give*, *hand*, *lend*, *pass*, *sell*, *serve*). In addition to the experimental items, we constructed 202 filler items; 95 written sentences to be read aloud and 107 pictures to be described. Forty filler

Table 2
Mean percentages of PO responses out of all PO and DO responses by condition in Experiment 2.

	DO prime	PO prime	Priming effect (PO – DO prime)
Matrix verb not repeated	62.0 (1.9, 7.3)	68.1 (1.9, 6.7)	6.1
Matrix verb repeated	61.6 (1.9, 5.4)	68.0 (1.8, 5.1)	6.4

Note. Standard errors of the means in parentheses, followed by the percentages of *other* responses.

sentences (spread over the experiment) were followed by simple *Yes-No* questions about the contents in the previous sentence (e.g., *The urgent parcel will arrive tonight* was followed by *Is the parcel arriving next week?*). This was done to ensure that the participants would pay close attention to each sentence. The experimental items were never followed by a question.

Procedure

The instructions were the same as in Experiment 1. In addition, the participants were informed that they would occasionally be asked *Yes-No* questions about the sentences that they had just read and they should answer by using the right shift key for *Yes* and the left shift key for *No*. The participants were told that they would receive feedback to their answers, indicating whether the answer was correct or incorrect. The experiment was preceded by a practice session consisting of 8 trials. Following the practice, 2 fillers preceded the first experimental trial. Halfway through the experiment, the participants were asked to take a short break. All the experimental sessions were digitally recorded using a table microphone. The experiment lasted about 60 min.

Results

Table 2 shows the mean percentages of PO target completions out of all PO and DO completions. We scored and analysed the data in the same way as in Experiment 1. Analyses were done without matrix verb repetition or its interaction with prime structure as random effects because this resulted in a singular fit. We found an effect of prime structure: $\beta = 0.231$, $SE = .069$, $z = 3.36$, $p < .001$; participants produced more PO targets after PO than after DO primes. There was no effect of matrix verb repetition ($\beta = -0.004$, $SE = .053$, $z = -0.08$, $p = .934$) and critically, no interaction between prime structure and matrix verb repetition ($\beta = -0.011$, $SE = .053$, $z = -0.21$, $p = .836$). Thus, as in the previous experiment, there was no matrix verb boost effect. This was further supported by the Bayes factor using BICs to compare the models with and without the prime structure \times matrix verb repetition interaction. It showed very strong support for the null hypothesis, that is, no matrix verb boost, $BF_{01} = 49.22$.

Two of the verbs (*disagree* and *loathe*) in the experiment were not listed in the Longman Dictionary of Contemporary English or in Oxford Advanced Learner's Dictionary as permitting non-finite verb phrases (to-infinitives) as direct objects in the active voice in standard British English grammar. The analyses without the items containing these verbs showed the same pattern of results as the main analyses, with an effect of prime structure ($\beta = 0.205$, $SE = .064$, $z = 3.20$, $p = .001$), but no interaction between prime structure and matrix verb repetition ($\beta = 0.009$, $SE = .056$, $z = 0.16$, $p = .877$). The Bayes factor showed very strong support for the absence of a matrix verb boost, $BF_{01} = 46.30$.

Analysis of the *other* target completions (see Table 2) showed an effect of matrix verb repetition ($\beta = 0.190$, $SE = .095$, $z = 2.01$, $p = .044$). Participants produced more *other* completions when the matrix verb was not repeated than when it was, in other words, they produced more reversible ditransitives (either PO or DO) when the matrix verb was repeated than when it was not. There was no effect of prime structure or prime structure \times matrix verb repetition interaction ($ps > .5$). To avoid a singular fit, all random slopes were removed from this model.

Discussion

As in Experiment 1, the results showed a main effect of priming but no evidence of a lexical boost when the matrix verb was repeated. The repetition of the less frequent matrix verbs did not lead to increased priming of the ditransitive constructions in the infinitive phrases. In contrast to Experiment 1, where we observed a main effect of prime structure on *other* completions, Experiment 2 showed a main effect of matrix verb repetition, with fewer *other* completions when the matrix verb was repeated. Because this occurred regardless of whether the prime had a PO or DO structure, it is not a structural effect. It indicates that participants produced more target completions with the same thematic roles as in the prime (recipient and theme in either order rather than, for example, only a theme) when the matrix verb was repeated than when it was not, suggesting that they tended to produce a similar meaning when the matrix verb was repeated.

Our results give further support to the conclusion from Experiment 1 that priming is related to the head verb only and is not affected by the repetition of other verbs in the sentence. This finding is in line with the residual activation model, in which the lexical boost is only bound to the local relationship between the verb lemma and the syntactic structure it encodes.

Experiment 3

In Experiments 1 and 2, participants needed to name the items in the target pictures (the theme and the recipient) in order to complete the sentence fragments. Many previous priming studies have used a sentence completion method without the task of describing pictures (e.g., Corley & Scheepers, 2002; Kantola & Van Gompel, 2011; Pickering & Branigan, 1998; Pickering et al., 2002; Scheepers, 2003; Van Gompel et al., 2012). In Experiment 3, we examined whether our findings would generalize to a task where the materials from Experiment 2 were run without the task of describing pictures. Participants were given the same target fragments without pictures to describe and they were free to complete the sentence fragments in the way they wanted.

Method

Participants

Forty students from the same population as in Experiments 1 and 2 participated in the experiment.

Materials

The experiment contained the same written materials as Experiment 2. All the pictures were removed from the test files; the sentence fragments from the target and filler pictures now appeared in the same position on the screen as the read-aloud sentences. The experimental design was identical to Experiment 2, except that participants did not receive any questions about the contents in the experimental or filler sentences.

Procedure

The participants were seated in front of the computer screen and were told that they would see both written sentences and sentence fragments on the screen. Their task was to read aloud the complete sentences and continue the sentence fragments in the way they wanted but so that they would make a meaningful and grammatically correct

Table 3
Mean percentages of PO responses out of all PO and DO responses by condition in Experiment 3.

	DO prime	PO prime	Priming effect (PO – DO prime)
Matrix verb not repeated	60.9 (3.5, 59.0)	72.4 (3.2, 58.5)	11.5
Matrix verb repeated	63.8 (3.1, 50.0)	68.9 (3.0, 50.4)	5.1

Note. Standard errors of the means in parentheses, followed by the percentages of *other* responses.

sentence. They were asked to use the first completion that came to mind and not to take too much time thinking of possible continuations. All the other aspects of the procedure were the same as in Experiment 2. The experiment lasted about 50 min.

Results

Table 3 shows the percentages of PO target completions out of all PO and DO completions. We analysed the data in the same way as in Experiment 2. There was an effect of prime structure: $\beta = 0.304$, $SE = .099$, $z = 3.04$, $p < .001$, with participants producing more PO targets after PO than after DO primes. There was no effect of matrix verb repetition ($\beta = -0.010$, $SE = .092$, $z = -0.11$, $p = .915$) and no interaction between prime structure and matrix verb repetition ($\beta = 0.027$, $SE = .091$, $z = 0.310$, $p = .763$). Again, there was no matrix verb boost effect. The Bayes factor comparing the BICs for the models with and without the prime structure \times matrix verb repetition interaction showed strong evidence for the absence of a lexical boost: $BF_{01} = 28.31$.

Analyses without the items containing the verbs *disagree* and *loathe* showed the same results: An effect of prime structure ($\beta = 0.303$, $SE = .122$, $z = 2.48$, $p = .013$), but no lexical boost ($\beta = 0.049$, $SE = .097$, $z = 0.51$, $p = .612$). Again, the Bayes factor showed strong evidence for the absence of a lexical boost: $BF_{01} = 24.31$.

The proportions of *other* completions were higher than in Experiments 1 and 2 (see Table 3), because participants were not constrained by the pictures and often produced monotransitive completions. Analysis of the *other* target completions showed an effect of matrix verb repetition ($\beta = 0.235$, $SE = .053$, $z = 4.41$, $p < .001$). Participants produced more *other* completions when the matrix verb was not repeated than when it was. There was no effect of prime structure or interaction between prime structure and matrix verb repetition ($ps > .8$).

Discussion

Experiment 3 showed a clear priming effect but no evidence of elevated priming when the matrix verb was repeated. Whereas in Experiments 1 and 2, the participants needed to find words for the depicted items, in Experiment 3 the participants were free to complete the sentence fragments in the way they wanted. The results confirmed the findings from Experiments 1 and 2 and suggest that it does not matter for priming whether participants' sentence completions are constrained by pictures or they can complete the sentence fragments without any constraints. As in Experiment 2, we also found a main effect of matrix verb repetition on the proportions of *other* responses, again suggesting that participants more often completed the target with a similar meaning by using the same thematic roles (rather than structure) as in the prime when the matrix verb was repeated than when it was not.

Experiment 4

The preceding experiments showed no lexical boost from the matrix verb on the priming of the ditransitive structures (DO/PO) in the embedded infinitive phrase, whereas numerous previous studies have shown that priming is boosted when the head verb of the primed structure is repeated (see Pickering & Ferreira, 2008, for a review and Mahowald et al., 2016, for a meta study). These findings together suggest that the verb must be the syntactic head of the structure in order to boost its priming. However, neither previous studies nor Experiments

1–3 demonstrated a head verb boost in the embedded structures. Although Branigan et al. (2006) showed abstract structural priming between primes and targets both when the DO/PO structure was placed in a main clause (e.g., *The racing driver showed the torn overall to the mechanic*) and in an embedded matrix clause (e.g., *The reporter claimed that the racing driver showed the torn overall to the mechanic*), they did not investigate whether the repetition of the ditransitive verb (*showed*) caused a lexical boost. In addition, the primed structure in the Branigan et al. study was a complete clause containing both a subject and a finite predicate, whereas in our materials, the DO/PO structure was embedded in a structure that had no subject of its own and the predicate contained an infinitive verb.

In Experiment 4, we tested primes such as in (6a–f) and targets as in (7) to investigate whether we would obtain a lexical boost if we repeated the ditransitive head verb in the primed structure. Also, we wanted to see whether in the same experiment, we would replicate the absence of a matrix verb boost. We manipulated the repetition of both the head and matrix verb by using conditions in which (1) neither the matrix verb nor the head verb were repeated between prime and target (e.g., *hesitated* and *lend* in 6a and 6b are different from *proceeded* and *show* in 7), (2) only the matrix verb in the prime (e.g., *proceeded* in 6c and 6d) was repeated in the target or (3) only the head verb (e.g., *show* in 6e and 6f) was repeated.

- 6a. The painter hesitated to lend the apprentice the ladder. (DO prime, no verb repetition).
- 6b. The painter hesitated to lend the ladder to the apprentice. (PO prime, no verb repetition).
- 6c. The painter proceeded to lend the apprentice the ladder. (DO prime, matrix verb repetition).
- 6d. The painter proceeded to lend the ladder to the apprentice. (PO prime, matrix verb repetition).
- 6e. The painter hesitated to show the apprentice the ladder. (DO prime, head verb repetition).
- 6f. The painter hesitated to show the ladder to the apprentice. (PO prime, head verb repetition).
7. The farmer proceeded to show ... (target).

If the repetition of the head verb results in a lexical boost, we should observe more priming in the conditions where this verb is repeated (6e and 6f) than in the conditions where neither verb is repeated (6a and 6b). Furthermore, if there is no boost from the matrix verb, as we found in the previous experiments, then priming should be no larger when the matrix verb is repeated (6c and 6d) than when neither verb is repeated (6a and 6b).

Experiment 4 was similar in design and method to Experiments 1 and 2. Participants read aloud a prime sentence (6a–6d) and then described pictures by completing a sentence fragment in the target (7).

Method

The experiment was pre-registered in ASPREDICTED: <https://aspredicted.org/jh3f6.pdf>.

Participants

Participants were recruited via Prolific, an online participant recruitment system. A total of 86 participants completed the study. Data from 72 participants were included in the analyses. Fourteen participants were excluded prior to the analysis either because their microphone did not work, their recordings were not clear enough to be

transcribed, they frequently clicked the button to progress to the next trial before they had finished the sentence completion, they did the experiment in a noisy environment, or they did not do the task alone.

All included participants were between 18 and 35 years and were either studying for an undergraduate or postgraduate university degree. All were native speakers of British English and did not report any language or reading difficulties.

Materials

The materials and the experimental design were similar to those in Experiments 2 and 3 (Appendix C). The main difference was that we now manipulated both matrix verb repetition and head verb repetition, which resulted in six experimental conditions. We replaced all matrix verbs from Experiments 2 and 3 that did not permit a non-finite phrase as a direct object in the active voice according to dictionaries of standard British English. In addition, because we manipulated both whether the matrix verb and the head verb were repeated in the prime and target, we changed some of the sentences from Experiments 2 and 3 so that they sounded natural in all conditions. These changes to the materials resulted in 27 matrix verbs for the experiments. In contrast to the previous experiments, we did not counterbalance the verbs in the conditions within items; instead, this was done between items so that each matrix verb and each head verb occurred equally often as a repeated verb and a non-repeated verb across items.

The 48 experimental items occurred in six experimental versions defined by prime structure (PO vs DO) and verb repetition (no verb repetition vs matrix verb repeated vs head verb repeated). As before, all variables were manipulated both within participants and within items using a factorial design with complete Latin square counterbalancing of all variables, resulting in six experimental lists. We used 201 fillers; 94 complete sentences to be read aloud and 107 sentence fragments with pictures. Between 3 and 7 fillers items appeared between the experimental trials.

Procedure

Gorilla Experiment Builder (Anwyl-Irvine et al., 2020) was used to present the items and collect data. The participants were first given a written description of the experiment. They were asked to read the instructions very carefully, do the microphone test and study the given examples of the task before they started a practice session. The instructions and examples were the same as in Experiment 2 except we added five examples of how participants could complete sentence fragments using pictures (none were DO/PO completions). During the experimental session, the participants occasionally received information about how far in the experiment they had come (e.g., “Well done, you have now completed 75 % of the experiment.”). Halfway through the experiment, the participants were asked to take a short 1–2 min break. They were also asked not to take any other breaks during the session.

Results

We coded the target completions in the same way as in the previous experiments. Table 4 shows the percentages of PO target completions out of all PO and DO completions along with the percentages of *other* target completions. Because the verb repetition predictor variable had three levels (no verb repetition vs matrix verb repeated vs head verb repeated), we used treatment coding for both this variable and the prime

Table 4

Mean percentages of PO responses out of all PO and DO responses by condition in Experiment 4.

	DO prime	PO prime	Priming effect (PO – DO prime)
No verb repeated	60.7 (2.1, 9.5)	65.8 (2.1, 8.0)	5.1
Matrix verb repeated	57.9 (2.1, 7.1)	65.8 (2.0, 6.6)	7.9
Head verb repeated	58.7 (2.1, 7.5)	70.5 (2.0, 6.4)	11.8

Note. Standard errors of the means in parentheses, followed by the percentages of *other* responses.

structure predictor variable (DO vs PO prime). The no verb repetition level was used as the baseline with which the matrix verb repeated and head verb repeated levels were compared. Note that this means that the results do not show main effects of the predictor variables, but simple effects. Because none of the models with random slopes converged, only random intercepts by participants and items were used.

The resulting model showed a significant interaction between prime structure and whether the head verb was repeated or not (i.e. comparing priming in the no repetition vs head verb repetition conditions), indicating a head verb repetition boost: $\beta = 0.625$, $SE = .231$, $z = 2.71$, $p = .007$. In contrast, there was no interaction between prime structure and matrix verb repetition (i.e. comparing priming in the no repetition vs matrix verb repetition conditions), indicating that there was no matrix verb repetition boost: $\beta = 0.160$, $SE = .227$, $z = 0.70$, $p = .482$. The model also showed a marginally significant structural priming effect in the baseline no verb repetition conditions: $\beta = 0.284$, $SE = .162$, $z = 1.76$, $p = .079$.

To explore directly whether the lexical boost was different in the matrix verb repeated and the head verb repeated conditions, we recoded the verb repetition variable so that the matrix verb repetition level was the baseline with which the other verb repetition levels were compared. This model showed a significant interaction between prime structure and whether the matrix verb or head verb was repeated, indicating that there was a lexical boost in the head verb repeated conditions compared to the matrix verb repeated conditions: $\beta = 0.465$, $SE = .228$, $z = 2.04$, $p = .042$. It also revealed a significant priming effect in the matrix verb repeated conditions: $\beta = 0.443$, $SE = .159$, $z = 2.79$, $p = .005$.

To check the absence of a lexical boost in the matrix verb repeated conditions further, we built logit mixed effects models with just the no repetition and matrix verb repeated conditions (i.e. excluding the head verb repeated conditions). No random slopes were included because models including them did not converge. We then compared a model that included the interaction between prime structure and matrix verb repetition with a model that did not include this interaction (but was otherwise identical). A likelihood ratio test showed no difference between the models ($\chi^2(1) = 0.533$, $p = .465$) and the Bayes factor comparing them showed very strong evidence for the absence of a lexical boost $BF_{01} = 35.30$.

We analysed the proportions of *other* completions in the same way as the proportions of PO target completions, except that prime structure was included as a random slope by participants and items. A logit mixed effects model with no repetition as the baseline level showed no interaction between prime structure and whether the matrix verb was repeated or not, nor between prime structure and whether the head verb was repeated ($ps > .6$). There was also no effect of prime structure in the no repetition condition ($\beta = -0.280$, $SE = .258$, $z = -1.09$, $p = .277$). In the model with matrix verb repetition as the baseline, there was no interaction between prime structure and whether the repeated verb was the matrix verb or head verb and no prime structure effect in the matrix verb repetition conditions ($ps > .6$).

Discussion

Experiment 4 showed larger structural priming when the head verb of the DO/PO structure was repeated than when it was not, whereas the experiment showed no boost in priming when the matrix verb was repeated. This demonstrates that a head verb boost can be obtained

when the DO/PO structure is embedded in a subordinate phrase within a matrix clause. Critically here, the results showed no lexical boost when the matrix verb, which is not the head of the primed DO/PO structure, was repeated; this is in line with our previous experiments. We conclude that a lexical boost does not occur with the repetition of just any verb but is specific to the repetition of the verb that syntactically heads the primed structure. This supports the residual activation model (Pickering & Branigan, 1998), in which the boost is restricted to the verb that heads the primed structure, whereas the model does not predict any boost from a verb that is not directly associated with DO/PO structures.

In the conditions where no verbs were repeated, structural priming was only marginally significant. Numerically, this abstract priming effect was somewhat smaller than in Experiments 1–3. It is possible that this is due to a difference in the method. Experiments 1–3 were conducted in the lab, whereas Experiment 4 was carried out online. It is possible that participants concentrated less when they did the experiment online than when they did it in the lab. Alternatively, the marginally significant lexically-independent priming may be due to random fluctuations in this effect. Several previous studies also failed to find significant priming when the head verb was not repeated. For example, Pickering and Branigan (1998) only found significant abstract priming when the target was preceded by two primes. The priming effect was also not significant in Corley and Scheepers (2003), who used an online completion method without pictures. Scheepers et al. (2017) only found priming when they combined all three experiments in their study and Van Gompel et al. (2022) did not find significant abstract priming in their Experiment 1. However, regardless of the reason why the abstract priming effect was only marginally significant, the critical finding from Experiment 4 is that repetition of the head verb did boost priming.

Finally, in contrast to Experiments 2 and 3, we found no significant effect of whether the matrix verb was repeated or not on the proportions of *other* responses. There was also no effect of whether the head verb was repeated or not on the proportions of *other* responses.

Combined results

For a more powerful analysis, we combined the data from all four experiments, excluding the head verb repeated conditions in Experiment 4. We carried out a logit mixed effects analysis that included prime structure and matrix verb repetition as centered predictor variables. To avoid a singular fit, we had to remove all random slopes except the prime structure slopes by participants. In line with the results from the individual experiments, there was an effect of prime structure ($\beta = 0.249$, $SE = .032$, $z = 7.71$, $p < .001$), but no interaction between prime structure and matrix verb repetition ($\beta = -0.016$, $SE = .031$, $z = -0.50$, $p = .614$). To calculate the Bayes factor, we compared the BIC of a model that included the fixed factors prime structure and matrix verb repetition as well as their interaction with the BIC of a model that did not include the interaction but that was otherwise the same. This showed very strong support for the absence of a matrix boost: $BF_{01} = 75.45$.

An analysis excluding the verbs that do not occur with to-infinitives in the standard grammar of British English showed similar results: An effect of prime structure ($\beta = 0.231$, $SE = .033$, $z = 6.95$, $p < .001$), but no interaction between prime structure and matrix verb repetition ($\beta = -0.009$, $SE = .033$, $z = -0.27$, $p = .785$). The Bayes factor comparing the models with and without interaction again showed strong evidence for the absence of a matrix verb boost, $BF_{01} = 77.59$.

General discussion

In four experiments, we investigated whether the lexical boost found in numerous structural priming studies is due to the repetition of the verb that was the syntactic head of the primed structure or whether the repetition of any verb boosts the priming. In previous studies of structural priming and the lexical boost, the key finding has been that priming is boosted by verb repetition (e.g., Mahowald et al., 2016). In all

these studies the verb that was repeated was the head of the primed structure. In our study, we opted for a different approach and repeated the matrix verb that, albeit being the syntactic head of the sentence, is not the syntactic head of the primed structure. If structural representations are only associated with their syntactic head, the repetition of the matrix verb should have no effect on the amount of priming of DO/PO structures in the infinitive phrase. But if they are associated with any verb in the sentence, the repetition of the matrix verb should result in a lexical boost. Our results showed clear structural priming effects in all experiments and Experiment 4 showed that the repetition of the head verb caused a lexical boost but the repetition of the matrix verb did not lead to stronger priming of DO/PO structures.

Moreover, we observed no lexical boost when we used less frequent main verbs. Memory studies (e.g., Lohnas & Kahana, 2013; Malmberg & Nelson, 2003; Rugg & Doyle, 1992) have shown that infrequent words are recalled better and function as better retrieval cues but despite this, the use of less frequent verbs as matrix verbs in Experiments 2–4 did not result in a lexical boost. In addition, we observed no lexical boost regardless of whether participants used pictures to complete the target sentences (Experiments 1, 2 and 4) or whether they were free to complete the sentence fragments in the way they wanted (Experiment 3).

In order to exclude such an elusive increase of priming when the matrix verb was repeated, we conducted a combined analysis of the data from all experiments, based on 208 participants and 7278 trials. In line with the individual experiments, it showed no evidence for a matrix verb boost. We also calculated Bayes factors to statistically evaluate our null results in the four experiments (and in the combined analysis), which also confirmed our finding of no boost in priming when the matrix verb was repeated. Our results thus give further evidence for the account that the lexical boost occurs with lexical heads in phrase structures; verbs in verb phrases (Carminati et al., 2019) and nouns in nouns phrases (Cleland & Pickering, 2003), whereas the repetition of other kinds of lexical material between primes and targets does not boost the priming.

Given the linguistic importance of matrix verbs in sentences, the absence of a lexical boost is striking. They are the syntactic head of the embedded infinitive phrase containing the DO/PO structures and are semantically important because they express the manner of the action in the infinitive phrase (how it is done or not done at all). It appears that the lexical boost is not driven by the syntactic or semantic importance of the word in the sentence; rather, it appears that it is driven by the link between the head verb and the syntactic structures that it subcategorises for; that is, the link between the lemma node and the combinatorial node that encodes the syntactic structure associated with the lemma in the residual activation model.

Our results contrast with Scheepers et al. (2017), who showed that non-head argument nouns in ditransitive constructions, when repeated, increased priming in targets in the same way as the head verb. However, this finding was not replicated in the experiments of Carminati et al. (2019), who used three different methods in their study of the lexical boost and found no evidence for a lexical boost when non-head arguments in ditransitives (the agent, recipient, theme) were repeated; they only found a boost when the head verb of the prime structure was repeated. Carminati et al. proposed that the non-head boost, such as found by Scheepers et al., if it exists, may come and go depending on the subtle experimental methods, thereby contrasting it with the verb boost that is stable and reliably found in many experiments. This is supported by recent findings by Van Gompel et al. (2022), who found a head verb boost in ditransitive structures regardless of the method, whereas a non-head boost from the subject noun only occurred when participants could see the prime and target simultaneously, suggesting that it is more strategic in nature and only occurs when participants can visually check the prime when they complete the target. Our current results provide further support that the distinction between head and non-head is critical for the lexical boost. The idea that only repetition of the head of the primed structure can cause a lexical boost is also consistent with the results of Cleland and Pickering (2003), who found a lexical boost only

when they repeated the head noun in a phrase but no boost when they repeated the modifying adjective in the same noun phrase. These findings suggest that structures are only associated with their syntactic head; that is, verbs in verb phrases and nouns in noun phrases.

Our results and previous findings in the literature are consistent with the residual activation model (Pickering & Branigan, 1998), in which syntactic structures are associated with their syntactic head only. In this model, structures are linked to their syntactic head but not to other words in the sentence. A lexical boost occurs because of residual activation of the link between the head and the structure following the processing of the prime. The findings about the lexical boost are more challenging for models that assume that the repetition of any content word should result in a lexical boost. According to the implicit learning model (Chang et al., 2006), the lexical boost is triggered by any repeated content word. This repeated lexical item, provided that it is meaningful for the sentence context, forms a memory cue for the syntactic structure with which it occurred in the prime. Hence, it predicts that repetition of the matrix verb should result in a lexical boost. A similar claim of repeated lexical material leading to a lexical boost is made by the ACT-R learning model of Reitter et al. (2011). The boost in the model emerges from the associative learning that increases the activation of links between lexical material and syntactic structure, whether the repeated lexical material is the head or not. The model predicts that the repetition of a matrix verb in the target should lead to a lexical boost, contrary to our results. However, the head verb might form stronger associative links with the DO/PO structure than with the matrix verb because the head verb is syntactically closer to it. This would require modelling in the ACT-R model to determine whether this would predict our results. Nevertheless, it seems unlikely that the model would be able to account for Carminati et al.'s (2019) finding that the repetition of the theme or recipient noun did not cause a lexical boost. These nouns are part of the DO/PO structure and should therefore be very closely associated with it.

Our study did not investigate the time course of the lexical boost effect. Studies have shown that structural priming lasts across several intervening sentences, whereas the lexical boost effect tends to disappear more quickly (e.g., Branigan & McLean, 2016; Hartsuiker et al., 2008). This is often taken as evidence for dual process accounts of abstract priming and the lexical boost. However, Malhotra et al. (2008) demonstrated in a computational spreading activation model that this time-course difference can also be explained in a residual activation model. Because examining the time course of structural priming and the lexical boost does not distinguish between the models, the main goal in our study was instead to investigate whether the verb boost found in many experimental studies (Mahowald et al., 2016) is restricted to the head of the primed structure or whether it can be found with any repeated verb.

To conclude, the present study investigated, for the first time, whether syntactic structures in a sentence are associated with any verb in it. All experiments showed abstract structural priming of the ditransitive structure but the repetition of the syntactic head of the sentence, the matrix verb that was not the head of the of ditransitive structure, did not boost the priming. It is difficult to reconcile this finding with learning models that predict that the repetition of any content word from the prime sentence forms the basis of a lexical boost. Our results instead support the residual activation model that assumes that structural representations are only associated with their head and not with any other words in the sentence.

Author Note

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The experimental data and R analysis files can be downloaded via the Open Science Framework at <http://dx.doi.org/10.17605/OSF.IO/P8F2C>.

Appendix A. Experimental Sentences in Experiment 1

- 1 The painter hesitated/decided to lend the ladder/the apprentice.
The farmer hesitated/decided to hand
- 2 The millionaire promised/hurried to send a Rolex/the supermodel.
The knight promised/hurried to loan
- 3 The fashion designer refused/insisted to sell a dress/the actress.
The photographer refused/insisted to show
- 4 The athlete agreed/wished to pay a salary/the coach.
The pirate agreed/wished to give
- 5 The car salesman failed/managed to sell a Mini/the musician.
The astronaut failed/managed to hand
- 6 The bank manager planned/guaranteed to post a cheque/the minister.
The boxer planned/guaranteed to send
- 7 The actress promised/announced to leave the mansion/the bodyguard.
The king promised/announced to give
- 8 The actor forgot/intended to show the pictures/the agent.
The Eskimo girl forgot/intended to bring
- 9 The hotel owner refused/decided to loan a tent/the tourist.
The chef refused/decided to pass
- 10 The engineer considered/guaranteed to give a discount/the client.
The teacher considered/guaranteed to bring
- 11 The geologist attempted/declined to sell the excavator/the farmer.
The waiter attempted/declined to throw
- 12 The girlfriend failed/managed to bring a gun/the inmate.
The coach failed/managed to hand
- 13 The minister managed/hurried to email the report/the journalist.
The boy managed/hurried to throw
- 14 The butler forgot/avoided to serve a drink/the queen.
The clown forgot/avoided to bring
- 15 The estate agent guaranteed/hoped to sell the cottage/the gardener.
The guide guaranteed/hoped to show
- 16 The rock star decided/preferred to send the royalties/the drummer.
The fisherman decided/preferred to offer
- 17 The father agreed/promised to pay a wage/the babysitter.
The opera singer agreed/promised to give
- 18 The child pretended/attempted to feed a chocolate/the doll.
The woman pretended/attempted to give
- 19 The journalist hurried/threatened to mail the story/the editor.
The wife hurried/threatened to bring
- 20 The patient wished/intended to buy a sportscar/the nurse.
The piper wished/intended to sell
- 21 The old lady planned/insisted to serve a meal/the beggar.
The model planned/insisted to pass
- 22 The doctor hesitated/remembered to offer a tissue/the patient.
The girl hesitated/remembered to hand
- 23 The goalkeeper hurried/intended to toss the ball/the referee.

The angel hurried/intended to bring

24 The sheikh agreed/promised to lend the money/the investor.
The peasant agreed/promised to bring

25 The parents planned/decided to give a cello/the child.
The criminal planned/decided to show

26 The hotel receptionist forgot/hurried to pass the key/the porter.
The scientist forgot/hurried to send

27 The athlete insisted/declined to mail the protocol/the journalist.
The emperor insisted/declined to show

28 The gentleman wished/agreed to rent a limousine/the bride.
The cook wished/agreed to serve

29 The teenager refused/decided to show the tattoos/the teacher.
The golfer refused/decided to throw

30 The film star announced/planned to tell the story/the reporter.
The magician announced/planned to pass

31 The football hooligan volunteered/intended to hand the sports-
bag/the guard.
The policeman volunteered/intended to bring

32 The doctor declined/promised to give the vaccine/the patient.
The chief declined/promised to sell

33 The pirate insisted/considered to sell the raft/the sailor.
The nurse insisted/considered to loan

34 The fairy refused/intended to serve the potion/the elf.
The sunbather refused/intended to throw

35 The land owner hurried/planned to offer the lodge/the hunter.
The pilot hurried/planned to serve

36 The farmer intended/planned to rent the caravan/the tourists.
Sherlock Holmes intended/planned to offer

37 The TV chef managed/volunteered to serve a dinner/the
audience.
The surgeon managed/volunteered to sell

38 The babysitter promised/remembered to tell story/the toddler.
The hunchback promised/remembered to bring

39 The customer forgot/refused to pay a fee/the bank.
The flight attendant forgot/refused to serve

40 The tabloid agreed/declined to pay a settlement/the celebrity.
The hunter agreed/declined to lend

41 The life guard insisted/hurried to throw a rope/the swimmer.
The country singer insisted/hurried to lend

42 The woman threatened/hesitated to show the photos/the police.
The cook threatened/hesitated to serve

43 The artist preferred/wished to leave the painting/the collector.
The sumo wrestler preferred/wished to give

44 The company declined/agreed to give the documents/the
investigator.
The doorman declined/agreed to pass

45 The gentleman avoided/insisted to lend the money/the waitress.
The golfer avoided/insisted to give

46 The soldier intended/promised to hand the gun/the policeman.
The conductor intended/promised to sell

47 The teenager remembered/wished to send a postcard/the
grandmother.
The woman remembered/wished to give

48 The boxer refused/volunteered to give a lesson/the actor.
The sound technician refused/volunteered to bring

Appendix B. Experimental sentences in Experiments 2 and 3

1 The film producer proceeded/strove to pay the celebrity the
settlement.
The hunchback proceeded/strove to lend

2 The old lady volunteered/refused to serve the beggar the meal.
The model volunteered/refused to pass

3 The lifeguard neglected/hastened to throw the swimmer the
rope.
The country singer neglected/hastened to send

4 The babysitter omitted/attempted to feed the toddler the meal.
The soldier omitted/attempted to bring

5 The doctor desired/yearned to offer the patient the painkiller.
The girl desired/yearned to hand

6 The painter hesitated/vowed to lend the apprentice the ladder.
The farmer hesitated/vowed to show

7 The company threatened/guaranteed to give the investigator the
document.
The chauffeur threatened/guaranteed to sell

8 The customer endeavoured/undertook to pay the cashier the fee.
The flight attendant endeavoured/undertook to serve

9 The fashion designer aspired/craved to sell the actress the dress.
The photographer aspired/craved to show

10 The film producer pledged/disagreed to offer the actor the
contract.
The maid pledged/disagreed to bring

11 The student loathed/volunteered to show the teacher the diary.
The golfer loathed/volunteered to pass

12 The farmer opted/contrived to rent the tourist the caravan.
The detective opted/contrived to offer

13 The homeowner consented/arranged to pay the cleaner the
salary.
The pirate consented/arranged to show

14 The politician aimed/declined to give the immigrant the house.
The technician aimed/declined to bring

15 The butler rejoiced/craved to serve the queen the drink.
The conductor rejoiced/craved to offer

16 The General elected/longed to send the rebels the supplies.
The rock star elected/longed to sell

17 The child hesitated/pretended to feed the doll the chocolate.
The woman hesitated/pretended to give

18 The journalist hastened/vowed to mail the editor the story.
The paramedic hastened/vowed to bring

19 The patient demanded/yearned to show the nurse the certificate.
The criminal demanded/yearned to send

20 The geologist threatened/endeavoured to post the minister the
article.
The salesman threatened/endeavoured to rent

21 The parents guaranteed/intended to give the girl the cello.
The beekeeper guaranteed/intended to offer

22 The car salesman strove/undertook to sell the musician the Mini.
The astronaut strove/undertook to hand

23 The millionaire swore/desired to send the supermodel the Rolex.
The knight swore/desired to loan

24 The lawyer contrived/disagreed to bring the inmate the gun.
The coach contrived/disagreed to hand

25 The actress refused/arranged to leave the bodyguard the
mansion.
The prince refused/arranged to give

26 The detective longed/attempted to send the informant the
photograph.
The wizard longed/attempted to pass

27 The soldier proceeded/declined to hand the policeman the gun.
The surgeon proceeded/declined to sell

28 The archaeologist aimed/neglected to show the historian the
dagger.
The teenager aimed/neglected to feed

29 The sheikh pledged/elected to lend the investor the money.
The peasant pledged/elected to bring

30 The hotel receptionist omitted/grappled to give the porter the
key.
The bagpiper omitted/grappled to send

31 The spy loathed/consented to show the journalist the file.
The butcher loathed/consented to offer

32 The teenager demanded/vowed to take the girl the ring.
The cook demanded/vowed to serve

- 33 The politician opted/yearned to offer the reporter the story.
The magician opted/yearned to pass
- 34 The fairy desired/pretended to serve the elf the potion.
The Eskimo girl desired/pretended to feed
- 35 The rock star craved/longed to lend the waitress the money.
The cricketer craved/longed to give
- 36 The land owner undertook/hastened to offer the hunter the lodge.
The pilot undertook/hastened to serve
- 37 The teenager neglected/intended to send the grandmother the postcard.
The woman neglected/intended to feed
- 38 The bank manager endeavoured/swore to post the minister the cheque.
The boxer endeavoured/swore to send
- 39 The actor threatened/aspired to show the agent the photograph.
The rapper threatened/aspired to offer
- 40 The hotel owner hesitated/disagreed to loan the tourist the tent.
The chef hesitated/disagreed to pass
- 41 The estate agent aimed/strove to sell the gardener the cottage.
The racing driver aimed/strove to show
- 42 The parents loathed/omitted to pay the babysitter the wage.
The opera singer loathed/omitted to post
- 43 The pharmacist declined/elected to give the patient the drug.
The chief declined/elected to sell
- 44 The athlete intended/guaranteed to mail the journalist the protocol.
The businessman intended/guaranteed to show
- 45 The artist arranged/consented to leave the collector the painting.
The monk arranged/consented to serve
- 46 The woman pledged/refused to show the judge the document.
The cook pledged/refused to feed
- 47 The celebrity chef opted/attempted to serve the presenter the dinner.
The workman opted/attempted to give
- 48 The pirate proceeded/volunteered to sell the sailor the raft.
The nurse proceeded/volunteered to loan

Appendix C. Experimental sentences in Experiment 4

- 1 The film producer volunteered/proceeded to lend/bring the celebrity the money.
The hunchback proceeded to lend
- 2 The old lady intended/refused to serve/give the beggar the meal.
The model refused to give
- 3 The lifeguard neglected/hastened to hand/send the diver the postcard.
The country singer hastened to send
- 4 The painter hesitated/proceeded to lend/show the apprentice the ladder.
The farmer proceeded to show
- 5 The detective longed/threatened to send/pass the informant the photograph.
The wizard threatened to pass
- 6 The celebrity chef attempted/opted to serve/give the presenter a pie.
The workman opted to give
- 7 The caregiver neglected/intended to send/feed the grandmother the cake.
The woman intended to feed
- 8 The waiter hastened/undertook to offer/serve the customer the dessert.
The flight attendant undertook to serve
- 9 The fashion designer aspired/craved to sell/show the actress the dress.
The photographer craved to show

- 10 The producer pledged/omitted to offer/bring the actor the contract.
The maid omitted to bring....
- 11 The student intended/volunteered to show/pass the teacher the assessment.
The golfer volunteered to pass
- 12 The farmer opted/refused to rent/offer the tourist the caravan.
The detective refused to offer
- 13 The homeowner hesitated/arranged to bring/show the cleaner the key.
The pirate arranged to show
- 14 The company threatened/guaranteed to give/sell the investigator the document.
The chauffeur guaranteed to sell
- 15 The butler proceeded/neglected to serve/offer the queen the drink.
The conductor neglected to offer
- 16 The army general attempted/pledged to send/sell the rebels the supplies.
The rock star pledged to sell
- 17 The child pretended/hesitated to feed/give the doll the chocolate.
The woman hesitated to give
- 18 The journalist hastened/vowed to pass/bring the editor the story.
The paramedic vowed to bring
- 19 The candidate neglected/demanded to show/send the employer the certificate.
The criminal demanded to send
- 20 The hotel owner hesitated/decided to loan/pass the tourist the map.
The chef declined to pass
- 21 The parents guaranteed/intended to give/offer the girl the cello.
The beekeeper intended to offer
- 22 The salesman refused/opted to sell/hand the musician the trumpet.
The astronaut opted to hand
- 23 The millionaire swore/desired to send/loan the supermodel the Rolex.
The knight desired to loan
- 24 The pub owner endeavoured/hesitated to show/serve the landlord the lunch.
The monk hesitated to serve
- 25 The actress arranged/aimed to pass/give the bodyguard the file.
The prince aimed to give
- 26 The babysitter omitted/attempted to feed/bring the toddler the meal.
The soldier attempted to bring
- 27 The soldier proceeded/declined to hand/sell the policeman the gun.
The surgeon declined to sell
- 28 The peasant aimed/neglected to show/feed the traveller the goose.
The teenager neglected to feed
- 29 The lawyer refused/intended to bring/hand the inmate the gun.
The coach intended to hand
- 30 The hotel receptionist omitted/opted to offer/send the porter the key.
The bagpiper opted to send
- 31 The sheikh guaranteed/endeavoured to loan/bring the investor the money.
The peasant endeavoured to bring
- 32 The nanny demanded/strove to feed/serve the girl the spinach.
The cook strove to serve
- 33 The politician opted/proceeded to offer/pass the reporter the story.
The magician proceeded to pass

- 34 The fairy desired/pretended to serve/feed the elf the potion.
The Eskimo girl pretended to feed
- 35 The rock star craved/longed to bring the composer the money.
The cricketer longed to give
- 36 The landowner undertook/hastened to feed/serve the hunter the turkey.
The pilot hastened to serve
- 37 The politician aimed/declined to give/bring the immigrant the passport.
The technician declined to bring
- 38 The bank manager endeavoured/swore to post/send the minister the cheque.
The boxer swore to send
- 39 The actor declined/aimed to show/offer the agent the photograph.
The rapper aimed to offer
- 40 The geologist opted/endeavoured to give/rent the astronomer the equipment.
The salesman endeavoured to rent
- 41 The estate agent strove/aspired to sell/show the gardener the cottage.
The racing driver aspired to show
- 42 The parents vowed/omitted to hand/post the babysitter the wage.
The opera singer omitted to post
- 43 The pharmacist declined/attempted to pass/sell the patient the drug.
The chief attempted to sell
- 44 The athlete intended/guaranteed to bring/show the journalist the protocol.
The businessman guaranteed to show
- 45 The doctor desired/neglected to offer/hand the patient the painkiller.
The girl neglected to hand
- 46 The woman refused/desired to give/feed the dictator the poison.
The cook desired to feed
- 47 The spy declined/hesitated to pass/offer the journalist the tape.
The butcher hesitated to offer
- 48 The pirate proceeded/refused to sell/loan the sailor the raft.
The nurse refused to loan

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