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Evidence for a constituent order boost in structural priming

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The study investigates the role of constituent order in structural priming. We report the results from a PO/DO priming experiment in German, in which we experimentally manipulated verb position in primes and targets. Significant structural priming effects occurred irrespective of whether verb position was the same in prime and target or not. However, additional similarity in constituent order was able to boost structural priming effects, with significantly stronger priming when the verb occurred in the same position in prime and target. We argue that existing one-stage and two-stage accounts of formulation struggle to account for the entire data pattern and propose an alternative account of formulation which can explain our results.

1. Introduction

During sentence production, speakers have to make real-time decisions on a particular structure for the sentence they intend to produce. For instance, when producing a ditransitive sentence in English, speakers have to choose between a prepositional object (PO) and a double object (DO) structure. In addition, speakers also have to make decisions about the particular order of constituents within a sentence. For example, when intending to produce a ditransitive sentence with a prepositional object structure, they can choose between a shifted constituent order in which the recipient is mentioned first (as in *The racing driver showed to the helpful mechanic the problem with the car*, from Pickering et al., 2002) and a non-shifted constituent order (as in *The racing driver showed the problem with the car to the helpful mechanic*).

A key controversy in research on sentence production revolves around the issue of whether both the decision for a particular structure and the decision for a particular constituent order are made at the same stage of formulation or not. *Two-stage accounts* of formulation (e.g. Bock & Levelt, 1994; Garrett, 1975) assume that each of the two decisions is made at a distinct stage of formulation: At the *functional* stage, the formulator first decides to use a particular structure (such as a PO), and assigns thematic roles and grammatical functions to the constituents which are part of the chosen structure accordingly. At a subsequent *positional* stage, the formulator decides in which order these constituents should be produced. For instance, when producing a shifted ditransitive PO structure in a sentence such as *The racing driver showed to the helpful mechanic the problem with the car*, the formulator would first make the decision to use a PO structure, and assign thematic roles to the arguments of which this structure consists. Only after this would the formulator decide on the particular order of these constituents, and make the decision to produce the prepositional phrase *to the helpful mechanic* first. *One-stage accounts* of formulation, in contrast, are based on the assumption that both decisions are made in a single step. For example, one such account, the *combinatorial node model* (e.g. Hartsuiker et al., 2004; Hartsuiker & Pickering, 2008; Pickering & Branigan, 1998; Pickering et al., 2002;), assumes that syntactic structures such as a DO, PO or shifted PO structure are represented through combinatorial nodes situated at the lemma stratum. These combinatorial nodes contain information about both of the arguments which are part of the respective structure, and also about the order in which these arguments should occur in a sentence. For a non-shifted PO structure, for instance, the corresponding combinatorial node contains the information that the structure consists of a VP, two NPs which specify theme and recipient, and a preposition, and specifies that these constituents have to occur in a particular order, in this case VP – NP – prep – NP. The account assumes that an otherwise similar structure in which these constituents occur in a different order, for example, a shifted PO structure in a sentence such as *The racing driver showed to the helpful mechanic the problem with the car*, possesses its own combinatorial node. During sentence production, the formulator activates a particular combinatorial node, which at the same time determines both the structure of the sentence and the order in which the constituents occur within the sentence.

An experimental paradigm which has been extensively employed to try and distinguish between one-stage and two-stage accounts of formulation is *structural priming*. In a typical structural priming experiment, participants are exposed to a prime sentence which contains a particular structure, and shortly thereafter produce a target sentence in which they can either re-use the same structure as in the preceding prime sentence or an alternative structure (Bock, 1986). A considerable number of studies have convincingly shown that, when producing the target sentence, speakers tend to re-use structures they have previously encountered in the preceding prime sentence. One example of how the structural priming paradigm can be used to differentiate between one-stage and two-stage accounts of formulation comes from Pickering et al. (2002). In a set of PO/DO priming experiments, Pickering et al. (2002) compared priming effects for shifted versus non-shifted PO sentences. Consider prime sentences such as (1a) to (1c):

(1) a. The racing driver showed the extremely dirty and badly torn overall to the mechanic. (non-shifted PO)
   b. The racing driver showed to the mechanic the extremely dirty and badly torn overall. (shifted PO)
   c. The racing driver showed the mechanic the extremely dirty and badly torn overall. (DO)

Pickering and colleagues presented their participants with prime sentences such as (1a) to (1c), and subsequently asked them to complete sentence fragments which could be completed with either a PO or a DO structure. While one-stage and two-stage models of formulation both predict that non-shifted PO prime sentences should prime PO target completions (i.e. with relatively more PO completions following non-shifted PO primes than following DO primes), the two accounts differ with regard to their prediction for shifted PO primes: According to two-stage accounts, the formulator first makes a decision to produce a PO structure, and only later decides in which order the constituents should occur. In other words, there is only a single representation for all PO structures, in which the exact order of the constituents which are part of the PO structure is not specified. This PO representation is activated during processing of any PO prime sentence, irrespective of whether the constituent order within the prime sentence is shifted or not. Thus, two-stage accounts of formulation predict that both shifted and non-shifted PO prime sentences should prime PO target completions. One-stage accounts, in contrast, assume that shifted and non-shifted POs are essentially two different structures, with a distinct representation for each of the two. As a result, only non-shifted POs should prime PO target completions, while shifted PO primes should not prime non-shifted POs and vice versa. Indeed, Pickering and colleagues found that only non-shifted PO primes primed PO target completions, with the number of PO completions following shifted PO primes being similar to the number of PO completions following DO primes. The authors thus concluded that their results support a one-stage account of formulation. Köhne et al. (2014) investigated the same phenomenon in a study on German, in which they again compared priming effects for German PO, DO, and shifted DO primes. While each of the three prime structures increased the number of corresponding responses in the target (i.e. with relatively more PO responses following PO primes, more non-shifted DO responses following DO primes, and more shifted DO responses following shifted DO primes), there was no priming between shifted and non-shifted DO sentences. The authors interpreted these results as evidence in favour of a one-stage account of formulation. Similar results were obtained by Bernolet et al. (2009) in a Dutch active/passive priming experiment, in which the by-phrase in passive prime sentences occurred either in sentence-medial or sentence-final position. The results showed priming effects for the specific constituent order (i.e. with PP-medial passives priming PP-medial passives and PP-final passives priming PP-final passives), but no priming between passive structures with different constituent orders.

The role of constituent order in structural priming has also been investigated in cross-linguistic priming studies. In such experiments, the key question is whether priming effects emerge for structures which exist in both languages, but require a different constituent order in each language. While such an approach may, at least *prima facie*, feel somewhat indirect and artificial, it possesses the considerable advantage that the above-mentioned restrictions associated with manipulating constituent order within a single language are largely circumvented. A good example is Loebell and Bock (2003), who investigated cross-linguistic structural priming effects for PO/DO and active/passive alternations between English and German. Their results showed significant cross-linguistic priming for PO vs. DO constructions, but not for active vs. passive constructions. To explain this finding, the authors argue that PO and DO structures possess the same constituent order in English and German, while for passives, constituent order differs between the two languages. Similar results supporting a one-stage account of formulation were found by Bernolet et al. (2007), who investigated cross-linguistic priming effects for relative clause constructions (e.g. *the sheep that is red*) vs. adjectival constructions (e.g. *the red sheep*). They report both a priming study between German and Dutch (where constituent order in both RC constructions and adjectival constructions is the same in both languages) and a study between English and Dutch (where the required constituent order in RC constructions differs between the two languages). Significant cross-linguistic structural priming only emerged between German and Dutch, suggesting that structural priming effects require cross-linguistic similarity with regard to constituent order. Finally, Jacob et al. (2017), in a study investigating cross-linguistic structural priming effects between English and German for the dative alternation, experimentally manipulated verb position within the prime and target sentences. The results showed significant priming effects only when the verb occurred in the same position in primes and targets.

In the studies discussed so far, significant structural priming effects only occurred for cases where constituent order was similar in primes and targets. In a number of other cross-linguistic priming studies, however, significant priming effects emerged even when primes and targets did not share the same constituent order. For instance, in Shin and Christianson's (2009) cross-linguistic priming study on priming effects between English and Korean PO and DO structures, significant priming effects emerged despite the fact that English and Korean ditransitive structures differ in constituent order. Similarly, Chen et al. (2013) found significant structural priming effects for the active/passive alternation between English and Mandarin Chinese, even though constituent order within the passive differs between the two languages. Finally, the already-mentioned study by Bernolet et al. (2009) also investigated cross-linguistic priming from PP-medial versus PP-final Dutch passive primes to English targets. Unlike in their within-Dutch priming study, where priming effects emerged only for the specific constituent order, both PP-final and PP-medial Dutch primes primed the use of English passive structures in the target. However, the fact that these priming effects were stronger for PP-final than for PP-medial passives suggests that even here, similarity in constituent order nonetheless played a role.

A practical problem with the methodological approach employed in these studies is that, at least for the structural alternations commonly investigated in structural priming studies (e.g. PO vs. DO, active vs. passive, transitive vs. intransitive, adjectival vs. relative clause), possibilities to experimentally manipulate constituent order in the primes are naturally quite restricted, due to properties of the language. Even in cases where moving a constituent to another position is in principle possible, such as for the English shifted PO structure used in Pickering et al. (2002) or passives with a sentence-medial or sentence-final by-phrase as in Bernolet et al. (2009), it is usually impossible to experimentally manipulate constituent order in the same way in both PO and DO (or in both active and passive) primes: For example, while English allows for shifted PO structures, shifted DO structures, such as **The man sent a letter the boy*, are ungrammatical in English. Another issue is that changing constituent order in this way automatically also changes a number of other properties of the sentence. For instance, the shifted and non-shifted versions of sentences (1a) and (1b) do not only differ with regard to the position of the prepositional phrase *to the mechanic*; instead, speakers typically use the shifted version to convey additional information, in this case, to strongly emphasize the recipient. Thus, a sentence such as (1b) is highly marked, and would (at least in natural conversations) typically only occur within a surrounding context which licences this somewhat unusual constituent order. This may lead to problems with the interpretation of priming effects. For instance, it is possible that priming effects are actually not structural in nature. Instead, participants may get primed by the fact that the recipient NP is strongly emphasized in the prime sentence, and may thus be more likely to produce a target sentence in which the recipient NP is also emphasized. In fact, Bernolet and colleagues explain the effects they observed of the position of the by-phrase in passive sentences along these lines (see Bernolet et al., 2009, for a detailed discussion).

While cross-linguistic priming studies avoid the above-mentioned issues with manipulating constituent order within a single language, investigating formulation in this way is not without problems, either. For instance, any cross-linguistic priming study necessarily puts the participants in a code-switching situation, in which the processing mechanisms for both their L1 and L2 have to be kept active. It is not clear whether formulation in such code-switching situations is entirely the same as in monolingual situations. Also, such studies often involve a number of practical issues related to the L2 proficiency of the participants.

2. The present study

In the studies discussed above, the experimental manipulation of constituent order automatically also caused differences with regard to other, non-structural properties, such as emphasis of the respective constituent. As a result, the priming effects observed in these studies may not necessarily be structural in nature. However, it is in principle possible to rely on a manipulation of constituent order which is not pragmatically motivated, but instead grammatical in nature. An instructive example of this approach is a within-German structural priming study by Chang et al. (2015), which relied on a particular structural property of German to experimentally manipulate the verb position in PO and DO prime sentences. For example, consider German PO prime sentences such as (2a) and (2b):

(2)	a.	Martin	**schickt**	den	Brief	an	die	Mutter.	
		Martin	send.$_{\text{3SG.PRS}}$	the.$_{\text{MASC.ACC.SG}}$	letter.$_{\text{SG}}$	to	the.$_{\text{FEM.ACC.SG}}$	mother.$_{\text{SG}}$	
		‘Martin sends the letter to the mother.’							
	b.	Martin	**hat**	den	Brief	an	die	Mutter	**geschickt**.
		Martin	has.$_{\text{3SG.PRS.AUX}}$	the.$_{\text{MASC.ACC.SG}}$	letter.$_{\text{SG}}$	to	the.$_{\text{FEM.ACC.SG}}$	mother.$_{\text{SG}}$	sent.$_{\text{3S.PTCP}}$
		‘Martin has sent the letter to the mother.’							

In German sentences such as (2a), the verb *schickt* occurs in V2 position. In an otherwise identical sentence such as (2b), in which the verb phrase is marked for perfective tense (and thus consists of auxiliary *hat* and the participle *geschickt*), the V2 position is occupied by the auxiliary *hat*, while the participle *geschickt* occurs in sentence-final position. Note that this possibility to manipulate verb position is based entirely on grammatical rules for the respective sentential structures, and does not involve any pragmatic considerations (such as emphasizing a particular constituent).

In a German PO/DO priming experiment, Chang et al. (2015) used this structural property of German to experimentally manipulate verb position in the prime. Participants were primed with PO and DO primes in which the verb occurred either in second position (such as (2a)) or in sentence-final position (such as (2b)), and subsequently produced targets with the verb in second position. The results revealed significantly stronger priming effects for V2 primes, such as (2a), than for verb-final primes, such as (2b). Chang and colleagues interpreted this result as evidence for a verb position boost in structural priming. To explain this finding, the authors proposed a theoretical account referred to as the *German position-structure lemma model*. The account assumes nodes for verb position within a German sentence, which are stored at the lemma stratum.

These nodes are connected with structural nodes for PO and DO structures. Crucially, the model also assumes connections between the verb position nodes and tense/aspect marking nodes for present or imperfective tense (i.e. with the verb-final node connected to the imperfective node and the V2 node connected to the present-tense node). Through these interconnections, the PO or DO node receives additional activation when the verb occurs in V2 position in both prime and target, resulting in a stronger priming effect.

Chang et al.'s (2015) study constitutes an illustrative example of how structural properties of German can be utilized to experimentally manipulate verb position within a sentence. Note, however, that prime sentences such as (2a) and (2b) differ with regard to both verb position (verb-second vs. verb-final) and verb form (*schickt* vs. *geschickt*). As a result, it is impossible to distinguish whether the observed boost effect occurs because the verb occurs in the same position in prime and target, or because prime and target share the same form of the verb. Also, Chang and colleagues relied on an experimental task in which verb position in the targets was not experimentally controlled. As a result, it is not entirely clear whether the boost effect was based on prime/target *similarity*, with stronger priming effects when the verb occurs in the same position in prime and target, or on *verb position in the prime as such*, with stronger priming when the prime contains a verb in V2 position (i.e. irrespective of verb position in the target): If the constituent which determines verb-argument structure (i.e. the head verb) is encountered earlier in the prime sentence, this might cause stronger activation of the prime structure, causing stronger priming effects.

The present study also relies on a particular structural property of German to experimentally manipulate constituent order within prime and target sentences. While German main clauses require the verb to occur in second position (henceforth referred to as *V2 order*), German subordinate clauses instead require the verb to be placed in sentence-final position (henceforth *V-final order*). Consider German example sentences such as (3a) and (3b):

(3) a. Der Mann **schickt** einen Brief an den Präsidenten.
the.$_{\text{MASC.NOM.SG}}$ man.$_{\text{MASC.SG}}$ send.$_{\text{3SG.PRS}}$ a.$_{\text{MASC.ACC.SG}}$ letter.$_{\text{SG}}$ to the.$_{\text{MASC.ACC.SG}}$ president.$_{\text{MASC.ACC.SG}}$
'The man sends a letter to the president.'

b. Liz sagt, dass der Mann einen Brief an den Präsidenten **schickt**.
Liz say.$_{\text{3SG.PRS}}$ that the.$_{\text{MASC.NOM.SG}}$ man.$_{\text{MASC.SG}}$ a.$_{\text{MASC.ACC.SG}}$ letter.$_{\text{SG}}$ to the.$_{\text{MASC.ACC.SG}}$ president.$_{\text{MASC.ACC.SG}}$ send.$_{\text{3SG.PRS}}$
'Liz says that the man sends a letter to the president.'

Sentence (3a) is an example of a ditransitive German main clause, in which the verb *schickt* obligatorily occurs in V2 position. Sentence (3b) consists of the exact same words as (3a), except for the fact that a short main clause and a complementizer (*Liz sagt, dass…*) are added at the beginning of the sentence. This turns the ditransitive clause into a subordinate clause. Because German subordinate clauses are obligatorily verb-final, the verb *schickt* occurs in sentence-final position in (2b). It is exactly this structural property of German that allows us to experimentally manipulate verb position within ditransitive sentences.

Compared with other possibilities to manipulate constituent order in cross-linguistic priming studies, such as the comparison between shifted and non-shifted English PO structures employed by Pickering et al. (2002), this way of manipulating constituent order possesses a number of advantages. For instance, constituent order (in this case, verb position) can be manipulated in the same way for both PO and DO structures (with the verb occurring either in V2 or in V-final position in both PO and DO sentences). This allows us to employ a 2x2 experimental design in which both prime type (PO vs. DO) and prime/target similarity in constituent order (same verb position vs. different verb position in prime and target) are included as independent variables. Another advantage is that, while shifted and non-shifted English PO structures differ with regard to the order of arguments *within* the structure of interest (i.e. the PO), the order of the two noun phrases remains the same in sentences such as (2a) and (2b), with only the position of the verb changing. Perhaps most importantly, while a speaker's motivation to use a shifted rather than a non-shifted English PO is typically pragmatic in nature (e.g. with a speaker intending to emphasize the recipient), a speaker's motivation to use different constituent orders in (3a) and (3b) is based purely on a grammatical rule (i.e. the fact that German subordinate clauses are obligatorily verb-final, while main clauses require V2 order).

In the following PO/DO priming experiment, we experimentally manipulate whether the verb occurs in the same position in prime and target or not, and investigate to what extent this kind of prime/target similarity with regard to verb position affects structural priming. Crucially, the theoretical accounts of formulation discussed above make different predictions with regard to this question. According to single-stage accounts of formulation, verb-second POs and verb-final POs are considered different structures, each with their own representation. As priming effects are based on pre-activation of this structural representation during processing of the prime, priming effects should only emerge when verb position is the same in prime and target. Two-stage accounts of formulation, in contrast, assume structural representations in which constituent order is not specified. This should lead to priming effects irrespective of whether the verb occurs in the same position in prime and target or not.

3. Method

Participants. Eighty native speakers of German (mean age 24.25, age *SD* = 4.28, 34 female) participated in the experiment for payment. While participants reported knowledge of a variety of foreign languages, all participants described themselves as monolingually raised native speakers of German with no native or near-native fluency in other languages.

Items. We created 24 experimental item sets. Each set contained 4 different versions of a prime sentence (V2 PO prime, V2 DO prime, verb-final PO prime, and verb-final DO prime) and two versions of a target fragment (V2 target, verb-final target). An example of a set of primes is shown in (4a–d):

(4) a. Der Rechtsanwalt schickte den Vertrag an den
the.$_{\text{MASC.NOM.SG}}$ lawer.$_{\text{SG}}$ send.$_{\text{3SG.PST}}$ the.$_{\text{MASC.ACC.SG}}$ contract.$_{\text{SG}}$ to the.$_{\text{MASC.ACC.SG}}$
Klienten. (V2, PO)
client.$_{\text{ACC.SG}}$
'The lawyer sent the contract to the client.'

b. Der Rechtsanwalt schickte dem Klienten den
the.$_{\text{MASC.NOM.SG}}$ lawyer.$_{\text{SG}}$ send.$_{\text{3SG.PST}}$ the.$_{\text{MASC.DAT.SG}}$ client.$_{\text{DAT.SG}}$ the.$_{\text{MASC.ACC.SG}}$
Vertrag. (V2, DO)
contract.$_{\text{SG}}$
'The lawyer sent the client the contract.'

c. Kristin dachte, dass der Rechtsanwalt den Vertrag an
Kristin think.$_{\text{3SG.PST}}$ that the.$_{\text{MASC.NOM.SG}}$ lawer.$_{\text{SG}}$ the.$_{\text{MASC.ACC.SG}}$ contract.$_{\text{SG}}$ to
den Klienten schickte. (V-final, PO)
the.$_{\text{MASC.ACC.SG}}$ client.$_{\text{ACC.SG}}$ send.$_{\text{3SG.PST}}$
'Kristin thought that the lawyer sent the contract to the client.'

d. Kristin dachte, dass der Rechtsanwalt dem Klienten
Kristin think.$_{\text{3SG.PST}}$ that the.$_{\text{MASC.NOM.SG}}$ lawyer.$_{\text{SG}}$ the.$_{\text{MASC.DAT.SG}}$ client.$_{\text{DAT.SG}}$
den Vertrag schickte. (V-final, DO)
the.$_{\text{MASC.ACC.SG}}$ contract.$_{\text{SG}}$ send.$_{\text{3SG.PST}}$
'Kristin thought that the lawyer sent the client the contract.'

V2 primes (i.e. prime sentences with the verb in second position) always consisted of a subject (*Der Rechtsanwalt*) followed by a past-tense inflected verb (*schickte*) and either by a prepositional object structure (*den Vertrag an den Klienten*) or by a double object structure (*dem Klienten den Vertrag*) consisting of the same noun phrases as the corresponding prepositional object. Because German requires case marking on articles, all noun phrases within the POs and DOs were morphologically marked as either dative objects or accusative objects.

Verb-final primes (i.e. primes with the verb in sentence-final position) were identical to V2 primes except for the fact that the sentence contained an additional subject (*Kristin*), a verb (*dachte*), and a subordinate conjunction (*dass*) at the beginning of the sentence, which turned the clause that followed it into a subordinate clause. Because German is verb-final in subordinate clauses, the subordinate verb (*schickte*) occurs at the end of the clause in this case. The introductory NP-VP phrases were kept as short as possible for all items.

In addition to the 4 primes, each of the 24 item sets contained two different versions of a target fragment, such as (5a) and (5b):

(5) a.

Der	Bauer	schickte _____.	
the.$_{\text{MASC.NOM.SG}}$	farmer.$_{\text{SG}}$	send.$_{\text{3SG.PST}}$	(V2 target)

The farmer sent _____.

b.

Oliver	sagte,	dass	der	Bauer _____	schickte.	(V-final target)
Oliver	say.$_{\text{3SG.PST}}$	that	the.$_{\text{MASC.NOM.SG}}$	farmer.$_{\text{SG}}$	send.$_{\text{3SG.PST}}$	

Oliver said that the farmer _____ sent.

The V2 versions of all target fragments consisted of a subject (*Der Bauer*), a past-tense inflected verb (*schickte*), and a gap indicating that the target fragment should be completed. As verb repetition has been shown to generally facilitate structural priming effects, the verb in each target fragment was always the same as the verb in the preceding prime sentence, as recommended by Scheepers et al. (2017). For all experimental materials, we selected verbs which are biased towards ditransitive use (see e.g. Callies & Szczesniak, 2008; Drenhaus, 2004; Liamkina, 2008).

The verb-final versions of the target fragments were the same as their corresponding V2 versions, except for two additional properties. First, in order to manipulate verb position within the clause, a subject (*Oliver*), a past tense verb (*sagte*), and a subordinate conjunction (*dass*) were added at the beginning of the sentence; this turns the following clause into a subordinate clause. Second, the subordinate verb (*schickte*) was presented at the end of the subordinate clause, in accordance with the rule that German subordinate clauses are verb-final.

We added a total of 96 filler sentences. 50% of these were complete sentences, the other 50% were incomplete sentence fragments. Half of the incomplete filler fragments included a to-be-filled gap at the end of the fragment (similar to the experimental main clause target fragments), while the other half included the gap in the middle of the sentence (similar to the experimental subordinate clause target fragments).

Experimental Design. The experiment is based on a 2x2 factorial design consisting of the factors Prime Type (PO vs. DO) and Constituent Order similarity (same constituent order in prime and target vs. different constituent orders in prime and target). Within the same Constituent Order in prime and target condition, 50% of all experimental items were prime-target pairs with V2 primes and V2 targets, while the other 50% were items with verb-final primes and verb-final targets. Similarly, within the different Constituent Order in prime and target condition, 50% of all items were prime-target pairs with V2 primes and verb-final targets, while the other 50% were items with verb-final primes and V2 targets.

The 8 possible prime-target combinations from each item set were distributed across 8 presentation lists according to a Latin Square design. Note that, while items with verbs in V2 position in both prime and target, and items with verbs in sentence-final position in both prime and target, were considered items from a single condition (same Constituent Order in prime and target) with regard to experimental design and analysis, they were distributed across the presentation lists as if they were two different conditions. The same held for the two variants of items in the different Constituent Order condition (i.e. items with V2 structure in the prime, but verb-final structure in the target, or vice versa). This resulted in 8 presentation lists, with each list containing exactly one of the 8 versions of each item. Prior to the testing session, each participant was randomly assigned to one of the presentation lists, and tested on only this list, ensuring that each participant encountered each item in only one condition, which avoids repetition effects.

Each list contained a total of 6 prime-target pairs from each of the four experimental conditions, plus a total of 96 filler sentences. A randomized order of items was generated, the only restrictions being that each experimental target fragment occurred immediately after its corresponding prime and that at least 3 filler items occurred between any two experimental items. The same order of sentences was used for each of the 8 presentation lists, with all 8 versions of an experimental item occurring in the same position in all 8 lists.

Procedure. Participants were tested in a quiet laboratory room. All sentences were presented on a 17'' computer screen using the DMDX experiment software (Forster & Forster, 2003). Prior to the experiment, participants were instructed that they would see a number of either complete German sentences or incomplete German sentence fragments on a computer screen. Their task was to read the sentences aloud as soon as they appeared on screen and, if the sentence was incomplete, to complete it in a grammatically correct way as spontaneously as possible (also aloud). Participants were not informed of any connection between complete sentences and incomplete sentence fragments. The stimuli remained on-screen until the participant pressed a button to complete the trial, or until 8 seconds had passed.

4. Results

Of all 1920 experimental target trials completed by the 80 participants, 827 (43.1%) were completed with a DO and 466 (24.3%) with a PO. Of the remaining target trials, 589 (30.6%) were completed with a monotransitive (e.g. *Der Busfahrer übergab das Geschenk*); for 26 (1.4%) trials, participants did not produce any completion until the timeout for the trial was reached. Finally, for 12 (0.6%) trials, participants produced an incomplete or grammatically incorrect completion. The proportions of monotransitive completions relative to all completions in a particular condition turned out to be similar across the four conditions (same clause type/PO prime: 32%, same clause type/DO prime: 29%, different clause type/PO prime: 33%, different clause type/DO prime: 32%).

Figure 1 shows the mean proportions of PO completions relative to the sum of PO and DO completions by condition.

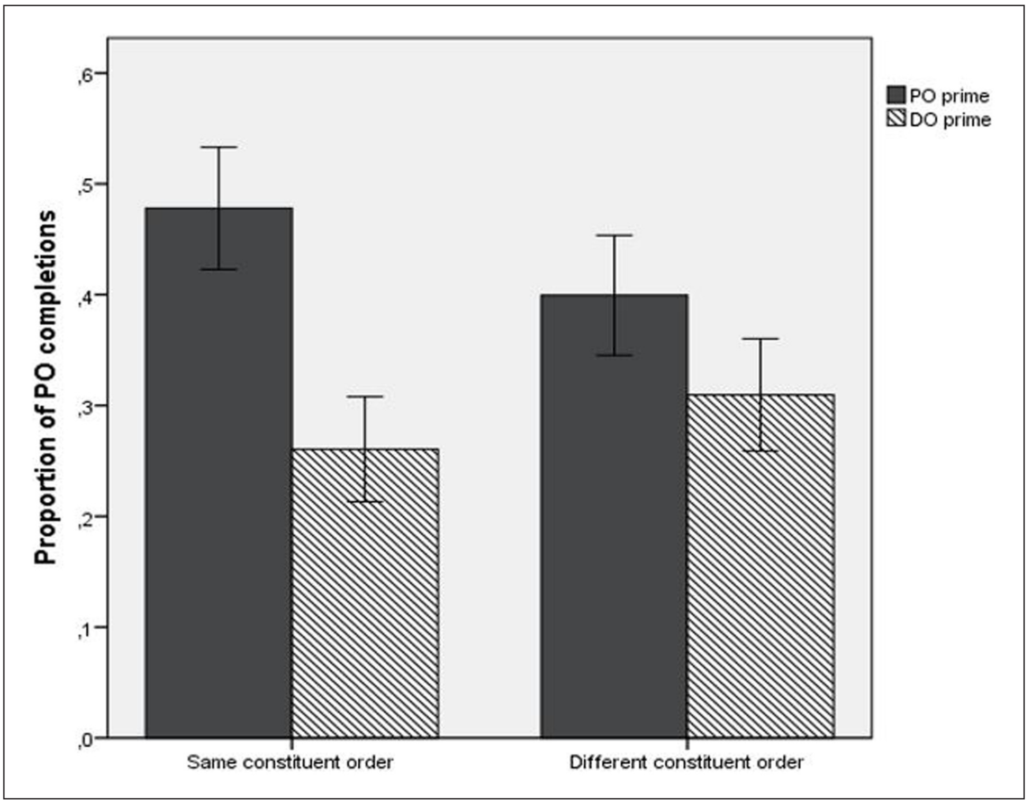

Figure 1: Mean proportions of PO completions by clause type and prime type.

The results were analyzed with logit-mixed-effects models (Jaeger, 2008). The model contained Prime Type (PO prime vs. DO prime), Constituent Order (same constituent order in prime and target vs. different constituent order in prime and target), and the interaction between the two, as fixed factors, and random effects for Subjects and Items. Contrasts were applied to obtain main effects for the fixed factors. In accordance with Barr et al. (2013), we relied on a maximal random-effects structure, with random slopes and intercepts by subjects and items for all predictors. We applied the optimizer *bobyqa* (bound optimization by quadratic approximation) from the *nloptr* package. Fixed effects from the model are shown in **Table 1**.

Table 1: Summary of fixed and simple effects in the model analyses.

		Estimate	**Std. error**	**Wald's Z**	***p***	
Fixed effects:	*intercept*	–0.6803	0.201	–3.382	< .001	***
	main effect of prime type	0.7886	0.158	4.990	< .001	***
	main effect of constituent order	0.0719	0.138	0.520	.603	
	prime type x *clause type*	0.6873	0.261	2.630	< .01	**
Simple effects:	*priming for same constituent order*	1.0964	0.180	6.097	< .001	***
	priming for different constituent order	0.4487	0.1834	2.447	< .05	*

Notes: * = p < .05, ** = p < .01, *** = p < .001.
Formula: *target ~ primetype * clausetype + (1 + primetype * clausetype | participant) + (1 + primetype * clausetype | item).*

The model revealed a significant main effect of Prime Type, with more PO completions following PO primes than following DO primes. Crucially, the model also showed a significant interaction between Prime Type and Constituent Order, with a stronger priming effect in the same Constituent Order condition. To explore the interaction further, we calculated additional logit-mixed-effects models to determine the effect of Prime Type separately for the two levels of the factor Constituent Order (i.e. separately for items in which prime and target shared the same constituent order and for items in which constituent order differed between prime and target). As shown in **Table 1**, these additional models showed significant priming effects for both items in which prime and target shared the same constituent order and for items which did not. In sum, this suggests that, while priming was significantly stronger when constituent order was similar in prime and target, significant priming still emerged when this was not the case.

In the above analysis, the same Constituent Order in prime and target condition comprises both trials with V2 order in both prime and target and trials with verb-final order in both prime and target. This is justified given that, with regard to our research question, the important factor is whether prime and target share the same constituent order or not. However, the design also allows for a post-hoc analysis in which each of the four possible prime-target combinations is considered as a separate condition. While such a post-hoc analysis is obviously limited with regard to statistical power, primarily because of the relatively small number of data points per participant for each prime/target combination, we still consider it valuable, because it allows for a more direct comparison with results from previous research (Branigan et al., 2006; Scheepers, 2003).

Proportions of PO completions relative to the sum of PO and DO completions, separately for each prime/target combination, are shown in **Figure 2**.

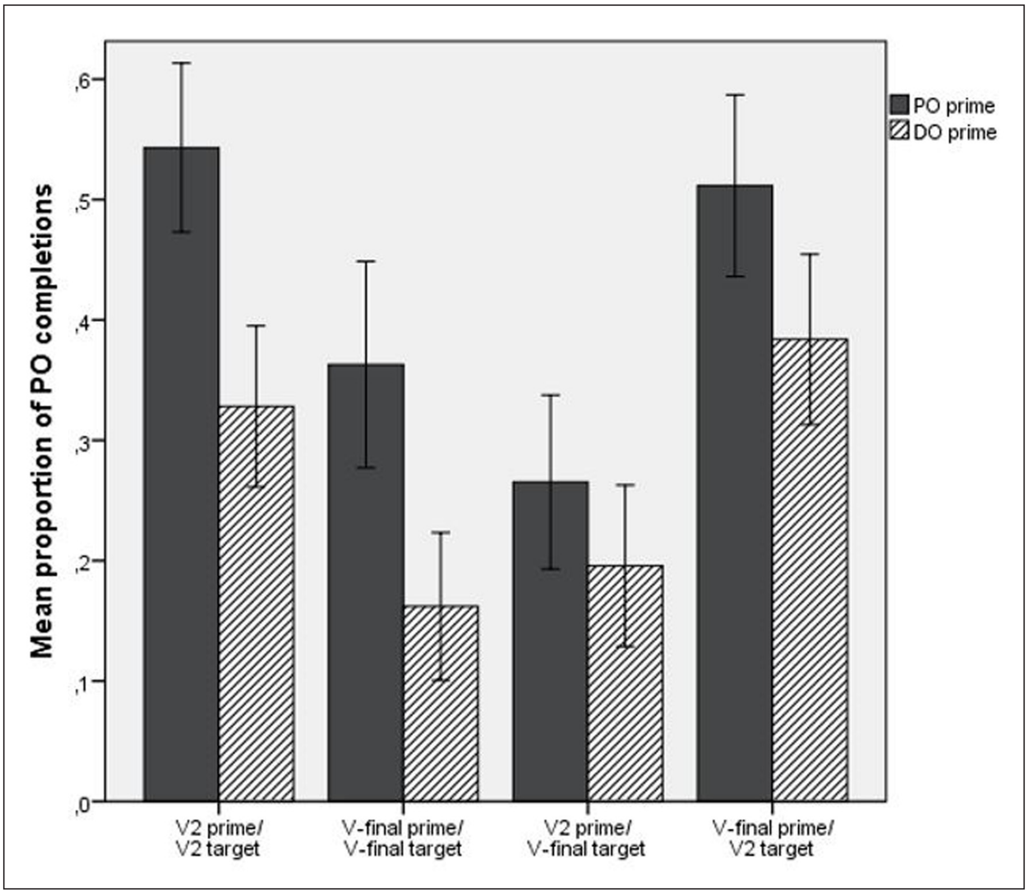

Figure 2: Mean proportions of PO completions by prime type and constituent order.

Again, we used a logit mixed effects model to analyze the data. The model contained Prime Type (PO vs. DO), Verb Position in Prime (V2 vs. V-final), Verb Position in Target (V2 vs. V-final), and the interactions between them, as fixed factors, and Participants and Items as random factors. The model showed a significant effect of prime type, with more PO completions following PO primes than following DO primes. The two-way interactions between Prime Type and Verb Position in Prime, between Prime Type and Verb Position in Target, and between Verb Position in Prime and Verb Position in Target were all non-significant, suggesting that neither V2 nor verb-final clauses were *per se* unsuitable primes or targets. Crucially, the model also showed a significant three-way interaction between Prime Type, Verb Position in Prime, and Verb Position in Target, showing that the size of the priming effect was not equally large across all four conditions, but differed depending on the specific combination of prime and target clauses. We conducted additional logit-mixed effects models to determine whether the numerical trends for priming effects within each of the four prime/target combinations are statistically significant. Each of these models contained Prime Type (PO prime vs. DO prime) as a fixed factor and random slopes and intercepts for Participant and Item as random factors. As shown in **Table 2**, the priming effects were significant in all conditions except for the V2 prime/ verb-final target condition.

Table 2: Fixed and simple effects for the post-hoc analysis.

		Estimate	**Std. Error**	**Wald's Z**	***p***	
Fixed effects:	*intercept*	–0.93	0.24	–3.91	< **.001**	***
	prime type (PO vs. DO)	1.03	0.24	4.27	< **.001**	***
	verb pos. in prime (V2 vs. verb-final prime)	0.28	0.22	1.28	.20	
	verb pos. in target (V2 vs. verb-final target)	–1.48	0.43	–3.41	< **.001**	***
	prime type x verb pos. in prime	0.38	0.40	0.96	.340	
	prime type x verb pos. in target	–0.23	0.40	–0.57	.558	
	verb pos. in prime x verb pos. in target	0.47	0.38	1.25	.211	
	prime type x verb pos. in prime x verb pos. in target	1.67	0.71	2.33	**.020**	*
Simple effects:	*priming from V2 primes to V2 targets*	1.33	0.33	3.97	< **.001**	***
	priming from V-final primes to V-final targets	1.48	0.34	4.37	< **.001**	***
	priming from V2 primes to V-final targets	0.29	0.42	0.69	.49	
	priming from V-final primes to V2 targets	0.80	0.30	2.69	< **.01**	**

Formulae for all four models: *target ~ primetype + (1 + primetype | participant) + (1 + primetype | item)*.

5. Discussion

Our experiment was designed to investigate the role of constituent order in structural priming. The results showed a significant main effect of prime type, with participants producing more PO completions following PO primes than following DO primes, irrespective of whether primes and targets were similar with regard to verb position or not. In itself, this finding is hardly surprising, and consistent with the results from a vast number of previous structural priming studies. However, note that, as shown in **Table 1**, this priming effect is not exclusively driven by items with a similar constituent order in prime and target, but also reaches significance for stimuli in which constituent order differed between the two sentences. This suggests that structural priming does not require similarity with regard to constituent order, but can also occur when constituent order in the target differs from the one in the prime.

In isolation, the fact that we observed significant priming irrespective of constituent order would have to be considered evidence in favor of a two-stage account of formulation. Importantly, however, in addition to the main effect of prime type, our results also revealed an interaction between prime type and constituent order, with stronger priming effects for cases in which constituent order was the same in prime and target. In other words, while significant priming effects occurred irrespective of constituent order, additional similarity in constituent order between prime and target was able to boost these priming effects. At least to some extent, this boost can be considered similar to a *lexical boost effect* reported in a number of previous structural priming studies, in which structural priming effects were significantly stronger when prime and target shared the same verb (e.g. Carminati et al., 2019; Corley & Scheepers, 2002; Hartsuiker et al., 2008; Pickering & Branigan, 1998; Schoonbaert et al., 2007). Thus, we subsequently refer to this interaction as a *constituent order boost*.

At first glance, it might appear as if the observed constituent order boost could be accounted for by the basic properties of main clauses versus subordinate clauses. For instance, it is conceivable that subordinate clauses may be less salient than main clauses, which could potentially lead to weaker priming effects. However, our results show that priming from subordinate clauses to subordinate clauses is just as strong as priming from main clauses to main clauses. This suggests that subordinate clauses are not bad primes (or bad targets) *per se*, but can cause priming effects of the same magnitude as main clause primes, as long as their corresponding target sentence (or, in the case of subordinate clause targets, the corresponding prime sentence) is also a subordinate clause. In a similar way, our results for the conditions with main clause primes clearly show that main clauses do not generally cause strong priming effects irrespective of the target. We thus conclude that the observed boost effect must necessarily be based on the particular combination of prime and target structures rather than on properties of main clauses versus subordinate clauses as such.

Before discussing to what extent this modulating effect of prime/target similarity in constituent order can be accounted for by current theoretical accounts of formulation, an important alternative explanation for the boost effect deserves to be mentioned. In our study, we manipulated constituent order by exploiting the fact that German main clauses require V2 order, while German subordinate clauses require V-final order. While this way of manipulating constituent order comes with a number of advantages, all V2 stimuli used in our experiment were necessarily main clauses, while all V-final stimuli were subordinate clauses. As a result, it is theoretically possible that the observed boost effect is not caused by similarity in constituent order, but instead by similarity with regard to level of embedding. In other words, structural priming effects from main-clause primes to main-clause targets may be stronger than priming effects from main-clause primes to subordinate-clause targets, irrespective of the constituent order within the clauses. Indeed, for cross-linguistic structural priming, there is at least some evidence that level of embedding can potentially influence structural priming effects (Jacob et al., 2017). In German, it is unfortunately impossible to resolve this potential confound, simply because German subordinate clauses are obligatorily verb-final, while main clauses obligatorily require V2 constituent order. That said, we nonetheless consider this alternative explanation unlikely, particularly in view of previous studies investigating effects of level of embedding in English (a language in which both main clauses and subordinate clauses require the same constituent order). For instance, Branigan et al. (2006) compared structural priming effects from English main clauses to main clauses versus main clauses to subordinate clauses. In the crucial experiment, in which the otherwise exactly identical stimuli either occurred as part of a main clause or within a subordinate clause, they found priming effects of a similar magnitude, irrespective of whether both primes and targets were main clauses or whether they differed with regard to level of embedding. The authors therefore argue in favor of a *local* account of formulation, in which the formulator chooses a particular structure (such as a PO) irrespective of the structural context surrounding this structure (i.e. no matter whether the PO occurs as part of a main clause or a subordinate clause). With respect to our results, these findings for a language in which main and subordinate clauses do not differ in constituent order suggest that the boost effect observed in our study is likely based on constituent order rather than level of embedding.

How do our results fit in with the key findings from previous studies investigating the role of constituent order in structural priming? Recall that such studies have yielded contradictory results, with some studies (e.g. Bernolet et al., 2007; Jacob et al., 2017; Köhne et al., 2014; Loebell & Bock, 2003; Pickering et al., 2002) suggesting that structural priming can only occur when prime and target are similar with regard to constituent order, and other studies (e.g. Chen et al., 2013; Shin & Christianson, 2009) reporting significant structural priming effects even when constituent order was different in prime and target. However, most of these previous studies were not designed to investigate whether additional similarity in constituent order can boost structural priming effects. Instead, the key question investigated in these studies was only whether structural priming requires similarity in constituent order or not. Because of this, these previous studies did not include control conditions in which the two sentences were additionally also similar in constituent order. Thus, while the fact that significant priming emerged in these studies is consistent with our findings, a boost effect may well have emerged if these studies had included the respective control conditions. With regard to this issue, note that in both Shin and Christianson (2009) and Chen et al. (2013), the observed structural priming effects, while significant, were numerically relatively small. As for studies which have instead concluded that structural priming requires similarity in constituent order, even the conditions in which constituent order was different between prime and target typically showed at least a numerical trend towards a priming effect, which did not reach significance. In sum, our key finding (i.e. structural priming does not require similarity in constituent order, but is boosted by it) offers a possible explanation for why these previous studies have come to different conclusions, and can largely account for the findings from all these studies.

To what extent can existing theoretical accounts of formulation account for the data pattern observed in the present study? One-stage accounts of formulation predict that structural priming effects should only occur when prime and target share the same constituent order, with no priming when constituent order differs between two sentences. Indeed, our results show an interaction between prime type and constituent order, with stronger priming when constituent order was similar in prime and target. However, the fact that significant priming effects even emerged when constituent order was different in prime and target is difficult to account for by one-stage models. Two-stage accounts of formulation, on the other hand, struggle to explain why similarity in constituent order boosts structural priming effects: If formulation was indeed based on representations for PO and DO structures which do not contain information about constituent order, the activation of a PO representation during processing of the prime sentence should always prime PO target completions, irrespective of verb position. We thus conclude that neither one-stage nor two-stage accounts can fully explain the observed data pattern.

Recall again that Chang et al. (2015) found a similar verb position boost as in our study. Their proposed position-structure lemma model explains this boost effect through associations between tense/aspect marking nodes and positional nodes specifying a particular position of the verb in the sentence (for instance, with the verb form *schickt* associated with the V2 positional node, and *geschickt* with the verb-final positional node). This allows Chang and colleagues to account for the observed boost effect in their study, because their V2 and verb-final primes systematically differed with regard to tense and aspect marking on the verb (e.g. *schickt* in V2 primes versus *geschickt* in verb-final primes). In our study, in contrast, the form of the verb is the same in V2 primes and verb-final primes. Thus, their account would predict a verb position boost effect only for their study, not for ours.

To what extent is it possible to modify existing theoretical accounts so that they can explain our results? For instance, Hartsuiker and Pickering's (2008) *Shared Syntax* account assumes that two structures from two different languages (such as, for example, English and Spanish PO structures) can be represented as a single combinatorial node as long as they are "similar enough". If we extend this rationale to within-language structural priming, it could perhaps be assumed that German V2 and verb-final PO structures, while different with regard to verb position, are still similar enough with regard to other properties, and thus also share a single combinatorial node. This account would be able to explain why we observed significant priming between V2 and verb-final PO and DO structures. However, given that the combinatorial nodes do not contain any information about constituent order anymore, the decision for a particular constituent order would then have to occur somewhere else. In other words, this approach would essentially turn the combinatorial-node model into a two-stage model of formulation, which would then struggle to explain why priming effects are boosted when constituent order is similar in prime and target.

Van Gompel and Arai (2018), specifically for cross-linguistic priming in bilinguals, have proposed an extended version of the Shared Syntax account which could potentially be extended to within-language priming to account for the constituent order boost. Just as in the Shared Syntax account, they assume that structures which are very similar in two languages may possess only a single shared representation. However, they suggest that, even when two structures require a different constituent order in each language, and therefore each possesses a separate representation, the combinatorial nodes for these two different structures can also be associated with each other. Along these lines, we could assume that German V2 and verb-final PO structures each possess their own combinatorial nodes, but that these two nodes are associated. This should lead to strong priming between verb-final primes and verb-final targets, and also to weaker, but still significant, priming when prime and target differ in constituent order. However, while the idea of associations between combinatorial nodes for structures from two different languages strikes us as reasonable, extending this account to, and assuming that such associations can also occur between, structures within the same language would result in a highly complex and costly network of interconnections of different strengths between a multitude of structural representations (particularly for languages with relatively free constituent order). Also, an account of this kind would have to explain how an association between two different combinatorial nodes emerges during language acquisition, given that the two structures are only rarely encountered together.

In the following, we sketch a basic theoretical framework for the formulation stage of language production, which can account for the observed constituent order boost. The key idea behind the suggested account is that formulation involves two different kinds of structural representations, which both independently contribute to the priming. We further assume that one of these two representations contains information about constituent order, while the other does not. If prime and target are similar with regard to only one of these representations, this is already sufficient for a structural priming effect to emerge. However, if the two sentences are similar with regard to both representations, priming is boosted.

Our account is based on a modified version of a particular two-stage model, the *dominance-only* account originally discussed by Pickering et al. (2002). The account distinguishes between a *dominance-only* and a *linearization* stage of formulation. The dominance-only stage involves the retrieval of a stored representation of the respective syntactic structure. This representation only contains information about dominance, not about constituent order. Subsequently, at the linearization stage, a fully detailed hierarchical tree representation, which contains information about constituent order, is computed. For our account, we make the additional assumption that that both representations are not only used in formulation, but are also activated during the processing of a sentence. We also assume that the hierarchical tree representation, when computed during the processing of a prime sentence, remains active in working memory, and can thus prime the production of subsequent sentences with the same constituent order. This allows both representations to contribute to the priming effect, in an additive way.

Assume that, during the processing of a verb-final PO prime sentence, participants activate the stored representation for PO structures. The stored representation does not contain any information about constituent order, and thus primes PO sentences in general, irrespective of verb position in the target. The computed hierarchical tree, in contrast, does contain information about verb position, and thus specifically primes verb-final PO sentences. Thus, if participants are subsequently required to produce a verb-final target sentence, both representations contribute to the priming effect, while if the target sentence is verb-second, priming occurs only through the stored representation activated at the dominance-only stage.

Pickering et al. (2002) initially rejected the dominance-only account because their results showed that non-shifted PO prime sentences primed non-shifted POs to a greater extent than shifted PO primes. They thus concluded that the representation responsible for structural priming must contain information about constituent order, as otherwise shifted POs should have primed non-shifted POs to the same extent as non-shifted POs. However, with respect to experiments of this kind, our account would predict a constituent order boost, with strong priming from non-shifted to non-shifted POs and weaker, but still significant priming from shifted POs to non-shifted POs (relative to DO primes or baseline primes). This is precisely what Pickering and colleagues found in their study.

With respect to the general architecture of this account, note that it is not uncommon for theoretical accounts of language production to assume two different kinds of structural representations. For example, Momma (2022) proposed an account of the production of sentences containing filler-gap dependencies which also assumes that structural priming effects are based on two different structural representations. Even in theoretical linguistics, accounts have been proposed which describe the grammatical structure of a sentence in terms of both a representation which does not contain information about constituent order and a second representation in which constituent order is specified. For instance, Lexical-Functional Grammar (e.g. Bresnan, 1982; Bresnan, 2001; Dalrymple, 2001; Falk, 2001; Kroeger, 2004). describes the syntactic structure of a sentence in terms of both a Feature Structure (which contains no information about constituent order) and a Constituent Structure (C-structure).

Theoretical accounts of structural priming which include the computation of hierarchical tree representations have been proposed before (e.g. Scheepers, 2003; Scheepers et al., 2011). A traditional counter-argument against such accounts, and instead in favor of lexically-grounded, stored structural representations situated at the lemma stratum, is the existence of the already mentioned lexical-boost effect, i.e. the fact that structural priming tends to be stronger when prime and target contain the same verb. However, our account also involves the activation of a stored structural representation. Such representations can be connected to the lexical representations of verbs. This allows our account to explain lexical-boost effects in the same way as traditional accounts, such as Pickering & Branigan's (1998) combinatorial-node model.

In sum, while we acknowledge that this account is necessarily somewhat speculative, it offers an explanation for both the observed structural boost effect and the fact that structural priming can even emerge without similarity in constituent order. Also, the account constitutes an attempt to bridge the gap between structural priming research and accounts of on-line sentence processing, which often assume the computation of a hierarchical tree representation. Our account contains clear assumptions about the nature of the representations computed during both processing of a (prime) sentence and formulation of a (target) sentence.

6. Conclusion

The most important finding from the present study is that structural priming effects do not require similarity in constituent order, but are boosted when constituent order is similar in prime and target. We conclude that this constituent order boost can largely explain why previous studies on formulation, especially studies investigating whether cross-linguistic priming can occur between languages with different constituent orders for a particular structure, have yielded seemingly contradictory results.

Abbreviations

Glossing abbreviations follow the Leipzig Glossing Rules.

ACC	accusative
AUX	auxiliary
DAT	dative
DO	double-object ditransitive
FEM	feminine
MASC	masculine
NOM	nominative
NP	noun phrase
PO	prepositional-object ditransitive
Prep	preposition
PRS	present
PST	past tense
PTCP	participle
SG	singular
V2	verb-second
V-final	verb-final
VP	verb phrase
3SG	third person singular

Data accessibility statement

Raw data and R script for the study are available on OSF: https://osf.io/hzf9a/?view_only=845e2ce8609244e2be459dadbba94e0b

Ethics and consent

The study was conducted following the ethical guidelines for experimental research with human participants as defined in the Declaration of Helsinki. Informed consent was obtained from all participants prior to testing.

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Competing interests

The authors have no competing interests to declare.

Authors' contributions

Conceptualization, G.J., K.K., N.F, and S.A.; methodology, G.J., K.K., N.F, and S.A.; formal analysis, G.J.; investigation, G.J. and A.K.; resources, S.A.; data curation, G.J., K.K., N.F, and A.K.; writing – original draft preparation, G.J., K.K., and N.F.; writing – review and editing, G.J. and K.K.; visualization, G.J. and K.K.; supervision, S.A.; project administration, G.J. and A.K.; funding acquisition, G.J. and S.A. All authors have read and agreed to the published version of the manuscript.

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