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The lexical boost effect is stronger in main clauses than in subordinate clauses

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Structural priming effects are stronger if there is lexical overlap between prime and target, the so-called lexical boost effect to structural priming. While abstract structural priming is long-lasting and seems to reflect implicit learning, the lexical boost effect decays quickly and might be induced by residual activation or explicit memory. A recent study only found a lexical boost effect in ditransitive structures in subordinate clauses when the head verb in the subordinate clause rather than the matrix head verb was repeated between prime and target. We report an experiment in which the lexical boost effect is weaker in subordinate clauses than in main clauses when repeating the head verb. Our findings suggest that the lexical boost effect caused by repeating head verbs can be disrupted due to an increased amount of interfering material.

KEYWORDS

structural priming, lexical boost effect, residual activation, explicit memory, language production

1 Introduction

Speakers have the tendency to repeat a structure that they have recently encountered. This phenomenon is called structural priming and is exploited as a research paradigm to investigate the representation of syntactic structures. Bock (1986) found that participants produced more passive sentences (*The building manager was mugged by a gang of teenagers*) to describe a target picture displaying a transitive event after a passive prime sentence (*The referee was punched by the fans*) than after an active prime sentence (*The fans punched the referee*).

Although this effect also occurs if lexical items are different between prime and target (see Pickering and Ferreira, 2008 for an overview), the priming effect is larger if there is lexical repetition between prime and target (Pickering and Branigan, 1998). While abstract structural priming is long-lasting [i.e., persisting even after ten intervening items between prime and target (Bock and Griffin, 2000)] and is probably due to an error-based implicit learning mechanism (Chang et al., 2006), the so-called lexical boost effect is short-lived and decays rapidly (Hartsuiker et al., 2008).

There is a debate on whether the source of the lexical boost effect is residual activation and/or explicit memory. First, the lexical boost effect may be explained from the residual activation account (Pickering and Branigan, 1998). Lexical nodes are linked to combinatorial nodes representing syntactic structures. After priming with the phrase *give the dog a bone*, there is residual activation of the lexical node of *give*, the direct-object dative node, and the link between the lexical node and the combinatorial node. Therefore priming effects should be stronger if the verb *give* is repeated in the target than if the prime

and the target contain different verbs. Alternatively, the lexical boost effect may be induced by explicit memory of the prime sentence (Chang et al., 2006). The repeated lexical items may provide a cue for memory retrieval. In line with this proposal, Rowland et al. (2012) suggested that the lexical boost effect increases during language development in children upon maturation of memory systems. Zhang et al. (2020) found that structural priming of Dutch genitives was weaker if participants had to solve mathematical problems between the prime and target, showing that structural priming effects are reduced if there is an increased cognitive load.

Crucially, the residual activation account predicts that the lexical boost effect only occurs if the head of the construction is repeated between prime and target, while the lexical boost effect may be induced by repetition of any lexical item if the source is explicit memory. Empirical findings show a mixed picture. Scheepers et al. (2017) investigated lexical repetition effects in English ditransitives, repeating either the head verb or one of the non-head nouns (the agent, the recipient, or the theme noun) between prime and target. The repetition of any lexical item led to a lexical boost effect in structural priming. Moreover, the more lexical items were repeated between prime and target, the stronger the lexical boost effect was, implying that any content word can serve as an additional cue for memory retrieval of the syntactic structure.

However, Carminati et al. (2019) failed to replicate the findings of Scheepers et al. (2017) and only observed an effect of the repetition of the head verb. Similarly, Huang et al. (2023) did not find an effect of repetition of the agent, theme or recipient noun in Mandarin ditransitive sentences. Importantly, van Gompel et al. (2023) suggest that non-head noun repetition only occurs if there is a very explicit repetition, such as a visual cue (as was the case in Scheepers et al., 2017). They observed a significant lexical boost effect of the agent noun in English ditransitives only if participants could still see the prime when completing the target sentence. At the same time, repeating the head verb leads to a lexical boost effect on structural priming regardless of whether there is a visual cue. Note that most structural priming studies do provide a visual cue for the head verb, however: in the commonly used picture description task, the verb is often written below the picture. The findings of Van Gompel indicate that a non-head lexical boost effect can appear when explicit memory is strongly called upon, while the lexical boost effect caused by head repetition is due to a more automatic process such as residual activation.

Recently, Kantola et al. (2023) further investigated the lexical boost effect of non-head lexical items. Instead of repeating the non-head nouns of ditransitive sentences, they tested structural priming of ditransitive structures in subordinate clauses, while repeating the verb of the matrix clause (which is the syntactic head of the sentence). In a series of experiments, they tested whether participants were primed more strongly after a prime sentence *The hotel owner refused to loan a tent to the tourist* if the target sentence prompt had the same matrix verb (*The chef refused to pass…*) rather than a different matrix verb (*The chef decided to pass…*). Surprisingly, Kantola et al. did not observe a lexical boost effect when the matrix verb but not the head verb was repeated. A lexical boost effect was only found when the head verb of the primed structure was repeated between prime (*The painter hesitated to show the apprentice the ladder*) and target (*The farmer proceeded to show…*). Their results support a residual activation account as explanation for the lexical boost effect: the lexical boost effect seems to be driven by the link between the verb and the primed syntactic structure in the subordinate clause.

An alternative explanation for the findings of Kantola et al. (2023) may be that the lexical boost effect is smaller if there is more interfering material, similar to the rapid decay of structural priming if there is a lag between prime and target (Hartsuiker et al., 2008). Crucially, it may not only be the case that explicit memory can induce a non-head lexical boost effect under particular circumstances (cf. van Gompel et al., 2023), but also that a head lexical boost effect can be disrupted due to interfering material. The interfering material from the main clause may put a higher load on the working memory, which makes it harder to retain the sentence structure and to use lexical cues to retrieve it. In the items of Kantola et al., the distance between the prime matrix verb *refused* and the production of the ditransitive target structure (*refuse – loan – refuse – pass X)* is larger than the distance between the prime head verb *loan* and the target structure (*show – proceed – show X)*, also in terms of the number of intervening verbs. This may explain why Kantola et al. found a lexical boost effect in the latter case, but not when the matrix verb is repeated between prime and target.

If interfering verbs may disrupt the lexical boost effect, we may expect that the lexical boost effect is smaller in a subordinate clause than in a main clause, even if the head verb of the primed syntactic structure is repeated. Branigan et al. (2006) showed that in abstract structural priming, the priming effect has the same magnitude in the main clause as in the subordinate clause. However, given the short-lived nature of the lexical boost effect, the presence of the main clause may already lead to the decay of the lexical boost effect. In the current study, we therefore tested structural priming of Dutch passives occurring either in a main clause or a subordinate clause with and without lexical repetition of the head verb of the passive structure, and compared the magnitude of the lexical boost effect between clause types.

Different from English, where the prepositional phrase (PP) always follows the participle verb, in Dutch, there is optionality for PP placement in passives. Importantly, the Dutch PP-final (*De zwemmer wordt achtervolgd door de politieagent* "The swimmer is being followed by the policeman") and PP-medial passives (*De zwemmer wordt door de politieagent achtervolgd*—lit. "The swimmer is-being by the policeman followed") only differ in terms of syntactic linearization and not in terms of sentence length, thematic role ordering or information structure (Bernolet et al., 2009), factors which potentially affect lexical cue retrieval and thus the lexical boost effect. PP-final and PP-medial passives can be primed separately in an abstract structural priming experiment (van Lieburg et al., 2023). As such, any structural priming effects and interactions with lexical overlap presumably take place on the level of constituent structure and should not be attributed to priming on other levels.

2 Materials and methods

2.1 Participants

One hundred and forty one participants completed the experiment (91 female, 45 male, and 5 other). Participants were recruited online on the internal student channels of the University

of Antwerp, Belgium. We gave away gift vouchers among the participants as a reward for their participation. Participants had Dutch as their L1, were aged between 18 and 35 (mean = 22.8, *SD* = 3.9), had (corrected to) normal vision and did not have dyslexia. The research was approved by the university's ethical committee Social Sciences and Humanities under file SHW_18_77.

2.2 Materials and design

We designed a structural priming experiment with a picture description task and auditory primes. The experiment included five prime conditions (a baseline and the two passive structures in a condition with and without lexical overlap), which we tested within participants. We had a main clause condition and a subordinate clause condition, which was varied across participants.

The materials were adapted from van Lieburg et al. (2023) and included pictures from the International Picture Naming Project (Bates et al., 2003). We created 40 critical prime-target pairs and 80 filler prime-target pairs. Following Mahowald et al. (2016), the power to detect the lexical boost effect would be over 99%. The power to detect a medium interaction between prime condition and clause type (with a coefficient of 0.5) would be approximately 80% (although the table assumes two prime conditions without lexical overlap, while we additionally have two conditions with lexical overlap).

For the prime items, we constructed a set of prime sentences which occurred in five prime conditions (baseline, PP-final passive/Different verb, PP-medial passive/Different verb, PP-final passive/Same verb, PP-medial passive/Same verb). The baseline prime sentences were conjoint noun phrases (see Example 1–5).

(1) **Baseline condition**
de zwemmer en de politieagent
the swimmer and the policeman
'the swimmer and the policeman'

(2) **PP-final passive/Different verb**
De zwemmer wordt achtervolgd *door de politieagent*.
the swimmer AUX follow.PTC by the policeman
'The swimmer is being followed by the policeman.'

(3) **PP-medial passive/Different verb**
De zwemmer wordt *door de politieagent* achtervolgd.
the swimmer AUX by the policeman follow.PTC

(4) **PP-final passive/Same verb**
De zwemmer wordt gesleept *door de politieagent*.
the swimmer AUX drag.PTC by the policeman
'The swimmer is being dragged by the policeman.'

(5) **PP-medial passive/Same verb**
De zwemmer wordt *door de politieagent* gesleept.
the swimmer AUX by the policeman drag.PTC

The same prime sentences were used in the main clause condition and in the subordinate clause condition. To create the different prime conditions in the subordinate clause condition, the sentences (2–5) were inserted in a matrix clause (Example 6). The matrix clause included verbs that could take the prime sentence as their complement clause (e.g., *vertellen* "tell," *dromen* "dream," *vrezen* "fear"). We increased the complexity of the baseline primes by inserting them in a transitive phrase (Example 7).

(6) **Subordinate matrix clause**
De vrouw droomt dat… (de zwemmer [door de politieagent] wordt
the woman dreams that… the swimmer [by the policeman] AUX
achtervolgd/ gesleept [door de politieagent]).
follow.PTC/ drag.PTC [by the policeman]
"The woman is dreaming that… (the swimmer is being followed/dragged by the policeman)"

(7) **Baseline prime in the subordinate clause condition**
De vrouw bespiedt de zwemmer en de politieagent.
the woman spies the swimmer and the policeman
"The woman spies on the swimmer and the policeman"

Filler prime sentences included 40 active sentences and 40 intransitive sentences. The prime sentences were recorded by a female native speaker of Dutch. We also selected a verification picture for each prime sentence. Half of the verification pictures matched the action described by the prime sentence and half of the verification pictures displayed a different action.

For each target item, we selected a picture and a Dutch transitive verb. Critical target pictures displayed an agent and a patient performing an action that could be described by the transitive verb (e.g., a suitcase being dragged by a boy). In the subordinate clause condition, the agent of the matrix clause was presented to the left of the scene depicting the action from the subordinate clause. The head verb of the passive prime sentence matched the verb from the Same verb conditions of the corresponding prime item (e.g., *slepen* "drag"). In the subordinate clause condition, the verb of the matrix clause was always different between prime and target, regardless of the prime condition. A red frame indicated the patient in order to elicit passive responses. Figure 1 shows an example of a prime-target pair in both conditions.

For each target sentence, we created a sentence prompt. For the critical items in the matrix clause condition, the sentence prompt included the patient (e.g., *de koffer* "the suitcase" for the target picture in Figure 1). As for the subordinate clause condition, we included the matrix clause in the sentence prompt (e.g., *De leraar zegt dat de koffer* "The teacher is saying that the suitcase") in order to keep the completion time of the experiment constant and to avoid fatigue effects.

Filler target pictures either elicited an active sentence (having a red frame around the agent) or an intransitive sentence (displaying only one entity and an intransitive verb) The sentence prompt in the active and intransitive filler items was the subject of the sentence (e.g., *De leraar* "The teacher").

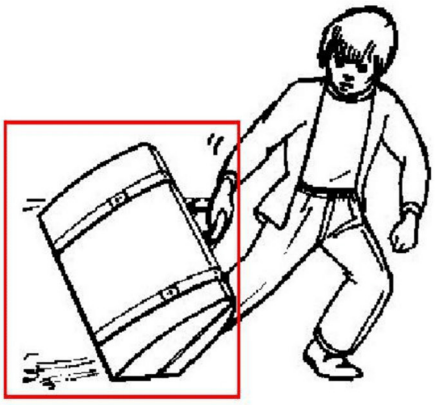
In the experiment, we pseudo-randomized the order of the prime-target items to ensure that there was always at least one filler between two target items. The experimental list started with four fillers in order to familiarize the participants with the procedure. We constructed five different lists for the main clause condition and similarly, five lists for the subordinate clause condition. While the target items were kept constant across lists, the prime sentences occurred in a different prime condition in every list. Within each

a) Main clause condition

Prime (PP-final passive, different verb):
De zwemmer wordt achtervolgd door de politieagent.
'The swimmer is being followed by the policeman.'

Prime (PP-final passive, same verb):
De zwemmer wordt gesleept door de politieagent.
'The swimmer is being dragged by the policeman.'

Target:
Sentence prompt: *De koffer* 'the suitcase'



slepen

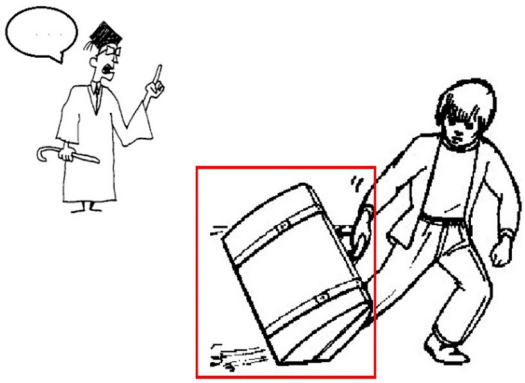
Expected target response:
(De koffer) wordt gesleept door de jongen.
'(The suitcase) is being dragged by the boy'.

b) Subordinate clause condition

Prime (PP-final passive, different verb):
De vrouw *droomt* dat de zwemmer wordt achtervolgd door de politieagent.
'The woman *dreams* that the swimmer is being followed by the policeman.'

Prime (PP-final passive, same verb):
De vrouw *droomt* dat de zwemmer wordt gesleept door de politieagent.
'The woman *dreams* that the swimmer is being dragged by the policeman.'

Target:
Sentence prompt: *De leraar roept dat de koffer* 'the teacher shouts that the suitcase'



slepen

Expected target response:
(De leraar roept dat de koffer) wordt gesleept door de jongen.
'(The teacher shouts that the suitcase) is being dragged by the boy'.

FIGURE 1
Example of a prime-target pair in the main clause condition and in the subordinate clause condition.

list, each prime condition was presented equally often (i.e., 8 items per prime condition).

The experiment was programmed in PsychoPy (Peirce et al., 2019) and hosted on its online platform Pavlovia. The experiment was embedded in a Qualtrics survey (Qualtrics, Provo, UT) with the instructions on the experiment.

2.3 Procedure

Participants performed the experiment online and were provided with written instructions. After reading the instruction and giving their informed consent in Qualtrics, they were forwarded to the experiment on Pavlovia. Participants were

randomly assigned to one of the conditions (main clause vs. subordinate clause) and to one of the five lists within each condition. At each trial, participants first listened to the prime sentence. Then the screen was replaced by the verification picture. They had to indicate whether the picture matched the preceding sentence by clicking on a green button (match) or a red button (mismatch). They were then presented with the target picture, the target verb written below it, and a text box already containing the sentence prompt. Participants were instructed to write a completion to the sentence prompt, describing the target picture, while using the provided verb. A session took about 25 min.

2.4 Coding

The target responses were coded as PP-final passive, PP-medial passive or "Other." "Other" responses included responses in which a different verb was used and responses of a different structure, including agentless/short passives *(de koffer wordt gesleept* "the suitcase is being dragged") and active sentences.

3 Results

We collected 5,640 responses. Three thousand two hundred and ninety four of the responses (58.4%) were coded as PP-final passive and 1,007 of the responses (17.9%) were classified as PP-medial passive. One thousand three hundred and thirty nine responses (23.7%) were coded as "Other" (including agentless/short passives). We excluded the "Other" responses for further analyses. Table 1 shows the number of responses per prime condition and per clause type. Figure 2 shows the proportion of PP-final and PP-medial responses per prime condition.

We first tested in which conditions there was significant structural priming relative to the baseline prime condition by fitting the responses to a generalized linear mixed model (R-package *lme4*, Bates et al., 2015) with a BOBYQA optimizer to increase the convergence ability (Powell, 2009). We included Prime Condition (five levels), Clause Type (two levels), and their interaction as fixed factors; the baseline prime condition and the main clause condition were chosen as reference levels. We started with a model with a maximal random effects structure (Barr et al., 2013) including random slopes for Prime Condition and Clause Type to Participants and Target Items and random intercepts for Participants and Target Items. We reduced the model until there were no issues with convergence or singularity. The final model included random intercepts for Participants and Target Items and no random slopes. In the main clause condition, we observed significant priming effects in all prime conditions relative to the baseline (see Table 2). In the baseline prime condition and in the two different-verb conditions, there was no significant difference in the proportion of PP-final and PP-medial responses between the main clause condition and the subordinate clause condition. However, participants produced significantly fewer PP-final passives after a PP-final passive prime ($\beta = 0.970$, $SE = 0.376$, $p < 0.01$) and similarly, significantly fewer PP-medial passives after a PP-medial prime ($\beta = -0.805$, $SE = 0.297$, $p < 0.01$) in the subordinate clause condition than in the main clause condition if the verb was repeated between prime and target.

We computed *post-hoc* pairwise comparisons by using the *emmeans* function to test whether there was a lexical boost effect for PP-medials and PP-finals in the two clause types, that is, whether priming was significantly stronger in the same-verb conditions than in the different-verb conditions. In the main clause condition, the proportion of PP-final passives was significantly higher after a PP-final prime with verb overlap than after a PP-final prime with a different verb between prime and target ($\beta = 1.178$, $SE = 0.292$, $p < 0.01$). Similarly, participants produced more PP-medial passives after a PP-medial prime with verb overlap than after a PP-medial prime without verb overlap ($\beta = -1.432$, $SE = 0.184$, $p < 0.001$). In the subordinate clause, there was no significant difference between the same-verb and different-verb condition for the PP-final passives ($p = 0.328$); we only observed a significant lexical boost effect for PP-medial passives. Participants were more likely to produce a PP-medial passive after a PP-medial prime if the verb was repeated between prime and target than if a different verb was used ($\beta = -0.979$, $SE = 0.202$, $p < 0.001$).

4 Discussion

The results showed that the lexical boost effect was significantly weaker in subordinate clauses than in main clauses. In the main clause condition, priming of both PP-medial and PP-final passives was boosted by verb overlap between prime and target. In the condition with subordinate clauses, a lexical boost effect only occurred for PP-medial passives and not for PP-final passives. Also for PP-medial passives, the lexical boost effect was significantly weaker in subordinate clauses than in main clauses. In line with Branigan et al. (2006), who found that there is no effect of global structure on structural priming *per se*, we do not find a difference in the magnitude of structural priming between the two clause types in the different-verb conditions. Structural priming was only weaker in subordinate clauses than in main clauses in the same-verb conditions. This is in accordance with our hypothesis that interfering material from the main clause may decrease the lexical boost effect in the subordinate clause.

Our results thus mirror the findings of van Gompel et al. (2023): while an enhancing cue may facilitate the lexical boost effect in non-heads, interfering material may interrupt the lexical boost effect in heads. This may provide an alternative explanation for the findings of Kantola et al. (2023), who observed a lexical boost effect in subordinate clauses when the head verb of the subordinate clause was repeated but not when the matrix verb was repeated. There is more interfering material between the matrix verb of the prime and the target structure than between the head verb of the subordinate clause of the prime and the target structure. Although we do not dispute the role of residual activation *per se*, and we acknowledge that the lexical boost may be more robust when repeating head verbs rather than non-head verbs, our findings suggest that the absence of a lexical boost effect in non-head items in Kantola et al. (2023) may not be interpreted as conclusive evidence against models predicting a non-head lexical boost effect. Increasing the working memory load may disturb the lexical boost effect, even if heads are repeated between prime and target.

TABLE 1 Number of PP-final and PP-medial target responses per prime condition and per clause type.

Prime condition	Main clause condition		Subordinate clause condition	
	PP-final responses	PP-medial responses	PP-final responses	PP-medial responses
baseline	$n = 334$	$n = 82$	$n = 297$	$n = 82$
PP-final/Different verb	$n = 394$	$n = 52$	$n = 342$	$n = 65$
PP-final/Same verb	$n = 478$	$n = 22$	$n = 375$	$n = 56$
PP-medial/Different verb	$n = 295$	$n = 134$	$n = 294$	$n = 108$
PP-medial/Same verb	$n = 234$	$n = 244$	$n = 251$	$n = 162$

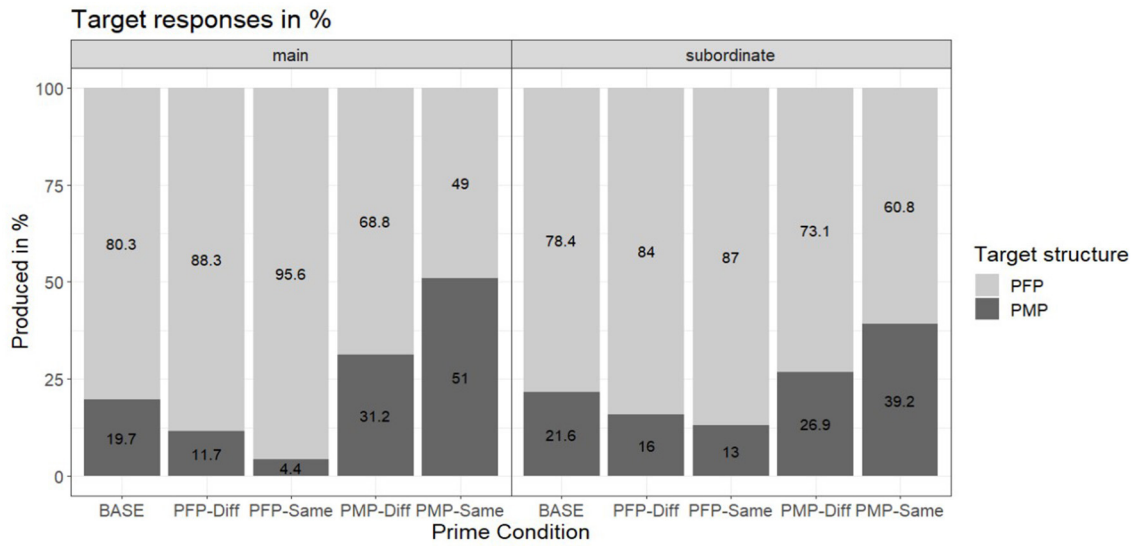


FIGURE 2
Proportion of structures produced per prime condition in the main clause and the subordinate clause conditions. PFP, PP-final phrase; PMP, PP-medial phrase; Diff, Different verb between prime and target; Same, Same verb between prime and target.

TABLE 2 Generalized linear mixed model [Target Structure ~ Prime*Clause Type + (1|Participant) + (1|Target Item)], $n = 4,265$, log-likelihood = −1,509.8).

	Estimate	SE	z-value	*p*-value
Intercept	−2.429	0.318	−7.649	<0.001***
Prime(PFP-Diff)	−0.871	0.228	−3.815	<0.001***
Prime(PFP-Same)	−2.049	0.282	−7.256	<0.001***
Prime(PMP-Diff)	0.893	0.202	4.425	<0.001***
Prime(PMP-Same)	2.325	0.204	11.416	<0.001***
Clause(subordinate)	−0.014	0.442	−0.031	0.975
Prime(PFP-Diff)*__Clause__(subordinate)	0.264	0.332	0.795	0.427
Prime(PFP-Same)*__Clause__(subordinate)	0.970	0.376	2.580	<0.01**
Prime(PMP-Diff)*__Clause__(subordinate)	−0.352	0.301	−1.169	0.243
Prime(PMP-Same)*__Clause__(subordinate)	−0.805	0.297	−2.713	<0.01**

The reference level is the baseline prime condition in the matrix clause. PFP, PP-final phrase; PMP, PP-medial phrase; Diff, Different verb between prime and target; Same, Same verb between prime and target. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

We replicated the finding of Kantola et al. (2023) that there is a lexical boost effect in subordinate clauses if the head verb of the subordinate clauses is repeated. Note that we primed the passive alternation in Dutch, whereas Kantola et al. tested ditransitive sentences in English. However, in the subordinate clause, we only found a lexical boost effect for one of the structural alternatives,

namely the PP-medial passive. Zhang et al. (2020) found that structural priming was only disrupted by an increased working memory load if the interfering material is demanding enough. If participants had to solve easy instead of difficult mathematical problems between the prime and target, there was no reduced lexical boost effect. The increased load on working memory due to the embedding of the critical structure in a matrix clause may be relatively limited, especially in our experiment where participants had to perform a written sentence completion task in which they had to complete a picture description. This might be why we were still able to observe a (reduced) lexical boost effect in PP-medial passives (but not for PP-final passives) in subordinate clauses. Priming of the PP-medial passive in Dutch is stronger due to the inverse preference effect (Ferreira and Bock, 2006) and thus more robust (cf. van Lieburg et al., 2023, who only observed PP-medial passive priming in an abstract structural priming experiment).

More research is needed to understand to what extent the absence of the lexical boost effect in non-head nouns (as observed by Carminati et al., 2019; van Gompel et al., 2023; Huang et al., 2023) may be caused by explicit memory effects. As a ditransitive sentence typically contains three nouns, it may be harder to use one of the nouns as a lexical retrieval cue than it is to use the only verb as a cue to retrieve the syntactic structure. If unrepeated lexical material within the sentence may disturb lexical retrieval of the repeated material, this would for instance suggest that it may be easier to boost structural priming with non-head noun repetition if the unrepeated arguments are pronouns rather than full noun phrases, causing less interference, like in the prime sentence *The farmer gave it to him* preceding the target *A farmer showed…* (cf. Warren and Gibson, 2002).

5 Conclusion

Our findings show that the lexical boost effect is weaker in subordinate clauses than in main clauses, if the head verb is the repeated verb. This suggests that the interfering material from the matrix clause restrains the use of the head verb as a lexical cue for syntactic structure retrieval.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: Open Science Framework: https://osf.io/cs976/.

Ethics statement

The studies involving humans were approved by the Ethics Committee for the Social Sciences and Humanities, University of Antwerp under file number SHW_18_77. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. SB: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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