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# Interactive structure building in sentence production

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ABSTRACT

How speakers sequence words and phrases remains a central question in cognitive psychology. Here we focused on understanding the representations and processes that underlie *structural priming*, the speaker's tendency to repeat sentence structures encountered earlier. Verb repetition from the prime to the target led to a stronger tendency to produce locative variants of the *spray-load* alternation following locative primes (e.g., *load the boxes into the van*) than following *with* primes (e.g., *load the van with the boxes*). These structural variants had the same constituent structure, ruling out abstract syntactic structure as the source of the verb boost effect. Furthermore, using cleft constructions (e.g., *What the assistant loaded into the lift was the equipment*), we found that the thematic role order (thematic role-position mappings) of the prime can persist separately from its argument structure (thematic role-syntactic function mappings). Moreover, both priming effects were enhanced by verb repetition and interacted with each other when the construction of the prime was also repeated in the target. These findings are incompatible with the traditional staged model of grammatical encoding, which postulates the independence of abstract syntax from thematic role information. We propose the *interactive structure-building account*, according to which speakers build a sentence structure by choosing a thematic role order and argument structure interactively based on their prior co-occurrence together with other structurally relevant information such as verbs and constructions.

## 1. Introduction

A central issue in language production research concerns how speakers sequence words and phrases, and the nature of representations that drive such processes. To explore this issue, researchers have examined *structural priming*, that is, the speaker's tendency to repeat an earlier encountered structure. For example, when speakers of English describe a so-called *dative* or *ditransitive* event of a girl handing a paint brush to a man, they show an increased tendency to use a prepositional object structure as in *The girl handed a paint brush to the man,* rather than a double object structure as in *The girl handed the man a paint brush,* after having encountered a prepositional object structure (e.g., Bock, 1986; 1989). Structural priming has been found with many other constructions including the active–passive alternation for transitive events (e.g., Bock, 1986) and the use of relative clause structures in noun phrase production (e.g., Cleland & Pickering, 2003; Fukumura & Zhang, 2023). It occurs within and across different languages and in both spoken and written modalities (see Branigan & Pickering, 2017; V. Ferreira & Bock, 2006; Mahowald et al., 2016; for a review and *meta*-analyses). However, the locus of the representations that drive structural priming and how speakers form such representations remain controversial. The goal of the current study is to address this.

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Earlier research on structural priming was guided by the *two-stage grammatical encoding account* (Bock & Levelt, 1994; Garrett, 1975, 1980), which proposes that grammatical encoding comprises two distinct stages. The first stage involves *function assignment*, where syntactic functions (e.g., subject, object) are assigned to event participants based on their thematic roles, with the *argument structure* of the verb playing a key role (e.g., Grimshaw, 1990). For example, the verb *hand* assigns the agent, theme, and recipient roles to its three arguments, and the selection of an argument structure determines which thematic roles are mapped onto which syntactic function. If speakers choose the argument structure that assigns the direct object to the theme and the oblique object to the recipient, this will result in a functional structure of a prepositional dative structure, such as *The girl handed a paint brush to the man*. Functional structures are assumed not to specify the linear order of constituents. Therefore, the linear order must be determined in a subsequent stage of *constituent assembly*. This stage is assumed to be guided by syntactic information, such as syntactic functions (e.g., the subject, the direct object) and categories (e.g., noun phrase, verb phrase, prepositional phrase), without involving thematic role information relevant to function assignment. According to the two-stage account, structural priming occurs during constituent assembly, driven by syntactic information abstracted from the thematic role information involved in function assignment.

Consistent with this two-stage account, earlier evidence appeared to suggest the isolation of structural priming from thematic role information. For example, Bock (1989) reported that the rates of prepositional objects involving a recipient role (relative to double object alternatives) were unaffected by whether the prime involved a recipient role (e.g., *The student brought a cake to the teacher*) or a beneficiary role (*The student brought a cake for the teacher*). Similarly, Bock and Loebell (1990) found that prepositional object datives could be elicited by both prepositional locative primes (e.g., *The wealthy widow drove her Mercedes to the church*) and prepositional dative primes (e.g., *The wealthy widow gave the Mercedes to the church),* despite the prepositional objects denoting different thematic roles (location vs. recipient). In the same study, it was also found that intransitive primes, such as *The airplane is landing by the control power*, can elicit passive structures as effectively as passive primes, such as *The airplane was alerted by the control tower*. Subjects of passive and intransitive sentences represent distinct thematic roles; patients and agents, respectively. Hence, the fact that both sentences equally primed passive structures indicates that structural priming is not driven by thematic roles relevant to function assignment, aligning with the two-stage account.

However, different syntactic structures typically involve distinct function assignments. For example, a prepositional object dative differs from a double object dative not only in abstract phrasal structure (NP VP[V NP PP] vs. NP VP[V NP NP])[1], but also in functional structure. If structural priming can only arise during constituent assembly, function assignment in the target proceeds irrespective of the functional structure of the prime. Therefore, in response to a prepositional object dative prime, speakers may adopt on a functional structure compatible with a double object dative, rather than one compatible with a primed prepositional dative, when planning a target. Thus, for structural priming to occur, the incompatible functional structure needs to be backtracked during constituent assembly. However, backtracking is incompatible with the feed-forward and incremental production processes assumed by the two-stage account; that is, each level of processing is guided by the representation processed directly above it, and the order in which the information is passed on to the next stage determines word order (Bock, 1982; Bock & Levelt, 1994; Kempen & Hoenkamp, 1987; Levelt, 1989). Other research suggests that speakers tend not to backtrack on a choice made at an earlier stage (V. Ferreira et al., 2005; Fukumura et al., 2022).

An alternative possibility is that structural priming occurs earlier in the production process, involving thematic role information. Benefactive *for*-datives and transfer *to*-datives may prime each other (Bock, 1989), because *for*-datives can imply the transfer of possession of a theme to a beneficiary, and they can alternate with double object structures only in such cases. For example, *I built his bed for him* can alternate with *I built him his bed*, but *I drove his car for him* cannot alternate with **I drove him his car* (Pinker, 1989). Hence, the absence of an interaction may be attributed to the fact that beneficiaries represent similar thematic roles as recipients in the dative alternation. Moreover, contrary to Bock and Loebell (1990), Potter and Lombardi (1998) showed, using a sentence recall task, that prepositional object dative primes such as *The tycoon willed that mansion to his young nephew very grudgingly* elicit prepositional object datives such as *The prompt secretary wrote a message to her boss every week* significantly more than prepositional locative primes such as *Lenore drove her new convertible to the beach early this afternoon* did. In Potter and Lombardi's study, different conditions involved different lexical items. Using better controlled materials, Ziegler and Snedeker (2018) replicated the findings of Potter and Lombardi, further demonstrating that the degree of thematic role overlap between prime and target modulates structural priming.

Indeed, a growing body of evidence is consistent with such a possibility (e.g., Cai et al., 2012; Chang et al., 2003; Cho-Reyes et al., 2016; Fleischer et al., 2012; Hare & Goldberg, 1999; Heydel & Murray, 2000; Köhne et al., 2014; Pappert & Pechmann, 2014; Salamoura & Williams, 2007; Ziegler & Snedeker, 2018; Ziegler et al., 2019). Structural priming has been found between sentences sharing the same constituent structure (Chang et al., 2003; Ziegler & Snedeker, 2018). Sentences with so-called "spray-load" verbs (Levin, 1993), such as *The farmer heaped the wagon with straw* and *The farmer heaped straw onto the wagon*, share the abstract syntactic structure (NP VP[V NP PP]), but differ in argument structure underpinning thematic role-function mappings. In the former (*heaped the wagon with straw*), the location precedes the theme, with the noun phrase (NP) denoting the location (*wagon*), which is assigned the direct object, and the prepositional phrase (PP) denoting the theme (*straw*), which is assigned the prepositional object. The thematic role order is reversed in the latter (*heaped straw onto the wagon*), where the theme is assigned the direct object, and the location is assigned the prepositional object. In a study using a sentence recall task, Chang et al. (2003) showed that participants recalled target sentences using the location-theme order more frequently after having recalled a prime sentence using a location-theme order as opposed to a theme-location order (see also Ziegler & Snedeker, 2018, who replicated the findings using a picture description task).

[1] NP = Noun Phrase, VP = Verb Phrase, PP = Prepositional Phrase, V = Verb.

Chang et al. (2006) argued that when abstract constituent structure fails to discriminate structural variants, semantic representations can drive structural alternations. In their Dual-Path model, the meaning system processes the message based on concepts and event roles, while the sequencing system generates sentence structures based on abstract syntactic categories. Although the sequencing system normally operates independently of the meaning system, structural variants can be learned based on thematic role-syntactic function mappings when abstract constituent structure fails to discriminate, as in the case of the theme-location alternation. Indeed, some evidence for thematic role order priming comes from structural variants having the same constituent structure, like the theme-location alternation in English. For example, Köhne et al. (2014) found more theme-recipient orders following theme-recipient order German double object primes (*Der Mann verspricht die Putzhilfe der Ehefrau*, The man promises [to get] the cleaning woman the wife) than following recipient-theme order German double object primes (*Der Mann verspricht der Ehefrau die Putzhilfe,* The man promises the wife [to get] the cleaning woman) (see also Pappert & Pechmann, 2014, for related findings). However, findings suggest that thematic role orders can persist across different constituent structures (Bernolet et al., 2009; Cai et al., 2012; Cho-Reyes et al., 2016; Fleischer et al., 2012; Hare & Goldberg, 1999; Salamoura & Williams, 2007), where abstract constituent structure discriminates structural alternatives.

For instance, Hare and Goldberg (1999) found that *provide-with* sentences in English, such as *The officers provided the soldiers with guns* prime double-object datives such as *The man handed a woman a box of sweets* rather than prepositional datives such as *The man handed a box of sweets to a woman. Provide-with* sentences have the same thematic role order as double-object datives (Agent-Recipient-Theme), whereas they have the same phrasal structure as prepositional datives (NP VP[V NP PP]). Hence, this finding suggests that priming can persist via a different route other than the persistence of function assignment and constituent assembly. Consistent with this possibility, Cai et al. (2012) found that thematic role-linear position mappings persist in dative alternations in Mandarin Chinese, leading to more prepositional object (PO) targets following topicalized double object (DO) primes that had the same theme-recipient order (*Naben shu niuzai song-gei le shuishou*, The book, the cowboy gave the sailor) than following standard DO primes that had a recipient-theme order (*Niuzai song-gei le shuishou naben shu*, The cowboy gave the sailor the book). However, topicalized DO primes elicited more DO responses than PO primes did, suggesting that thematic role-syntactic function mappings can also be primed. These findings led Cai et al. to argue that speakers construct a constituent structure by simultaneously tracking thematic role-position mappings and thematic role-syntactic function mappings. However, the critical questions pertinent to the present study remain, concerning what type of representations support such parallel mappings and whether the mappings between thematic roles and positions, as well as between thematic roles and syntactic functions, exert only additive effects on structural choice or if they interact with each other.

Bernolet et al. (2009) proposed that both thematic role-position mappings and thematic role-function mappings are influenced by thematic emphasis. In their cross-linguistic priming study, they found that agent-initial Dutch passives (e.g., *Door de non wordt de bokser achtervolgd*, By the nun is the boxer chased) elicited more agent-final English passives (e.g., *The skier is chased by the pirate*) than agent-initial Dutch actives (e.g., *De non achtervolgt de bokser*, The nun chases the boxer) did, demonstrating priming at the functional level. However, agent-initial Dutch passives elicited fewer agent-final English passives than agent-medial Dutch passives (e.g., *De bokser wordt door de non achtervolgd*, The boxer is by the nun chased) did. Bernolet et al. attributed these findings to the persistence of thematic emphasis; in their rating studies, the agent role in agent-initial Dutch active sentences was perceived as more emphasized than the agent role in agent-initial Dutch passive sentences, which, in turn, was perceived as more emphasized than the agent role in agent-medial and agent-final Dutch passive sentences. Based on these findings, Bernolet et al. argued that structural priming with the theme-location alternation (Chang et al., 2006) is driven by the persistence of thematic emphasis on the theme or location role, rather than by the persistence of thematic role order *per se*.

Similarly, Vernice et al. (2012) used cleft constructions in Dutch to show that emphasizing the patient role in a sentence increases the likelihood of passive responses in the declarative target sentences. However, in Vernice et al.'s study, thematic emphasis co-varied with thematic role ordering. In experiments using *it*-clefts (e.g., *Het is de cowboy die hij slaat*, It is the cowboy who he is hitting) or inverted wh-clefts (e.g., *De cowboy is degene die hij slaat*, The cowboy is the one who he is hitting), patient-focused primes always involved patient-agent orders, which corresponded to the thematic role order of passive target sentences (*De jongen wordt geraakt door de bal*, The boy is hit by the ball). One experiment aimed to address this issue, using patient-emphasised wh-cleft (e.g., *Degene die hij slaat is de cowboy*, The one who he is hitting is the cowboy); however, in this construction, while the identity of the patient (*cowboy*) is revealed at the end of the sentence, the thematic role order arguably is still patient-agent. Hence, it is not entirely clear whether the priming effect was driven by thematic emphasis or the persistence of thematic role order or both. In Cai et al.'s (2012) study, perceived thematic emphasis was found to be unrelated to the persistence of thematic role-position mappings.

## 2. Current study

The current study thus examined the representations underlying structural priming. Specifically, we investigated the locus of the *lexical boost effect* (Branigan et al., 2000; Carminati et al., 2019; Chang et al., 2015; Fukumura & Zhang, 2023; Hartsuiker et al., 2008; Pickering & Branigan, 1998; Segaert et al., 2013; Scheepers et al., 2017; Van Gompel et al., 2023). While structural priming can occur without any lexical repetition, the magnitude of structural priming typically increases when a lexical item is repeated from the prime to the target. This phenomenon is referred to as lexical repetition 'boosting' structural priming. Pickering and Branigan (1998) first demonstrated this effect in a written sentence completion task. They found that participants were more likely to adopt a prepositional object structure in their completions after having completed a prime that induced a prepositional object structure (e.g., *The racing driver showed the torn overall…*) compared to a prime that induced a double object structure (e.g., *The racing driver showed the helpful mechanic…*). Importantly, the priming effect was larger when the verb in the prime was repeated in the target (e.g., *show-show*) compared to when it was not (e.g., *give-show*).

According to Pickering and Branigan (1998), verb repetition boosts the persistence of *combinatorial nodes*, which are thought to underpin structural priming. The diagram in Fig. 1 illustrates their *residual activation model*, where a prepositional object (PO) prime activates the *NP,PP* node, while a double object (DO) prime activates the *NP,NP* node. The residual activation of these nodes increases the likelihood of corresponding PO or DO responses in the target sentence. Importantly, these combinatorial nodes are associated with the lexical properties of the verb's lemmas, as illustrated in Fig. 1, where the two combinatorial nodes are linked to the verbs *show* and *give*. Thus, if a PO prime occurs with the verb *show*, the processing of the PO prime activates not only the NP,PP node, but also its link to the verb *show*. As a result, when the verb *show* is repeated from the prime to the target, the activation of the NP,PP node is boosted by the residual activation of that link. This leads to an even higher likelihood of PO selection in the target sentence compared to cases when a different verb *give* is chosen in the target sentence.

The critical question is what "combinatorial nodes" entail in the residual activation account. The account followed the architecture of the two-stage model of grammatical encoding account, according to which structural priming arises during constituent assembly, not during function assignment. Consistent with this, Pickering et al. (2002) found that shifted PO structures, in which the prepositional phrase preceded the direct object, as in *The racing driver showed to the helpful mechanic the torn overall*, do not prime canonical POs any more than the baseline (cf. Hartsuiker & Kolk, 1998). The finding led to the proposal that constituent structure is constructed in a single stage, driven by the selection of a combinatorial node that specifies not only the hierarchical relations of the constituents but also their linear order. Shifted PO structures and canonical POs do not prime each other because, despite having the same function assignment, they differ in the linear order of the constituents and hence they are represented by different combinatorial nodes. Although verb repetition was not manipulated, it was suggested that verb selection is linked to the 'selection of a combinatorial node that mandates the construction of a fully specified constituent structure' (Pickering et al., 2002, p.603).

However, as we have just reviewed, structural priming may occur at multiple levels. This raises the question of precisely what representations are enhanced by lexical repetition. Investigating noun phrase production, Fukumura and Zhang (2023) found that lexical repetition enhances not only the persistence of syntactic structure but also the persistence of conceptual structure. When the noun in the prime was repeated in the target, it resulted in stronger syntactic priming, with an increased tendency to use a relative clause structure following a relative clause structure prime like *green bow that's spotted* than following a prime with a simpler alternative structure like *green spotted bow*. However, repeating any of the adjectives in the prime did not enhance syntactic priming. In contrast, when the noun or one of the adjectives in the prime was repeated, it enhanced 'conceptual order priming', with an increased tendency to repeat a color-before-pattern order (*green bow that's spotted*) following a color-before-pattern order prime (*blue sock that's striped*) than following a pattern-before-color order prime (*striped sock that's blue*). The fact that conceptual order priming was affected by adjective repetition as well as noun repetition indicated that the syntactic structure and the conceptual order are represented separately. Interestingly, however, the two priming effects appear to interact. Participants tended to repeat the relative clause of the prime more often when they repeated the adjective order from the prime (e.g., both having a color-before-pattern order) than when they adopted a different adjective order (e.g., a pattern-before-color order after a color-before-pattern order prime). Likewise, participants tended to repeat the adjective conceptual order of the prime more often when they repeated the syntactic structure of the prime than when they did not. These results indicated that different types of information interact during the process of structural priming.

The overarching aim of the current study was thus to investigate the representations underlying structural priming, focusing on the locus of the lexical boost effect. To this end, we began by asking whether and how lexical repetition might enhance structural priming in the theme-location alternation (Chang et al., 2003; Ziegler & Snedeker, 2018) such as sentences (1). The residual activation account posits that the verb's lemma is associated with abstract syntactic information involved in generating constituent structures (Pickering et al., 2002; Pickering & Branigan, 1998), in accord with the assumption that structural priming arises during constituent assembly rather than during function assignment (e.g., Bock & Levelt, 1994). We call this the **verb-constituent structure account**. In this view, we would not expect to observe verb boost effects in the theme-location alternation, as its structural variants (1a vs. 1b) share the abstract constituent structure (NP VP [V NP PP]). However, as we have just reviewed, structural priming could be driven by representations beyond abstract syntax. Hence, the question is which other representations can be enhanced through verb repetition.

1a. The assistant loaded the van with the boxes.
1b. The assistant loaded the boxes into the van.

As an alternative to the verb-constituent structure account, the **verb-argument structure account** proposes that verb repetition enhances structural priming during function assignment, because verb selection is associated with *argument structure selection*

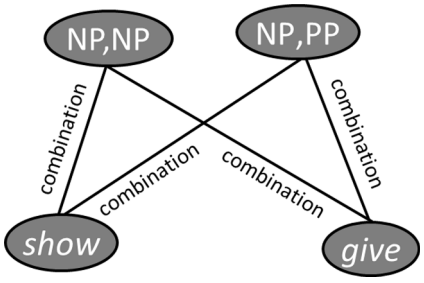


**Fig. 1.** Representations of **the residual activation account**, adapted from Pickering and Branigan (1998).

underpinning function assignment. That is, sentences (1a) and (1b) involve different argument structures, specifying different function assignments. Specifically, sentence (1a) has a '*with*-structure', where the subject is assigned to the agent, the direct object to the location, and the prepositional object to the theme. In contrast, sentence (1b) has a 'locative structure', where the direct object is assigned to the theme and the prepositional object to the location. Hence, the structural alternation in (1) may be primed due to the persistence of the argument structure from the prime sentence, influencing function assignment in the target sentence. The locative structure and the *with*-structure can be formalized as $x < y$, $P_{loc}\ z >$ and $x < y$, $P_{with}\ z>$, respectively (Rappaport & Levin, 1988). In these formalizations, $x$ represents an external argument (i.e., the subject), $y$ represents the direct argument, and $z$ represents the indirect argument. $P_{loc}$ and $P_{with}$ represent a locative preposition and the preposition *with* respectively. Thus, when the prime sentence (1a) is encountered, it biases the selection of a *with*-structure during function assignment in the target, increasing the likelihood of assigning the direct object to the location and the prepositional object to the theme.

Critically, the verb-argument structure account predicts that repeating the verb from primes increases the likelihood of argument structure persistence. The assumption is that verb and argument structure selection are associated because the syntactic features of verbs, such as subcategorization frames (e.g., Chomsky, 1965), can constrain possible argument structures (Bock & Levelt, 1994). Such associations may also arise because the meaning of the verb specifies the thematic role of the direct argument, with the preposition assigning the thematic role to the indirect argument (cf. Marantz, 1984; Rappaport & Levin, 1988). Hence, in the diagram in Fig. 2A illustrating the verb-argument structure hypothesis, the verb *load* is linked to the two argument structures involved in the theme-location alternation such as in (1). The *with*-structure node ('with') represents the processes underpinning the selection of the argument structure of the *with* variant (1a), and the locative structure node ('locative') represents the processes underpinning argument structure selection for the locative variant (1b). The bold lines indicate an increased activation of the *with*-structure, the verb *load,* and the link between them, as well as the abstract constituent structure NP VP[V NP PP], following a prime sentence such as (1a). If the activation of the link between the verb *load* and the *with*-structure node persists, the repetition of the verb should increase the activation of the *with*-structure in the target sentence.

Thus, the verb-argument structure account predicts a verb boost effect on the theme-location alternation, such as (1). This contrasts with the earlier-mentioned verb-constituent structure account, which is illustrated in Fig. 2B. According to this account, verb boost effects arise through the verb-constituent structure link, where the verb *load* is connected to the constituent structure node (NP VP[V NP PP]) rather than to the argument structures. On this view, due to the shared constituent structure between the structural variants of the theme-location alternation (1a vs. 1b), verb repetition should not enhance structural persistence. Crucially, neither account takes into consideration that the theme-location alternation, such as (1), involves distinct thematic role orders. In sentence (1a), the location follows the agent and is subsequently followed by the theme. In contrast, in sentence (1b), the theme, following the agent, precedes the location. As a result, a prime featuring an agent-location-theme order, like (1a), might elicit agent-location-theme orders due to the persistence of the thematic role order from the prime. As discussed earlier, there is indeed evidence suggesting that the thematic role

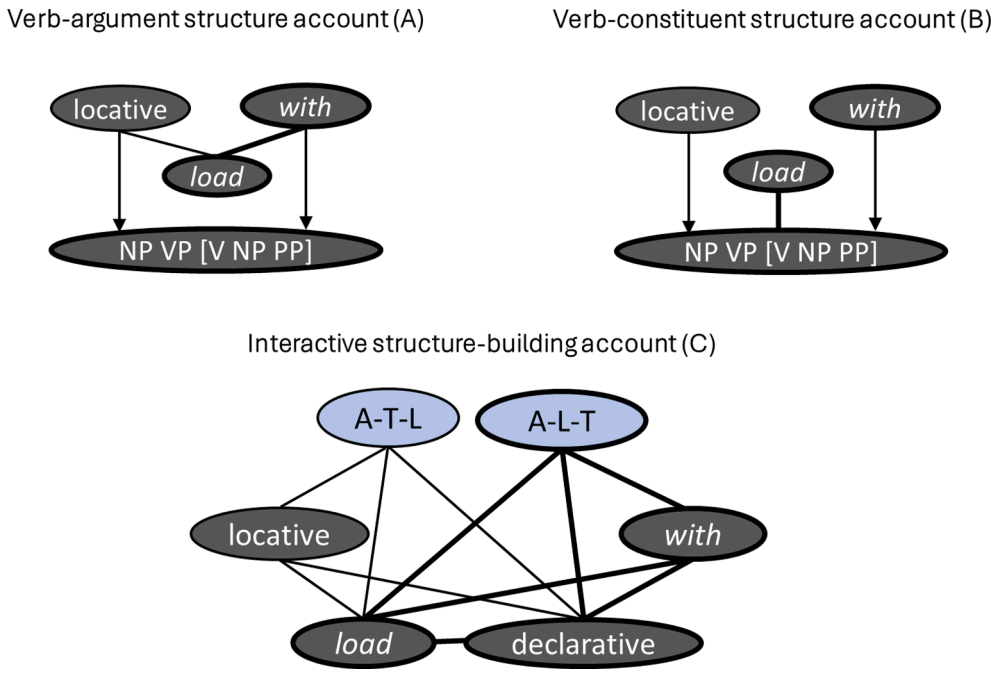


**Fig. 2.** Representations of **verb-argument structure account (A), verb-constituent structure account (B), and interactive structure-building account (C)**. A = Agent, T = Theme, L = Location. Locative = Locative argument structure, With = *With* argument structure.

order of the prime can persist in the target (e.g., Hare & Goldberg, 1999; Ziegler & Snedeker, 2018). Furthermore, lexical repetition has been shown to increase not only syntactic persistence (e.g., the repeated use of a relative clause) but also conceptual order persistence (e.g., the repeated use of a color-before-pattern order such as *blue striped bow*), and these two priming effects can reinforce each other and lead to stronger overall structural persistence (Fukumura & Zhang, 2023).

Hence, as the third account, the **interactive structure-building account** proposes that speakers activate abstract thematic role orders separately from argument structures, and verb selection is associated not only with argument structure selection but also with thematic role ordering, as these two processes occur interactively in a single stage. Fig. 2C illustrates the processes and representations proposed by this account, depicting the two thematic role orders as well as the argument structures. The A-L-T node corresponds to the order of agent (A)-location (L)-theme (T) in sentences such as (1a), while the A-T-L node corresponds to the order of agent (A)-theme (T)-location (L) in sentences such as (1b). The *with*-structure node and the locative structure node denote the representations and processes underlying the selection of the *with* argument structure (1a), where the direct object is assigned to the location and the prepositional object is assigned to the theme, and the locative argument structure (1b), where the direct object is assigned to the theme and the prepositional object to the location, respectively. These argument structure nodes might also include information relating to semantic representations associated with the argument structures (Anderson, 1971; Goldberg, 1995; Pinker, 1989; Rappaport & Levin, 1988; Levin & Rappaport Hovav, 2005). For example, the locative variant, as exemplified by *load the boxes into the van*, has been proposed to convey *change-of-location* meanings (*x* causes [*y* to come to be at *z*]), while the *with* variant, such as *load the van with boxes*, is associated with *change-of-state meanings* (*x* causes [*z* to come to be in STATE] by means of *x* causes [*y* to come to be at *z*]) (Rappaport & Levin, 1988; cf. Gropen et al., 1991; Pinker, 1989; Jackendoff, 1983).

In Fig. 2C, the thematic role orders and the argument structure nodes are linked to the verb *load*, representing a cluster of features associated with the verb's lemma. This cluster includes the verb's meaning (or *lexical concept*, Levelt et al., 1999) and its syntactic properties. Moreover, the diagram includes a node labelled 'declarative', which signifies the representations and processes relating to the selection of a declarative construction. This includes the conceptual feature or illocutionary force associated with declarative sentences, such as making an assertion (Searle, 1979). Construction nodes are shared among various argument structures and thematic role orders and distinct from abstract constituent structures that define syntactic categories and relationships between words and phrases. Inclusion of a construction node captures the relationship between thematic role ordering and construction selection. Specifically, if speakers intend to emphasize a specific thematic role in English, they may employ cleft constructions. Selection of a particular cleft construction, in turn, influences thematic role ordering. In a *what*-cleft construction, the emphasized role appears in the sentence's final position (e.g., *What the assistant loaded into the van was the boxes*). Conversely, in an *it*-cleft construction, the emphasized role is positioned at the beginning of the sentence (e.g., *It was the boxes that the assistant loaded into the van*). Furthermore, the co-occurrence of various structural features depends on the specific construction used. While both the *with* argument structure and locative structure can take different thematic role orders in cleft constructions (see Tables 5 & 10), in declarative constructions, the agent-location-theme order occurs with the *with* argument structure and the agent-theme-location order occurs with the locative argument structure (see Table 1). Therefore, in the diagram, the links between the A-L-T node and the *with*-structure node, as well as

**Table 1**
Example prime and target sentences in Experiments 1–3.

| | |
|---|---|
| **Experiment 1** | |
| *Verb Repeated Prime* | *Not-Repeated Prime* |
| 2a. The assistant loaded the van with (the boxes). | 2c. The assistant packed the van with (the boxes). |
| 2b. The assistant loaded the boxes into (the van). | 2d. The assistant packed the boxes into (the van). |
| *Target Completion* | |
| 3a. The man loaded (the trolley with the luggage). | |
| 3b. The man loaded (the luggage onto the trolley). | |
| **Experiment 2** | |
| *Theme Repeated Prime* | *Not-Repeated Prime* |
| 4a. The traveller packed the car with (the suitcases). | 4c. The traveller packed the car with (the skis). |
| 4b. The traveller packed the suitcases into (the car). | 4d. The traveller packed the skis into (the car). |
| *Target Completion* | |
| 5a. The man loaded (the trolley with the suitcases). | |
| 5b. The man loaded (the suitcases onto the trolley). | |
| **Experiment 3** | |
| *Location Repeated Prime* | *Not-Repeated Prime* |
| 6a. The tour operator packed the trolley with (the rucksacks). | 6c. The tour operator packed the sledge with (the rucksacks). |
| 6b. The tour operator packed rucksacks onto (the trolley). | 6d. The tour operator packed rucksacks onto (the sledge). |
| *Target Completion* | |
| 7a. The man loaded (the trolley with the suitcases). | |
| 7b. The man loaded (the suitcases onto the trolley). | |

*Note.* Example completions in brackets.

between the A-T-L node and the locative structure node, reflect the typical co-occurrence of these structural features in declarative constructions.[2]

The bold lines in Fig. 2C illustrate an increased activation of all nodes and connections following a prime sentence like (1a). In line with many theories of human memory and information processing, when a node becomes activated, its activation spreads to other nodes linked to it, increasing their levels of activation. Importantly, when multiple nodes are active, the activation of the connecting links increases due to the intensified transmission of activation among them. This can influence the future co-occurrence of the connected nodes. For instance, a location-theme order (*with*-structure) prime such as (1a) will activate not only the A-L-T node and the *with*-structure node, thereby increasing the probability of selecting these structural features in subsequent utterances, but also the verb *load*, the declarative construction node, and the links connecting these nodes. This forms the basis of the lexical boost effect, enhancing the probabilities of repeating these structural features alongside the verb and the primed construction. Consider a scenario where, following the prime (1a), the verb *load* is repeated in another declarative construction, resulting in enhanced activation of both the *load* and *declarative* nodes. This enhanced activation then spreads to all the interconnected nodes, during which the A-L-T node and the *with*-structure node receives particularly strong activation. This is because the links from these structural features to *load* and to the declarative node have been preactivated by the prime; as a result, the residual activation of these links feeds into the A-L-T node and the *with*-structure node. Hence, repeating the verb in a declarative sentence increases the probability of selecting these structural features.

All three models we have discussed assume that verb repetition leads to a lexical boost effect, enhancing structural priming. However, some researchers have suggested that not only verb repetition but also noun repetition can enhance structural priming. For instance, Chang et al. (2006) proposed that the lexical boost effect can occur with both verbs and nouns because they are content words, and their repetition can serve as a retrieval cue for the explicit short-term memory of the prime (see also Chang et al., 2012; Reitter et al., 2011). On this view, we cannot rely on verb boost effects to examine underlying structural representations, given that any content word repetition can potentially enhance priming effects. Consistent with this idea, Scheepers et al. (2017) found that repeating the agent or recipient role led to larger structural priming effects in dative alternations. Scheepers et al. manipulated the repetition of three nouns with distinct roles (agent, theme, and recipient) in addition to the verb in the same experiments. However, Carminati et al. (2019) failed to replicate these findings when they manipulated noun repetition and verb repetition in separate experiments. Carminati et al. thus proposed that the enhancement of syntactic priming occurs solely with the repetition of syntactic heads, such as verbs. This proposal has been supported by subsequent studies investigating verb boost effects in dative alternations (Huang et al., 2023; Kantola et al., 2023; Van Gompel et al., 2023). However, adjective repetition has been shown to boost adjective order priming (Fukumura & Zhang, 2023), and the role of noun repetition in enhancing structural priming might vary depending on the specific alternations being investigated. For example, Chang et al. (2006) suggested that language users rely more on semantic representations for the theme-location alternation, where constituent structure fails to discriminate between structural alternatives, unlike in dative alternations. On this view, the repetition of role-bearing filler nouns could potentially induce a lexical boost effect, particularly if language users associate the thematic roles with the concepts of the filler nouns in their semantic representations.

Thus, Experiments 1–3 examined if the priming of the theme-location alternation could be enhanced by repeating the verb (Experiment 1), the noun fulfilling the theme role (Experiment 2), and/or the noun fulfilling the location role (Experiment 3) from the prime to the target. As a preview, the findings of these experiments revealed that only verb repetition, not noun repetition, enhances theme-location alternation priming, ruling out the verb-constituent structure account. Experiments 4–6 then contrasted the interactive structure-building account and the verb-argument structure account by independently manipulating the argument structure and thematic role order of the prime using cleft constructions. Below we report each experiment in turn.

## 3. Experiment 1: Verb repetition

In all experiments, a web-based written sentence completion task was employed. Participants were tasked with completing a prime prompt in writing, selecting one of the provided words (as shown in the top panel of Fig. 3). Participants then described a given target picture by responding to target prompts (e.g., *The man loaded …*) using words present in the image (as depicted in the bottom panel of Fig. 3). Examples of sentences from Experiments 1–3 can be found in Table 1. In Experiment 1, each prime prompt featured either the same verb (2a & 2b, *load*) or a different verb (2c & 2d, *pack*) compared to the targets (*load*). The primes induced either a location-theme order completion (*with*-structure) (2a & 2c) or a theme-location order completion (locative structure) (2b & 2d). If structural priming plays a role, there should be more location-theme order responses (3a) following location-theme order primes (2a & 2c) than following theme-location primes (2b & 2d). Of particular interest is whether this priming effect interacts with verb repetition. According to the **verb-constituent structure account**, the effect should remain unaffected by verb repetition, because the structural variants of the theme-location alternation share the constituent structure, and verb selection is associated with the selection of an abstract constituent structure. However, both the **verb-argument structure account** and the **interactive structure-building account** predict a larger priming effect when the verb is repeated compared to when it is not. These hypotheses propose that verb selection is associated with argument structure selection (verb-argument structure account) or with both the argument structure and thematic role order selected in a particular construction of the prime (interactive structure-building account).

[2] However, this does not imply that extremely rare or novel connections cannot be formed. On the contrary, under certain conditions (e.g., priming, Ivanova et al., 2012, 2017), such connections can be formed and can influence structural choice. The diagram omits these ungrammatical connections because they are typically of extremely low activation unless they are specifically primed, and we did not use ungrammatical prime sentences in the current study.

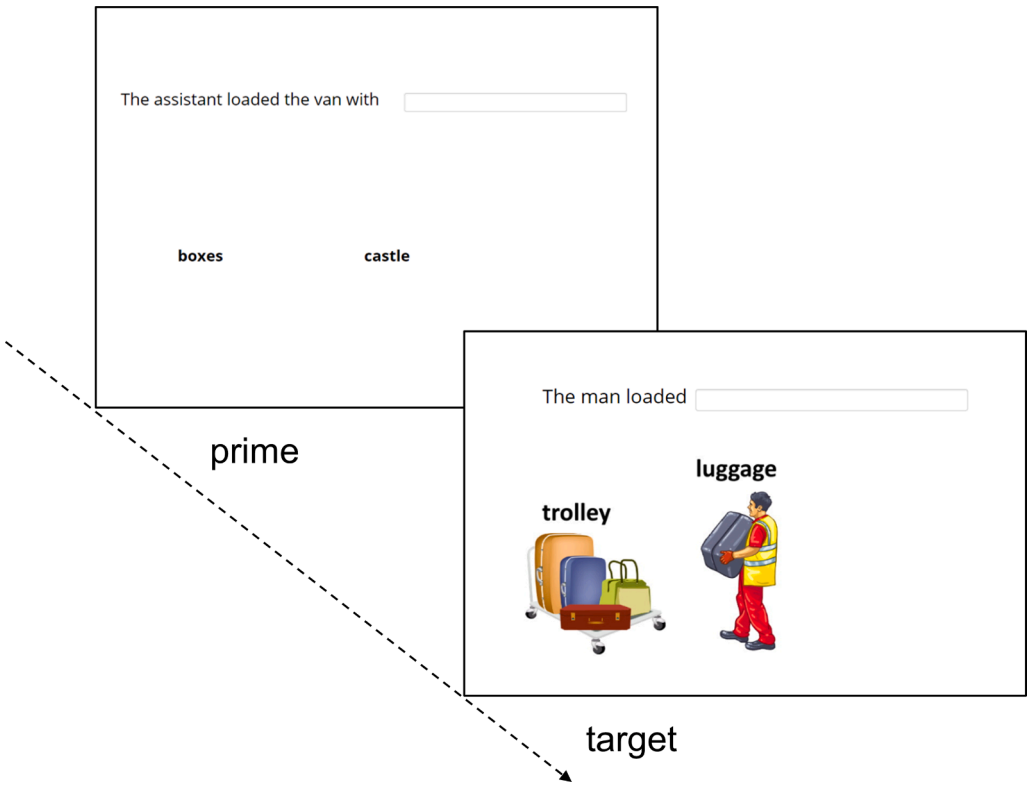


**Fig. 3.** Procedure and example prime and target display.[3]

### 3.1. Method

#### 3.1.1. Participants

Eighty native speakers of British English participated in the study, recruited from Prolific (www.prolific.com) in exchange for cash. All participants reported being a student, aged between 18 and 30, raised in an English-speaking monolingual household, and having no reading difficulties. The sample size was based on Experiment 1 of Chang et al.'s (2003) study, which had 83 participants and 16 experimental items. To increase statistical power for investigating interactions, we doubled the number of experimental items, and employed a picture description task, which was expected to result in much fewer exclusions compared to Chang et al.'s sentence recall task, whose exclusion rates were approximately 60 %.

#### 3.1.2. Materials

We constructed 32 experimental items, each comprising sentence fragments for prime and target trials, and a target picture. Both prime and target sentence fragments began with a subject noun, followed by a verb. In the location-theme order prime condition (2a & 2c) (*load/pack the van with the boxes*), the postverbal noun phrase denoted a location (*van*) followed by the preposition "with", prompting the mention of a noun phrase denoting a theme (*boxes*). In the theme-location prime condition (2b & 2d) (*load/pack the boxes into the van*), the postverbal noun phrase denoted a theme, followed by a locative preposition, prompting the mention of a noun phrase denoting a location. We used 16 verbs from Levin (1993), and verb repetition was manipulated by pairing up verbs with similar meanings, each occurring across four items: load/pack, rub/dab, smear/slather, splash/splatter, drizzle/spray, stuff/cram, pile/stack, and dust/sprinkle (see Appendices 13.1 & 13.2). Each prime prompt appeared across two different items, once as a repeated verb prime and once as a not-repeated verb prime, thereby counterbalancing the prime properties across conditions. We rotated the conditions such that each participant saw each prime only once.

The prime fragments had to be completed by choosing one of the two words provided below the prime fragments (e.g., *boxes* or *castle*) (see Fig. 3, top panel). The positions of these words on the screen were counterbalanced. The target fragments always started with the subject (agent) followed by the verb (e.g., *The man loaded*, as in 3), which had to be completed using the words embedded in the target picture (see Fig. 3, bottom panel). In the *repeated verb condition*, the prime and target fragments had the same verb, whereas in the *not-repeated verb condition*, they had different verbs. The prime and the target always had different agents, themes, and locations. The target picture (500 pixels × 500 pixels, 96 pixels per inch) depicted an action involving an agent, a theme, and a location. The

[3] The baggage handler's image was retrieved from Clipartmax.com.

agent and action were named in the target prompt (3), and the theme and location were named (in a font size of 36) in the image (e.g., luggage and trolley in Fig. 3 bottom panel). In addition, we constructed 72 filler items using various sentence structures, including transitive, intransitive, passive, and other forms. Similar to experimental items, each filler item also contained a sentence fragment that could be completed by choosing one of two words given, followed by a target image with another sentence fragment.

#### 3.1.3. Design

We used a 2 (prime structure: theme-location [locative structure] vs. location-theme [*with*-structure]) × 2 (verb repetition: repeated vs. not-repeated) within-subjects/items repeated measures design, resulting in the creation of four lists. Each list had 32 experimental items, with only one version of each item and 8 items per condition, and 72 filler items. The conditions and items were distributed across each list in a fixed quasi-random order, subject to the constraints that each verb should not occur more than twice and should appear in different prime orders and in different halves of the experiment, and there should be at least 2 filler trials between experimental trials. Twenty participants were randomly assigned to each list.

#### 3.1.4. Procedure

The experiment was conducted online using the Gorilla experiment builder (www.gorilla.sc). Following informed consent, participants confirmed their eligibility by answering a short demographic questionnaire. They then read instructions and went through the procedures and practice trials. Each trial began with the prime trial (Fig. 3 top panel), where participants completed a prime sentence fragment in a blank box by choosing one of the two possible words shown below the box. They then pressed a key, which triggered the presentation of a target sentence fragment. Participants completed the target sentence by describing a picture (Fig. 3 bottom panel). They had to use the words embedded in the picture, which helped to ensure that all the thematic roles would be mentioned. Once completed, they pressed a key to proceed to the next trial. Halfway through the experiment, there was a short break, and the experiment lasted about 30 min on average. During the practice trials, participants were asked to complete the sentence meaningfully and grammatically. They were told that they were free to add any words necessary and choose different word orders, and also told not to worry about spelling. The practice trials involved transitive sentences, passives, and dative alternations but never locative alternations.

#### 3.1.5. Scoring

We scored if participants produced a location-theme response ($n = 644$) (3a) or theme-location response (3b) ($n = 1889$). Theme-location responses had a post-verbal theme, followed by a locational preposition (e.g., on, into, onto, in, over, inside, across) and a location. Location-theme responses had a post-verbal location, followed by a preposition and a theme. Almost all location-theme responses had the preposition *with* (e.g., *The boy rubbed hands with soap*) ($n = 629$), though we included responses that used *in* for the verbs *slather/rub/splatter/splash* (e.g., *the boy slathered his body in sunscreen*) ($n = 15$) (the exclusion of these responses did not alter the results we report below). All other responses were coded as *Other* (1.1 % of total 2560 responses, $n = 27$) and excluded from analyses. These included cases where responses included only one thematic role ($n = 15$; e.g., *The woman stuffed the turkey*) or omitted prepositions ($n = 3$; e.g., *The boy slathered sunscreen his body*) or mentioned non-target prepositions including *from* ($n = 2$, e.g., *The girl splattered her trousers from the mud*) or *through* ($n = 1$, *The girl splashed liquid through the window*); the responses contained an error ($n = 1$; *The woman splashed face onto her face*); or there were technical errors ($n = 5$). These were excluded from analyses.

### 3.2. Results and discussion

Fig. 4 displays the percentages and standard errors of location-theme order (*with*-structure) responses relative to theme-location order (locative structure) responses (see Appendix 13.10 for count data). Throughout this article, we report results based on Wald z-scores from logit mixed effects models (Baayen et al., 2008; Barr et al., 2013), implemented in the lme4 package (Bates et al., 2015b) in R (version 4.0.3., R Core Team, 2021). The use of Wald z-scores for hypothesis testing is well-established and offers advantages over analyses such as Likelihood Ratio Test (LRT) models. One key advantage is that it allows for determining the significance of each parameter in a single analysis in R, eliminating the need for multiple comparisons required by LRT tests. This reduces computational complexity and ensures computational efficiency. Conducting multiple model comparisons can be challenging, especially when dealing with complex models or binomial distributions that often encounter convergence issues. To check the robustness of our findings, however, we carried out supplementary LRT tests, and the results are completely consistent with those obtained using Wald z-scores (see Appendix 13.20). Furthermore, we used Bayes Factors (e.g., Lee & Wagenmakers, 2013) to evaluate predictions regarding null effects and interpreted the results following the schemes proposed by Jeffreys (1961). The Bayes Factors were computed using the bayestestR package (Makowski et al., 2019). Data and R scripts are available at https://osf.io/m5whg/?view_only=86f83d06ab1a444581cea1b3aa57e4f.

The fixed effects were mean-centered and standardized, unless stated otherwise. This approach allowed us to interpret the results in terms of main effects and interactions by minimizing collinearity between variables (Baayen et al., 2008) and facilitated convergence in R (Gelman & Hill, 2007). All analyses included initial models with random slopes and intercepts by subjects and by items (Barr et al., 2013). To avoid overfitting (Bates et al., 2015a; Matuschek et al., 2017), we reduced the model complexity by suppressing correlations between random effects (Bates et al., 2015a, 2015b; Kliegl, 2014; Singmann & Kellen, 2020). Additionally, we simplified the model further by eliminating random effects with close-to-zero variances when encountering indications of failed model convergence (Bates et al., 2015a). This procedure had either no or negligible numerical impact on the results, indicating that including or excluding random effects with zero variances did not influence the outcomes.

In Experiment 1, we analyzed whether the choice of location-theme (*with*-structure) and theme-location (locative structure) orders

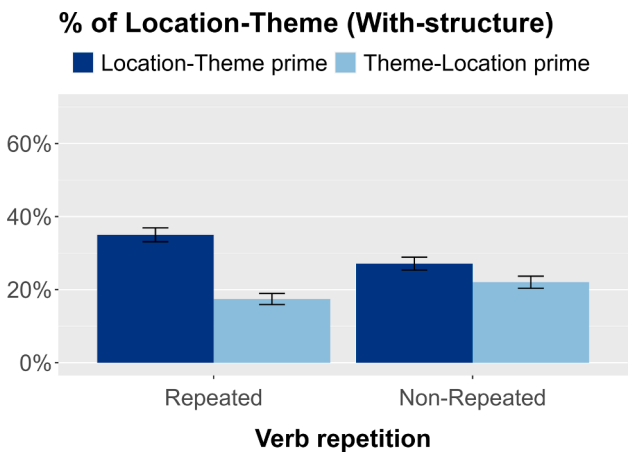


**Fig. 4.** Percentages and standard errors of Location-Theme (relative to Theme-Location) responses in Experiment 1.

**Table 2**
Analyses of structural choice in Experiment 1.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (Intercept) | −1.63 | 0.26 | −6.26 | < .001 |
| Prime Structure | 0.43 | 0.08 | 5.41 | < .001 |
| Verb Repetition | 0.05 | 0.07 | 0.66 | .508 |
| Prime Structure × Verb Repetition | 0.22 | 0.06 | 3.87 | < .001 |
| | *Verb Repeated* | | | |
| (Intercept) | −1.52 | 0.24 | −6.26 | < .001 |
| Prime Structure | 0.63 | 0.10 | 6.16 | < .001 |
| | *Not-Repeated* | | | |
| (Intercept) | −1.77 | 0.31 | −5.74 | < .001 |
| Prime Structure | 0.23 | 0.09 | 2.45 | .014 |

(coded as 1 and 0 respectively) was affected by prime structure (location-theme vs. theme-location, coded as 1 and 0 respectively) and verb repetition (repeated vs. not-repeated, coded as 1 and 0 respectively). Table 2 summarizes the results. As expected, participants adopted more location-theme orders (*with*-structures) following location-theme (*with*-structures) primes (31.1 %, $SE = 1.3$ %) than following theme-location (locative structures) primes (19.7 %, $SE = 1.1$ %), showing an effect of structural priming. Importantly, the effect was larger when the verb was repeated (17.6 %) than when the verb was not repeated (5.1 %), though simple effects were reliable in both cases. The Bayes Factor for this interaction ($BF_{01}$) was 0.064, providing no support for the null hypothesis. In fact, the small number supports the existence of the verb boost effect. Crucially, this verb boost effect cannot be attributed to enhanced constituent structure priming because the structural variants share the constituent structure. Experiment 1 thus provided evidence against the verb-constituent structure account. This account suggests that verb repetition enhances structural priming by boosting the activation of the primed abstract constituent structure. Therefore, according to this view, the magnitude of the structural priming effect should have remained unaffected by verb repetition, because the location-theme orders (*with*-structures) and theme-location orders (locative structures) share the same abstract constituent structure.

## 4. Experiment 2: Theme Repetition

While both the verb-argument structure account and the interactive structure-building account propose that verb repetition leads to increased structural priming, neither account predicts the same effect for the repetition of nouns representing thematic roles. However, as discussed earlier, it has been proposed that both verb and noun repetition can enhance structural priming (e.g., Chang et al., 2006; Reitter et al., 2011; Scheepers et al., 2017), challenging the validity of the structural representations assumed under these two accounts. Although recent findings in the dative alternation have failed to support such a hypothesis, the theme-location alternation might work differently from the dative alternation, as suggested by Chang et al. (2006), possibly relying more upon associations between thematic roles and noun concepts. Experiments 2 and 3 examined this possibility, investigating whether the repetition of nouns can lead to a larger priming effect. Specifically, Experiment 2 focused on assessing the impact of theme repetition. As shown in Table 1, the primes had either the location-theme (*with*-structure) (4a & 4c) or theme-location (locative structure) (4b & 4d) order, and they featured either the same theme (suitcases, 4a & 4b) or different themes (skis, 4c & 4d) from the target (5). If language users associate the prime structure with the noun fulfilling the theme role, we should observe a stronger tendency to produce sentences with the primed structure when the theme noun is repeated in the target than when it is not repeated.

### 4.1. Method

#### 4.1.1. Participants

A further 80 participants were recruited from the same population via Prolific as before. An additional participant was recruited but removed from analyses as they failed to follow instructions in one third of the experimental trials.

#### 4.1.2. Materials and procedure

These were the same as in Experiment 1, except that we adapted the materials in Experiment 1 such that the prime and target prompts always had different verbs and locations (see Appendices 13.3 & 13.4), and that we manipulated the repetition of theme: Primes had either the same themes (4a & 4b) or different themes (4c & 4d) from targets (5).

#### 4.1.3. Design

We used a 2 (prime structure: theme-location [locative structure] vs. location-theme [*with*-structure]) × 2 (theme repetition: repeated vs. not-repeated) within-subjects and within-items repeated measures design. The 32 experimental items and 72 filler items were distributed across four lists as in Experiment 1.

#### 4.1.4. Scoring

We scored if participants produced a theme-location response ($n = 1995$) or a location-theme response ($n = 537$) using the same coding scheme as in Experiment 1. As in Experiment 1, we included location-theme orders with the preposition *in* for the verb *dab* (1.7 %, $n = 9$; e.g., *The man dabbed his hand in some moisturiser*). We excluded cases (28 out of 2560, 1.1 %) when only one thematic role was mentioned ($n = 8$); the preposition was replaced by *full of* for the verbs *pack/cram/stuff/pile* ($n = 10$) or omitted ($n = 1$) or an unnecessary preposition was erroneously included (e.g., *The man dabbed at his hand with moisturiser*) ($n = 1$); the response was structurally ambiguous ($n = 1$; *The man crammed an armchair in the truck with other furniture*); the response contained a non-target proposition ($n = 1$, *The girl drizzled vinegar of her dish*), a non-target interpretation ($n = 1$, *The boy splashed in the mud next to a bench*) or an exchange error ($n = 3$, e.g., *The man dabbed his hand on moisturiser*); or there were technical errors ($n = 2$).

### 4.2. Results and discussion

Fig. 5 reports the percentages and standard errors of location-theme responses (see Appendix 13.10 for count data). The analyses included prime structure (location-theme vs. theme-location) and theme repetition (repeated vs. not-repeated) as fixed effects. Table 3 provides a summary of the results. As in Experiment 1, a main effect of prime order revealed more location-theme orders (*with*-structures) after location-theme (*with*-structure) primes (25.5 %, $SE = 1.2$ %) than after theme-location (locative structure) primes (16.9 %, $SE = 1.1$ %). However, there was no significant prime order × theme repetition interaction; in fact, the interaction went in the opposite direction from a lexical boost effect. The Bayes Factor ($BF_{01}$) for the interaction was 38.95, providing strong support for the null hypothesis. This contrasts with Experiment 1, where verb repetition from the prime to the target led to larger structural priming. Simple effects of prime order were reliable in both the theme-repeated condition (7.4 %) and the not-repeated condition (9.8 %). Experiment 2 thus showed that the repetition of the noun bearing the theme role does not enhance the priming of the theme-location alternation.

## 5. Experiment 3: Location Repetition

Experiment 3 examined the impact of location repetition on the theme-location alternation priming. As shown in Table 1, the

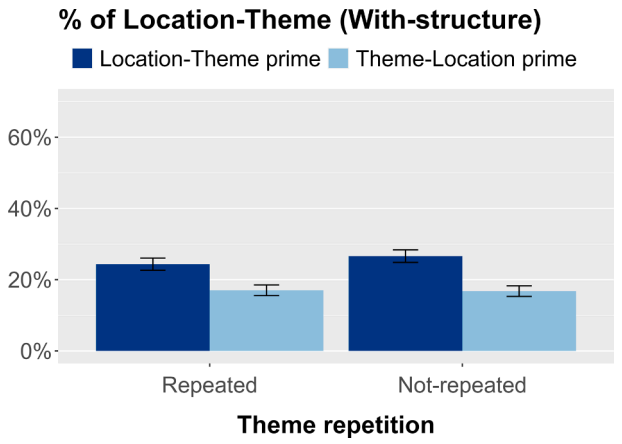


**Fig. 5.** Percentages and standard errors of Location-Theme (relative to Theme-Location) responses in Experiment 2.

**Table 3**
Analyses of structural choice in Experiment 2.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (Intercept) | −2.02 | 0.28 | −7.14 | < .001 |
| Prime Structure | 0.40 | 0.07 | 5.53 | < .001 |
| Theme Repetition | −0.04 | 0.06 | −0.70 | .487 |
| Prime Structure × Theme Repetition | −0.04 | 0.06 | −0.73 | .464 |
| | *Theme Repeated* | | | |
| (Intercept) | −2.02 | 0.29 | −7.08 | < .001 |
| Prime Structure | 0.33 | 0.10 | 3.44 | < .001 |
| | *Not-Repeated* | | | |
| (Intercept) | −2.01 | 0.30 | −6.78 | < .001 |
| Prime Structure | 0.46 | 0.10 | 4.73 | < .001 |

primes (6) had either the location-theme (*with*-structure) (6a & 6c) or theme-location (locative structure) (6b & 6d) order and either the same location (trolley, 6a & 6b) or different locations (sledge, 6c & 6d) from the target (7). If language users associate the noun fulfilling the location role with the structure of the prime sentence, the effect of prime structure on structural choice in the target (7a vs. 7b) should be larger when the location noun is repeated than when it is not.

### 5.1. Method

#### 5.1.1. Participants

A further eighty participants were recruited from the same population as before.

#### 5.1.2. Materials and procedure

These were the same as before, except that the prime and target always had different verbs and themes, and we manipulated location repetition: Primes and targets had either the same location (6a & 6b) or different locations (6c & 6d) from the targets (7) (see Appendices 13.5 & 13.6).

#### 5.1.3. Design

We used a 2 (prime structure: theme-location [locative structure] vs. location-theme [*with*-structure]) × 2 (location repetition: repeated vs. not-repeated) within-subjects and within-items repeated measures design. The 32 experimental items and 72 filler items were distributed across four lists as before.

#### 5.1.4. Scoring

We scored if participants produced a theme-location response ($n = 2110$) or a location-theme response ($n = 408$) using the same coding scheme as before. We included location-theme responses with the preposition, *in*, for the verb, *slather* ($n = 3$), but excluded cases (1.6 % of total 2560 responses, $n = 42$), where participants mentioned only one thematic role ($n = 5$); they used *full of* instead of a preposition (for the verb *stuff*) ($n = 3$) or omitted the preposition ($n = 1$); the thematic roles were mentioned in separate clauses ($n = 1$, e.g. *the man packed up the boxes and put them in the van*); a different location was mentioned ($n = 2$, e.g., *desk* rather than *shelf*); the responses contained exchange errors or conveyed implausible meanings ($n = 3$); there were technical errors ($n = 4$). Cases where participants chose the implausible location in the prime trials ($n = 23$) were also excluded.

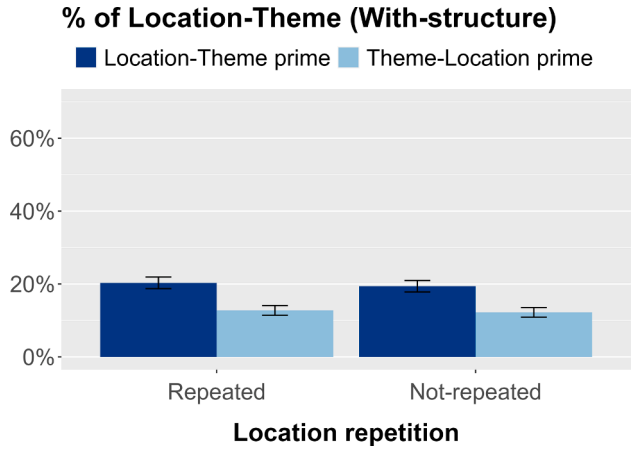


**Fig. 6.** Percentages and standard errors of Location-Theme (relative to Theme-Location) responses in Experiment 3.

**Table 4**
Analyses of structural choice in Experiment 3.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (Intercept) | −2.35 | 0.25 | −9.27 | < .001 |
| Prime Structure | 0.37 | 0.08 | 4.85 | < .001 |
| Location Repetition | 0.03 | 0.07 | 0.37 | .711 |
| Prime Structure × Location Repetition | 0.01 | 0.06 | 0.09 | .925 |
| | *Location Repeated* | | | |
| (Intercept) | −2.41 | 0.28 | −8.55 | < .001 |
| Prime Structure | 0.38 | 0.10 | 3.85 | < .001 |
| | *Not-Repeated* | | | |
| (Intercept) | −2.27 | 0.26 | −8.87 | < .001 |
| Prime Structure | 0.35 | 0.09 | 3.91 | < .001 |

### 5.2. Results and discussion

Fig. 6 reports the means and standard errors (see Appendix 13.10 for count data), and Table 4 summarizes the results. As before, a significant main effect of prime structure indicated a higher proportion of location-theme orders following location-theme primes (19.9 %, $SE = 1.1$ %) compared to theme-location primes (12.5 %, $SE = 0.9$ %). This main effect did not interact with the repetition of the location noun, and the simple effects of prime order were reliable in both the location-repeated condition (7.5 %) and the not-repeated condition (7.2 %). The results are in line with Experiment 2, where the repetition of the noun representing the location role did not interact with the priming effect. The $BF_{01}$ for this interaction was 49.98, again, providing very strong evidence in support of the null hypothesis.

Hence, the results from Experiments 1–3 indicate that verb repetition, but not the repetition of the nouns fulfilling the theme or location roles, reliably enhances the priming of the theme-location alternation. However, the absence of noun boost effects raises the question of whether our experiments had sufficient statistical power to detect significant interactions. To address this concern, we conducted combined analyses for Experiments 2 and 3, doubling the sample size, to investigate whether noun repetition interacts with the prime in the larger dataset. The results showed no significant noun repetition × prime structure interaction, *Estimate* = -0.02, $SE = 0.04$, $z = -0.42$, $p = .672$, with the Bayes Factor for this interaction ($BF_{01} = 65.26$) providing very strong support for the null hypothesis (see Appendix 13.11 for full results).[4] In contrast, another combined analysis contrasting Experiment 1 with the combination of Experiments 2 and 3 revealed a three-way interaction (prime structure × lexical repetition × experiment), confirming that the lexical boost effect depended on the repeated lexical item, *Estimate* = 0.24, $SE = 0.07$, $z = 3.42$, $p = .001$ (see Appendix 13.11 for full results). Overall, these additional analyses confirm that while the repetition of the verb enhances structural priming, the repetition of the theme or location does not have the same magnitude of effect, *if any*, on enhancing structural priming.

## 6. Experiment 4: From *What*-Cleft Prime To *What*-Cleft Target

Experiment 1 ruled out the verb-constituent structure account, according to which there should be no verb boost effect when the structural variants share the constituent structure. In this experiment, the thematic role orders and argument structures co-varied in declarative constructions. To examine the representations underlying structural priming further, Experiments 4–6 used cleft constructions. This allowed us to independently manipulate thematic role order and argument structure, as described below. The key question was whether verb repetition exclusively enhances the persistence of argument structure, as predicted by the **verb-argument structure account**. An alternative possibility was that verb repetition also reinforces the persistence of thematic role order, as posited by the **interactive structure-building account**, according to which the persistence of thematic role order should interact with that of argument structure when the construction of the prime persists in the target. Thus, in Experiment 4, both primes and targets involved *what*-cleft constructions. Each prime had either a location-theme order (8a, 8b, 8e, 8f), emphasizing the theme role, or a theme-location order (8c, 8d, 8g, 8h), emphasizing the location role. Within each thematic role order, argument structure and constituent structure were also varied. Sentences (8a, 8c, 8e, 8g) involve a *with*-structure, whereas sentences (8b, 8d, 8f, 8h) involve a locative structure. In NP-first sentences (8a, 8d, 8e, 8h), the noun phrase representing the direct object preceded the prepositional object. In PP-first sentences (8b, 8c, 8f, 8g), the prepositional phrase containing the prepositional object preceded the direct object.

[4] Note that post-hoc power analyses do not provide meaningful insights here. In Experiment 2, the repetition of the theme reduced the priming effect by 2.4% instead of enhancing it. Therefore, determining the required number of additional participants based on this effect would not inform us about the power needed to detect a noun boost effect. Similarly, in Experiment 3, the advantage of the priming effect following location repetition was only 0.3%, substantially smaller than the verb boost effect (12.5%) in Experiment 1. These results already indicate that noun repetition does not reliably influence priming when the same statistical power used for verb repetition is applied.

**Table 5**
Example prime and target sentences in Experiments 4–5.

| Thematic Role Order | Argument Structure | Constituent Structure | Sentence |
|---|---|---|---|
| | | **Experiments 4-5 Prime Sentence** | |
| *Verb Repeated* | | | |
| Agent-Location-Theme | *With*-Structure | NP-first | 8a. What the assistant loaded the lift with was (the equipment). |
| (Theme-focused) | Locative Structure | PP-first | 8b. What the assistant loaded into the lift was (the equipment). |
| Agent-Theme-Location | *With*-Structure | PP-first | 8c. What the assistant loaded with the equipment was (the lift). |
| (Location-focused) | Locative Structure | NP-first | 8d. What the assistant loaded the equipment into was (the lift). |
| *Not-Repeated* | | | |
| Agent-Location-Theme | *With*-Structure | NP-first | 8e. What the assistant packed the lift with was (the equipment). |
| (Theme-focused) | Locative Structure | PP-first | 8f. What the assistant packed into the lift was (the equipment). |
| Agent-Theme-Location | *With*-Structure | PP-first | 8g. What the assistant packed with the equipment was (the lift). |
| (Location-focused) | Locative Structure | NP-first | 8h. What the assistant packed the equipment into was (the lift). |
| | | **Experiment 4 Target Completion** | |
| Agent-Location-Theme | *With*-Structure | NP-first | 9a. What the man loaded (the bus with was the luggage). |
| (Theme-focused) | Locative Structure | PP-first | 9b. What the man loaded (onto the bus was the luggage). |
| Agent-Theme-Location | *With*-Structure | PP-first | 9c. What the man loaded (with the luggage was the bus). |
| (Location-focused) | Locative Structure | NP-first | 9d. What the man loaded (the luggage onto was the bus). |
| | | **Experiment 5 Target Completion** | |
| Agent-Location-Theme | *With*-Structure | NP-first | 10a. The man loaded (the bus with the luggage) |
| Agent-Theme-Location | Locative Structure | NP-first | 10b. The man loaded (the luggage onto the bus). |

*Note.* NP = Noun Phrase, PP = Prepositional Phrase. Example completions in brackets.

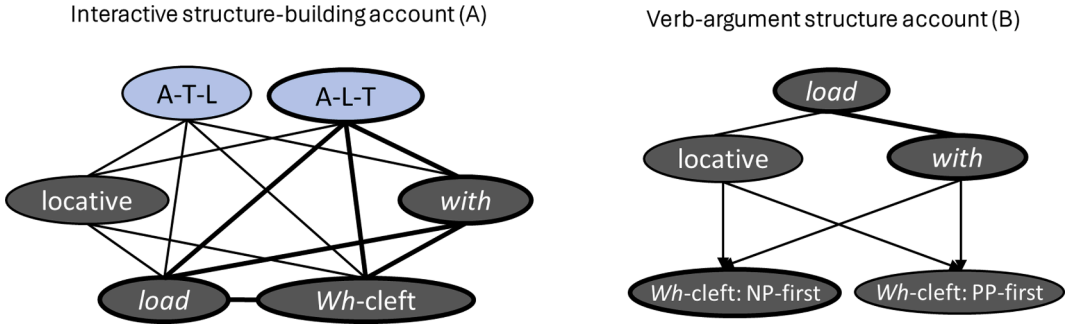


**Fig. 7. Representations of the interactive structure-building account (A) and the verb-argument structrue account (B).** Bold lines indicate an increased activation of relevant nodes and links following the prime (8a). ATL = Agent-Theme-Location, ALT = Agent-Location-Theme. NP = Noun Phrase, PP = Prepositional Phrase.

To illustrate the predictions of the two accounts, the diagrams in Fig. 7A and Fig. 7B represent the interactive structure-building account and the verb argument structure account, respectively. The bold lines in the diagrams indicate an increased activation of the relevant nodes and links activated when a what-cleft sentence such as (8a) has been presented as a prime.

According to the **interactive structure-building account** (Fig. 7A), a prime sentence such as (8a) activates the A-L-T node (representing an Agent-Location-Theme order), the *with*-structure node (representing a *with*-argument structure), the verb *load*, and the Wh-cleft node (representing the *what*-cleft construction), along with the links connecting these nodes. The increased activation of the A-L-T node and the *with*-structure node subsequently enhances the likelihood of repeating a location-theme order and a *with*-structure in the target, respectively. Now, imagine that the verb *load* is to be repeated in another *what*-cleft sentence. This repetition further enhances the activation of the verb *load* and the Wh-cleft node, leading to a spread of activation throughout the network. In this process, the A-L-T node and the *with*-structure node receive robust activation from their links to *load* and the Wh-cleft node. This is due to the pre-activation of these links by the prime (8a), which results in their residual activation contributing to the A-L-T and *with*-structure nodes when the activation spreads from *load* and the Wh-cleft node. Consequently, repeating *load* and a *what*-cleft construction in the target sentence boosts the activation of the A-L-T node and the *with*-structure node. This, in turn, increases the probability of repeating a location-theme order and a *with*-structure, alongside *load* and the *what*-cleft construction, in the target sentence.

In this account, verb repetition is not the sole factor capable of enhancing priming effects. Suppose that, following a prime such as (8a), speakers produce another what-cleft sentence with the same thematic role order in the target. This further enhances the A-L-T node and the Wh-cleft construction node. As this enhanced activation spreads from these nodes, the *with*-structure node, which is linked to these nodes, receives a substantial activation boost. This is because the links from the A-L-T node and the Wh-cleft node to the *with*-structure have been pre-activated by the prime sentence (8a), resulting in residual activation feeding into the *with*-structure node as well as the spreading activation from the A-L-T node and the Wh-cleft node. Consequently, when the A-L-T order and the *what*-cleft construction are repeated in the target, the probability of repeating a *with*-structure alongside the A-L-T order and the *what*-cleft construction increases. Similarly, if speakers intend to repeat the *with*-structure in another what-cleft sentence node in the target, it leads to an enhanced activation of the *with*-structure node alongside the Wh-cleft node in the target. When the activation from these

two nodes spreads through the network, the A-L-T node gains strong activation due to its pre-activated links to the *with*-structure node and the *what*-cleft structure node. Thus, further activating the *with*-structure node and the Wh-cleft construction node in the target increases the likelihood of a persisting A-L-T order alongside a *with*-structure and a *what*-cleft construction, given their co-occurrence in the prime.

Note that the diagram in Fig. 7A omits constituent structures (NP-first vs. PP-first), reflecting the model's assumption that the primary driver of structural priming is the persistence of argument structure and thematic role order. In this account, while the argument structure and thematic role order of the prime can interact, they can also persist independently. For example, the *with*-structure of the prime (8a) can elicit a *with*-structure in the target even if the A-L-T order of the prime (8a) does not persist. Likewise, the A-L-T order of the prime can persist in the target even when a locative structure, rather than a *with*-structure, is selected in the target. However, constituent structure cannot persist on its own; instead, its persistence hinges on the simultaneous persistence of both argument structure and thematic role order. If the thematic role order of the prime persists in the target (e.g., both employing a location-theme order, 9a & 9b following 8a), NP-first primes (8a) can elicit NP-first targets (9a) by sharing both argument structure (*with*-structure) and thematic role order (location-theme order). However, if a different thematic role order is adopted in the target (e.g., 9c & 9d following 8a), NP-first primes (8a) will not elicit NP-first targets (9d) due to disparities in argument structure and thematic role order. Likewise, when the prime's argument structure persists in the target (e.g., both having a *with*-structure, 9a & 9c following 8a), NP-first primes (8a) can elicit NP-first targets (9a) through the shared thematic role order and argument structure. However, if the argument structure does not persist in the target (e.g., 9b & 9d following 8a), NP-first primes (8a) will not induce NP-first targets (9d) due to the divergence in both argument structure and thematic role order.

In contrast, according to the **verb-argument structure account** (Fig. 7B), the constituent structure of the prime should be separately primed from its argument structure, because constituent structures are represented distinctly from argument structures. Thematic role orders are not represented in the diagram in Fig. 7B, as they are considered irrelevant for structure building in this model. Hence, accorting to this model, processing the prime (8a) should increase the activation of the constituent structure *What-cleft: NP first*, as well as the *with*-structure and the verb *load* along its link to the *with*-structure. The increased activation of the *with*-structure node and the constituent structure *What-cleft: NP first* should enhance the probability of subsequently selecting a *with*-structure and an NP-first constituent structure, respectively, in the target. The verb *load* is linked to the *with*-structure node but neither to the constituent structure nor to the thematic role order, which is absent in the model. Hence, verb repetition should enhance the persistence of the primed argument structure only. Furthermore, constituent structure persistence should happen not only when the argument structure and the thematic role order persist in the target, but also when different argument structures or thematic role orders are chosen in the target. Moreover, due to the sequential nature of argument structure selection preceding constituent structure selection, the persistence of the argument structure should remain unaffected by whether the linear order of constituents (and thus the thematic role order) also persists in the target or not.

### 6.1. Method

#### 6.1.1. Participants

A further eighty participants were recruited from the same population as before via Prolific and the University of Stirling student population. An additional 15 participants took part but were excluded from analyses because more than 12 out of 32 responses were invalid, mostly failing to include a copula verb after the *what*-clause (e.g., *What the boy packed stationary into the bag*).

#### 6.1.2. Materials, design and procedure

We had 32 experimental items. The prime sentences used in Experiments 1–3 were adapted to form *what*-cleft constructions, and the target prompts began with *what*-clauses which involved the subject and the verb, and we used identical or similar target events as those used in Experiments 1–3 (see Appendices 13.7 & 13.9). As shown in Table 5, the prime sentences had two thematic role orders: Agent-Location-Theme (A-L-T) order primes (8a, 8b, 8e, 8f) and Agent-Theme-Location order (A-T-L) primes (8c, 8d, 8g, 8h). In the *A-L-T order primes*, the location (e.g., *lift*) was mentioned after the verb in the *what*-cleft construction, with the theme mentioned after the copular verb, emphasizing the theme in the sentence. In *the A-T-L order primes*, the theme (e.g., *equipment*) immediately followed the verb in the *what*-cleft construction, and the location, mentioned after the copular verb, was emphasized. Within each thematic role order condition, *what*-clefts are derived from either *with* variants (*with*-structure, 8a, 8c, 8e, 8g), having the location role as the direct object of the verb, or locative variants (*locative structure*, 8b, 8d, 8f, 8h), having the theme role as the direct object of the verb. In addition, in *NP-first sentences* (8a, 8d, 8e, 8h), the verb within the *what*-clause preceded a noun phrase denoting the direct object, whereas in *PP-first sentences* (8b, 8c, 8f, 8g), the verb in the *what*-clause preceded a prepositional phrase containing the prepositional object. The 32 experimental items and 70 filler items were distributed across four lists as before. Because the experimental items always had *what*-clefts, some filler items had *what*-clefts ($n = 6$) or *it*-clefts, either in primes ($n = 19$) or targets ($n = 9$). The rest of the filler items were the same as those used in Experiments 1–3.

#### 6.1.3. Scoring

We scored if participants produced a *with*-structure ($n = 596$) and a locative structure ($n = 1647$) and if they produced location-theme order (theme-focused) responses ($n = 1968$) or a theme-location order (location-focused) response ($n = 275$) when producing a *what*-cleft target. In addition, we scored whether participants produced NP-first orders ($n = 751$) or PP-first orders ($n = 1492$). We included cases where the preposition *with* was replaced with another preposition for *slather* and *smear* (e.g., *What the boy slathered his body in was sunscreen*) ($n = 8$). Cases were excluded where a copula verb was omitted (e.g., *What the girl splattered the wall with paint*; $n =$

200); one of the roles was used as a modifier for another role (e.g., *What the man rubbed was wax onto the shoe*; $n = 61$); only one argument was mentioned ($n = 3$); the preposition was omitted ($n = 16$) or placed in a non-target position (e.g. *What the man drizzled the dish was with olive oil*; $n = 12$) or mentioned twice (e.g., *What the man stacked the shelves with was with tins*; $n = 2$) and the response contained a word change error ($n = 2$). Additionally, we excluded cases where participants did not complete the prime fragments as we expected (e.g., by choosing an implausible noun or including a redundant preposition; $n = 21$). In total, 317 out of 2560 trials (12.4 %) were excluded from analyses.

### 6.2. Results and discussion

Fig. 8 reports the percentages of target responses by prime thematic role order, prime argument structure and verb repetition (see Appendix 13.12 for count data and standard errors). In the following, we present three sets of analyses, each examining the rates of argument structure, thematic role order, or constituent structure in the target, respectively. These analyses were conducted to test specific hypotheses regarding different aspects of the two accounts contrasted in the experiment.

#### 6.2.1. Argument structure persistence

Here we examined the binary choice of argument structure (*with*-structure vs. locative structure), collapsing across thematic role order in the target. The first analysis focused on determining whether the argument structure of the prime persisted in the target (*argument structure priming*), and if this priming effect was stronger when the verb was repeated compared to when it was not, as predicted by both the interactive structure-building account and the verb-argument structure account. The model thus included fixed effects such as the thematic role order of the prime (location-theme vs. theme-location, coded as 1 and 0, respectively), verb repetition (repeated vs. not-repeated, coded as 1 and 0, respectively), and prime argument structure (*with* vs. locative, coded as 1 and 0, respectively) as fixed effects. For target responses, the *with*-structure was coded 1 and the locative structure as 0. Fig. 9 presents the means and standard errors for this analysis (see Appendix 13.13 for count data) and the results are summarized in Table 6 (1).

A main effect of prime argument structure indicated more *with*-structure responses after *with*-structure primes (37.4 %, $SE = 1.4$ %) than after locative structure primes (15.8 %, $SE = 1.1$ %). This argument structure priming effect interacted with verb repetition, with a larger effect of prime argument structure with repeated verbs (29.1 %) than with not-repeated verbs (14.2 %), though the effect was reliable regardless of verb repetition. There was no main effect of thematic role order, which indicated that the rates of *with*-structure and locative structure did not differ reliably depending on whether the prime had a location-theme order or a theme-location order. Neither the effect of prime argument structure nor the verb boost effect interacted with prime thematic role order, either, indicating no evidence that either effect was dependent on a particular thematic role order of the prime.

The second analysis aimed to determine whether the argument structure of the prime exhibited greater persistence when the

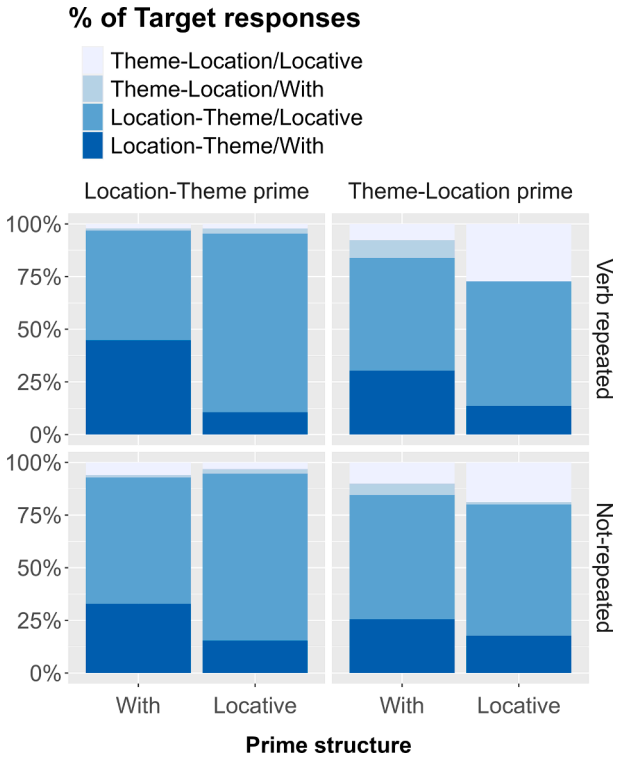


**Fig. 8.** Distributions of target responses in Experiment 4.

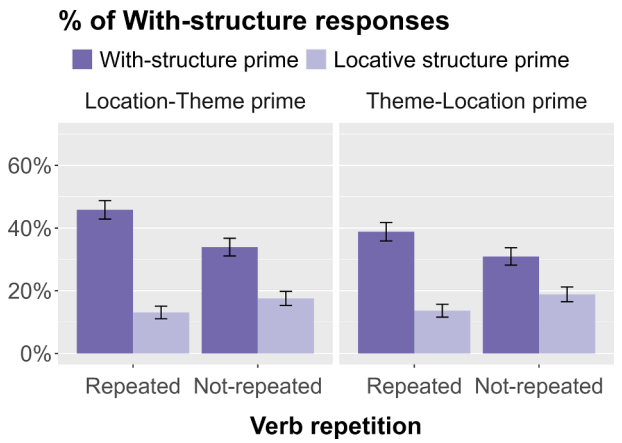


**Fig. 9.** Percentages and standard errors of *With*-Structure (relative to Locative Structure) responses by prime argument structure, prime thematic role order, and verb repetition in Experiment 4.

**Table 6**
Analyses of argument structure choice in Experiment 4.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (1) **Argument Structure × Verb Repetition** | | | | |
| (Intercept) | −1.62 | 0.24 | −6.63 | < .001 |
| Argument Structure (*With* vs. Locative) | 0.83 | 0.07 | 11.75 | < .001 |
| Thematic Role Order (Location-Theme vs. Theme-Location) | 0.05 | 0.06 | 0.88 | .381 |
| Verb Repetition (Repeated vs. Not-Repeated) | 0.04 | 0.06 | 0.62 | .535 |
| Argument Structure × Thematic Role Order | 0.11 | 0.07 | 1.66 | .097 |
| Argument Structure × Verb Repetition | 0.28 | 0.07 | 3.92 | < .001 |
| Thematic Role Order × Verb Repetition | 0.03 | 0.07 | 0.51 | .614 |
| Argument Structure × Thematic Role Order × Verb Repetition | 0.01 | 0.08 | 0.14 | .887 |
| | *Verb Repeated* | | | |
| (Intercept) | −1.53 | 0.25 | −6.04 | < .001 |
| Argument Structure | 1.10 | 0.11 | 10.25 | < .001 |
| | *Not-Repeated* | | | |
| (Intercept) | −1.53 | 0.23 | −6.76 | < .001 |
| Argument Structure | 0.51 | 0.08 | 6.19 | < .001 |
| (2) **Argument Structure × Thematic Role Order Congruence** | | | | |
| (Intercept) | −1.62 | 0.24 | −6.69 | < .001 |
| Argument Structure | 0.84 | 0.07 | 12.45 | < .001 |
| Thematic Role Order Congruence | −0.14 | 0.06 | −2.13 | .033 |
| Verb Repetition | 0.03 | 0.06 | 0.43 | .666 |
| Argument Structure × Order Congruence | 0.37 | 0.06 | 5.97 | < .001 |
| Argument Structure × Verb Repetition | 0.29 | 0.07 | 4.15 | < .001 |
| Order Congruence × Verb Repetition | −0.04 | 0.06 | −0.62 | .536 |
| Argument Structure × Order Congruence × Verb Repetition | 0.09 | 0.07 | 1.22 | .223 |
| | *Same Thematic Role Order* | | | |
| (Intercept) | −1.60 | 0.23 | −7.09 | < .001 |
| Argument Structure | 1.08 | 0.09 | 11.95 | < .001 |
| | *Different Thematic Role Order* | | | |
| (Intercept) | −1.50 | 0.27 | −5.59 | < .001 |
| Argument Structure | 0.38 | 0.09 | 4.11 | < .001 |

thematic role order of the prime persisted in the target, as predicted by the interactive structure-building account, but not by the verb argument structure account. Hence, the analysis included a new variable, *thematic role order congruence*, which was coded as 1 when participants adopted the same thematic role order as in the prime and 0 when they used a different thematic role order (cf. Fukumura & Zhang, 2023). Fig. 10 reports the means for this analysis (see Appendix 13.13 for count data) and Table 6 (2) summarises the results. The analysis revealed an interaction between argument structure and thematic role order congruence: The effect of prime argument structure was larger when the thematic role order of the prime was repeated in the target (29.8 %) than when it was not (10.4 %). However, the effect of prime argument structure was reliable regardless of whether the same thematic role order was repeated in the target or not. The prime argument structure × thematic role order congruence interaction was not modulated by verb repetition, showing no evidence of a verb boost effect on argument structure persistence being dependent on thematic role order congruence.

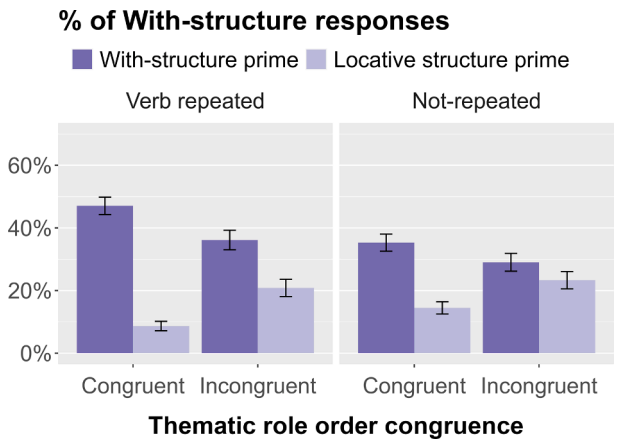


**Fig. 10.** Percentages and standard errors of *With*-Structure (relative to Locative Structure) responses by prime argument structure, thematic role order congruence, and verb repetition in Experiment 4.

*6.2.2. Thematic role order persistence*

Here we examined the binary choice of thematic role order or emphasis. The first analysis investigated whether the thematic role order of the prime persisted in the target (*thematic role order priming*) and whether this effect was larger following verb repetition, as predicted by the interactive structure building account, but not by the verb-argument structure account. The analysis thus included prime thematic role order, prime argument structure, and verb repetition as fixed effects. Location-theme order responses were coded as 1, while theme-location order responses were coded as 0. Fig. 11 reports the means (see Appendix 13.14 for count data), and Table 7 (1) summarizes the results. A main effect of prime thematic role order showed a higher rate of location-theme orders after location-theme primes (95.0 %, $SE = 0.6$ %) than after theme-location primes (80.3 %, $SE = 1.2$ %), demonstrating the persistence of prime thematic role order (or emphasis). A prime thematic role order × verb repetition interaction revealed a larger thematic role order effect when the verb was repeated (17.8 %) than when it was not (11.5 %). The absence of a thematic role order × argument structure interaction and a three-way interaction showed no evidence that thematic role order priming and the enhanced priming effect following verb repetition were affected by the argument structure of the prime.

The second analysis examined whether the thematic role order of the prime tended to persist more when the argument structure from the prime persisted in the target, and whether the thematic role order from the prime persisted with a different argument structure from the prime, as predicted by the interactive structure building account. For this analysis, we created a new variable called *argument structure congruence*, which was coded as 1 when participants adopted the same argument structure as the prime, and 0 when they used a different argument structure. Fig. 12 reports the means for this analysis (see Appendix 13.14 for count data), and Table 7 (2) summarizes the results. The analysis revealed a thematic role order × argument structure congruence interaction, with a larger effect of prime thematic role order when the target adopted the same argument structure as in the prime (22.3 %) than a different argument structure from the prime (3.2 %), though the effect of prime thematic role order was reliable in both cases. This interaction was not modulated by verb repetition, indicating that the relationship between thematic role order priming and argument structure

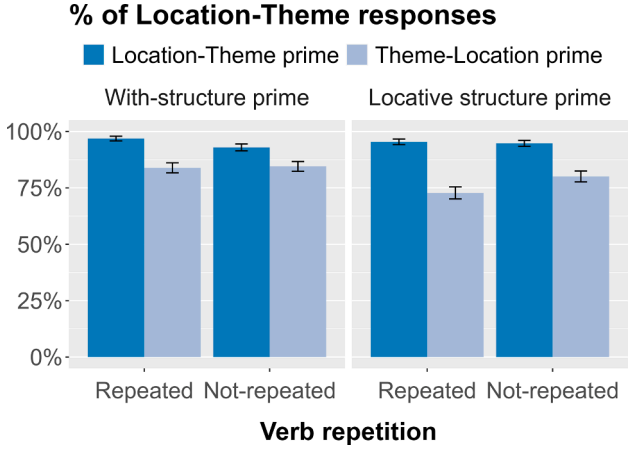


**Fig. 11.** Percentages and standard errors of Location-Theme (relative to Theme-Location) orders by prime thematic role order, prime argument structure and verb repetition in Experiment 4.

**Table 7**
Analyses of thematic role order in Experiment 4.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (1) **Thematic Role Order × Verb Repetition** | | | | |
| (Intercept) | 3.06 | 0.24 | 12.49 | < .001 |
| Thematic Role Order (Location-Theme vs. Theme-Location) | 0.99 | 0.12 | 8.59 | < .001 |
| Argument Structure (*With* vs. Locative) | 0.17 | 0.10 | 1.63 | .104 |
| Verb Repetition (Repeated vs. Not-Repeated) | 0.06 | 0.10 | 0.59 | .557 |
| Thematic Role Order × Argument Structure | −0.17 | 0.12 | −1.42 | .156 |
| Thematic Role Order × Verb Repetition | 0.20 | 0.09 | 2.21 | .028 |
| Argument Structure × Verb Repetition | 0.13 | 0.09 | 1.37 | .171 |
| Thematic Role Order × Argument Structure × Verb Repetition | 0.04 | 0.09 | 0.47 | .639 |
| | *Verb Repeated* | | | |
| (Intercept) | 2.80 | 0.24 | 11.43 | < .001 |
| Thematic Role Order | −1.09 | 0.17 | −6.27 | < .001 |
| | *Not-Repeated* | | | |
| (Intercept) | 2.79 | 0.26 | 10.63 | < .001 |
| Thematic Role Order | −0.72 | 0.12 | −5.86 | < .001 |
| (2) **Thematic Role Order × Argument Structure Congruence** | | | | |
| (Intercept) | 2.98 | 0.23 | 12.94 | < .001 |
| Thematic Role Order (Location-Theme vs. Theme-Location) | 0.97 | 0.12 | 7.93 | < .001 |
| Argument Structure Congruence | 0.01 | 0.10 | 0.07 | .943 |
| Verb Repetition | 0.06 | 0.10 | 0.61 | .545 |
| Thematic Role Order × Structure Congruence | 0.52 | 0.09 | 5.58 | < .001 |
| Thematic Role Order × Verb Repetition | 0.14 | 0.10 | 1.48 | .140 |
| Structure Congruence × Verb Repetition | −0.09 | 0.10 | −0.93 | .354 |
| Thematic Role Order × Structure Congruence × Verb Repetition | 0.07 | 0.09 | 0.78 | .438 |
| | *Same Argument Structure* | | | |
| (Intercept) | 2.85 | 0.24 | 11.65 | < .001 |
| Thematic Role Order (Emphasis) | −1.34 | 0.15 | −9.13 | < .001 |
| | *Different Argument Structure* | | | |
| (Intercept) | 2.98 | 0.30 | 9.91 | < .001 |
| Thematic Role Order (Emphasis) | −0.31 | 0.14 | −2.12 | .034 |

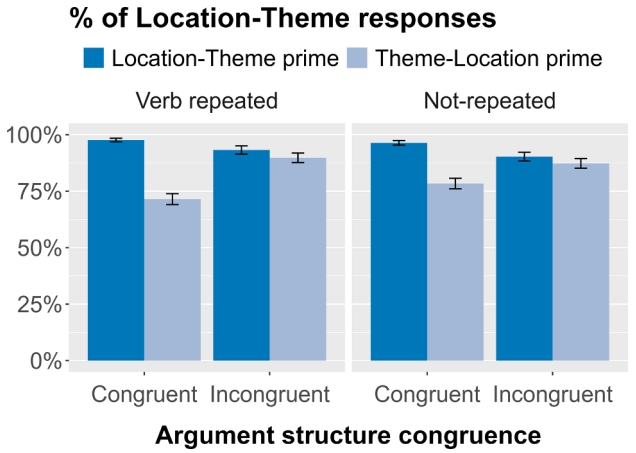


**Fig. 12.** Percentages and standard errors of Location-Theme (relative to Theme-Location) orders by prime thematic role order, argument structure congruence and verb repetition in Experiment 4.

congruence was not dependent on verb repetition. In this analysis, there was no reliable prime thematic role order × verb repetition interaction, which we discuss in 6.2.4.

### *6.2.3. Constituent structure persistence*

Thus far, our analyses have demonstrated the persistence of both the argument structure and thematic role order of the prime from *what*-cleft primes to *what*-cleft targets. While these two effects appeared to interact, both the argument structure and thematic role order of the prime were able to persist separately, even in the absence of their counterpart persisting. Here, we examine the impact of prime constituent structure, specifically, the order of syntactic categories (functions) in the prime (NP [direct object]-first vs. PP [prepositional object]-first), on structural choice in the target. Our primary focus was to determine whether the constituent structure of the prime persists in the target, even when a different argument structure or thematic role order is adopted in the target – a prediction consistent with the verb-argument structure account. An alternative possibility is that constituent structure persistence only occurs

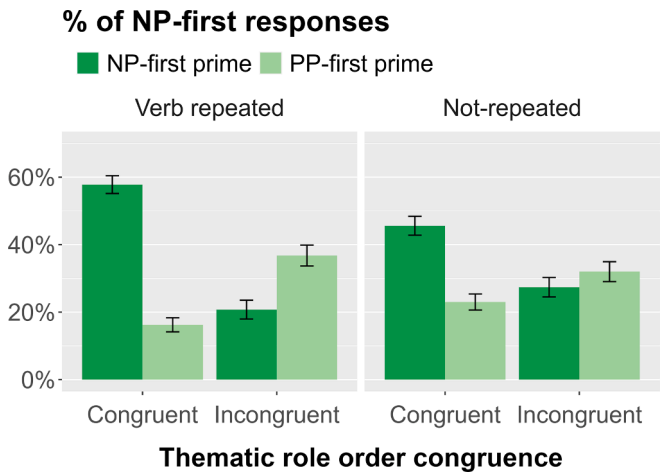


**Fig. 13.** Percentages and standard errors of NP-first (relative to PP-first) responses by prime constituent structure, thematic role order congruence, and verb repetition in Experiment 4. NP = Noun Phrase, PP = Prepositional Phrase.

when primes and targets share both thematic role orders and argument structures, as predicted by the interactive structure building account.

The first analysis thus examined whether constituent structure persistence interacted with thematic role order congruence, and if prime constituent structure persisted in the target even when a different thematic role order was selected in the target as predicted by the verb-argument structure account. We analyzed the rates of direct-object first (NP-first) responses (coded as 1) and prepositional object first (PP-first) responses (coded as 0) as a function of prime constituent structure (NP-first vs. PP-first, coded as 1 and 0), thematic role order congruence, and verb repetition. Fig. 13 reports the means for the first analysis (see Appendix 13.15 for count

**Table 8**
Analyses of constituent structure in Experiment 4.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (1) **Prime Constituent Structure × Thematic Role Order Congruence** | | | | |
| (Intercept) | −1.11 | 0.21 | −5.22 | < .001 |
| Prime Constituent Structure (NP-first vs. PP-first) | 0.45 | 0.06 | 7.91 | < .001 |
| Thematic Role Order Congruence (Congruent vs. Incongruent) | 0.10 | 0.06 | 1.67 | .095 |
| Verb Repetition (Repeated vs. Not-Repeated) | 0.00 | 0.06 | −0.06 | .952 |
| Prime Constituent Structure × Order Congruence | 0.67 | 0.06 | 11.37 | < .001 |
| Prime Constituent Structure × Verb Repetition | 0.08 | 0.06 | 1.32 | .188 |
| Thematic Role Order Congruence × Verb Repetition | 0.02 | 0.06 | 0.35 | .726 |
| Prime Constituent Structure × Order Congruence × Verb Repetition | 0.22 | 0.06 | 3.91 | < .001 |
| *Same Thematic Role Order* | | | | |
| (Intercept) | −0.93 | 0.19 | −4.85 | < .001 |
| Prime Constituent Structure | 0.98 | 0.08 | 11.63 | < .001 |
| Verb Repetition | 0.02 | 0.07 | 0.33 | .738 |
| Prime Constituent Structure × Verb Repetition | 0.26 | 0.07 | 3.58 | < .001 |
| *Different Thematic Role Order* | | | | |
| (Intercept) | −1.43 | 0.28 | −5.18 | < .001 |
| Prime Constituent Structure | −0.35 | 0.09 | −3.75 | < .001 |
| Verb Repetition | −0.03 | 0.09 | −0.35 | .724 |
| Prime Constituent Structure × Verb Repetition | −0.22 | 0.12 | −1.90 | .057 |
| **(2) Prime Constituent Structure × Argument Structure Congruence** | | | | |
| (Intercept) | −1.03 | 0.20 | −5.24 | < .001 |
| Prime Constituent Structure | 0.42 | 0.05 | 7.71 | < .001 |
| Argument Structure Congruence | 0.22 | 0.06 | 3.68 | < .001 |
| Verb Repetition | 0.02 | 0.05 | 0.39 | .698 |
| Prime Constituent Structure × Structural Congruence | 0.38 | 0.06 | 6.55 | < .001 |
| Prime Constituent Structure × Verb Repetition | 0.06 | 0.06 | 0.90 | .366 |
| Argument Structure Congruence × Verb Repetition | 0.09 | 0.06 | 1.69 | .090 |
| Prime Constituent Structure × Structural Congruence × Verb Repetition | 0.04 | 0.06 | 0.81 | .415 |
| *Same Argument Structure* | | | | |
| (Intercept) | −0.75 | 0.16 | −4.68 | < .001 |
| Prime Constituent Structure | 0.69 | 0.07 | 10.21 | < .001 |
| *Different Argument Structure* | | | | |
| (Intercept) | −1.48 | 0.27 | −5.45 | < .001 |
| Prime Constituent Structure | −0.03 | 0.10 | −0.27 | .785 |

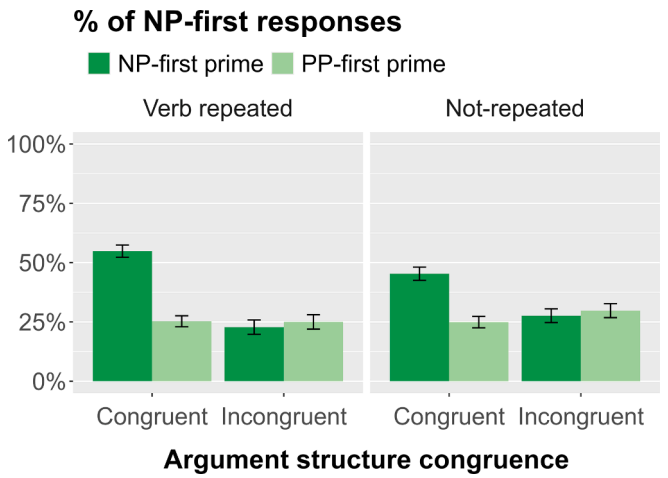


**Fig. 14.** Percentages and standard errors of NP-first (relative to PP-first) responses by prime constituent structure, argument structure congruence, and verb repetition in Experiment 4. NP = Noun Phrase, PP = Prepositional Phrase.

data), and Table 8 (1) summarizes the results. A main effect of prime constituent structure indicated a higher rate of NP-first responses after NP-first primes (40.8 %, *SE* = 1.5 %) compared to PP-first primes (26.1 %, *SE* = 1.3 %). However, there was a significant interaction between prime constituent structure and thematic role order congruence, as well as a significant three-way interaction between prime constituent structure, thematic role order congruence, and verb repetition. When participants adopted the same thematic role order as in the prime, there were more NP-first responses following NP-first primes than following PP-first primes, and this tendency was enhanced by verb repetition. However, when participants adopted a different thematic role order from the prime, there were *fewer* NP-first responses following NP-first primes than PP-first primes, and this tendency was marginally amplified by verb repetition.

A second analysis examined whether and how the constituent structure of the prime interacted with argument structure congruence in constituent structure selectin in the target, and whether constituent structure priming occurred when a different argument structure was selected in the target. The verb-argument structure account assumes that the constituent structure of the prime should persist in the target even with a different argument structure from the prime is adopted in the target. The analyses thus included prime constituent structure, argument structure congruence and verb repetition as fixed effects. Fig. 14 reports the means for this analysis (see Appendix 13.15 for count data), and Table 8 (2) summarizes the results. The analyses revealed an interaction between prime constituent structure and argument structure congruence. Simple effects revealed that when the prime and target shared the argument structure, there were more NP-first responses following NP-first primes than following PP-first primes. However, there was no effect of prime constituent structure when the prime and target differed in argument structures: NP-first primes did not reliably elicit NP-first targets relative to PP-first primes.

### *6.2.4. Summary and discussion of Experiment 4*

In summary, Experiment 4 yielded several important findings. First, both the argument structure and thematic role order of the prime persisted from *what*-cleft primes to *what*-cleft targets. Whilst both effects persisted in the absence of one another, these effects were related. Participants were more likely to repeat the argument structure of the prime when they adopted the same thematic role order as in the prime, and they tended to repeat the thematic role order of the prime more often with the same argument structure as the prime. Second, both effects were enhanced by verb repetition, which appears to have had a larger boost effect on argument structure persistence (14.9 %) compared to thematic role order persistence (6.3 %), suggesting that verbs may be more strongly associated with argument structures than with thematic role orders. We should also note that when the primed argument structure was reused in the target, it boosted thematic role order persistence by 19.1 %, which is substantially larger than the verb boost effect on thematic role ordering, indicating that the thematic role order of the prime may be more strongly associated with the argument structure of the prime than with the verb. This might explain why the model that included the interaction between thematic role order and argument structure congruence showed no verb repetition × thematic role order interaction.

Third, while the argument structure and thematic role order of the prime could persist separately from each other, the prime constituent structure (NP-first vs. PP-first) did not exert an independent influence on structural choice; constituent structure persistence was completely dependent on both argument structure persistence and thematic role order persistence. When participants adopted the same thematic role order as in the prime, more NP-first targets were observed following NP-first primes than following PP-first primes. In these cases, NP-first primes and targets shared the argument structure, whereas PP-first primes featured different argument structures. When participants adopted a different thematic role order from the prime, we found no evidence for constituent structure persistence; there were *fewer* NP-first targets and more PP-first targets following NP-first primes than following PP-first primes. This was because PP-first primes, not NP-first primes, shared their argument structure with NP-first targets. Moreover, when participants repeated the argument structure of the prime, NP-first primes led to more NP-first targets; NP-first primes then

shared the thematic role order with NP-first targets. When participants selected a different argument structure, however, NP-first primes did not elicit NP-first targets; NP-first primes and targets differed in thematic role order as well as argument structure. Hence, the results indicate that constituent structure can persist only when both the argument structure and thematic role order of the prime simultaneously persist in the target.

All in all, these results are compatible with the interactive structure building account, which proposes that (1) argument structure priming and thematic role order priming interact; (2) verb repetition can enhance both thematic role order priming and argument structure priming by increasing the probability of the primed thematic role order or argument structure being repeated for the same construction as in the prime; (3) the persistence of constituent structure arises from the combination of thematic role order persistence and argument structure persistence; (4) the constituent structure of the prime will not persist when the prime and target differ in argument structure or thematic role order, whereas argument structure and thematic role order can persist in the absence of its counterpart persisting. In contrast, the results were incompatible with the verb-argument structure account, which posits that (1) verb repetition should enhance argument structure priming but not thematic role order priming; (2) the likelihood of argument structure priming should be independent of the persistence of thematic role orders; (3) the constituent structure of the prime should persist separately from the argument structure of the prime.

## 7. Experiment 5: From *What*-Cleft Prime To Non-Cleft Target

The aim of Experiment 5 was to examine the representations underpinning verb boost effects further. According to the interactive structure building account, these effects stem from a general inclination to select structural features based on their previous co-occurrence. When the verb is repeated alongside its associated construction node, the co-activation of the repeated verb and construction nodes in the target boosts the activation of the associated thematic role order and argument structure in the prime. This leads to a higher likelihood of these structural features persisting together with the verb and construction in the target. However, in cases where the prime and the target involve distinct constructions, the likelihood of a verb boost effect is expected to decrease. This is because the links between the structural features (i.e., argument structure and thematic role order) and the target construction have not been primed. Consequently, even though the primed argument structure and thematic role order might gain some activation from their connections to the repeated verb, they cannot receive enhancements from the target construction node. Therefore, verb repetition is less likely to enhance structural persistence across different constructions compared to cases where the construction is repeated from the prime. However, there is an alternative possibility: Verb boost effects may instead solely stem from the links connecting the verb and the argument structure or thematic role order. If this is the case, verb repetition would enhance structural persistence regardless of whether the construction is repeated from the prime to the target. To test these hypotheses, Experiment 5 examined the structural choice in non-cleft targets following *what*-cleft primes.

### 7.1. Method

#### 7.1.1. Participants

An additional 80 participants were recruited from the same population as before.

#### 7.1.2. Materials, design and procedure

These were the same as Experiment 4, except that the target prompts began with the subject noun (agent) followed by the verb, inducing declarative completions, as in (10) in Table 5 (see Appendices 13.7 & 13.9).

#### 7.1.3. Scoring

We scored if participants produced a theme-location response ($n = 2013$) or a location-theme response ($n = 500$) when producing a non-cleft (declarative) target using the same coding scheme as before. We included cases where the preposition *in* was used for the verb *slather* ($n = 8$) or the verb *drizzle* ($n = 2$) in the location-theme order responses. Cases were excluded where participants had chosen an implausible alternative word in the prime ($n = 13$) or included an additional preposition in the prime trials (e.g., *What the lawyer stuffed with the banknotes were <u>into</u> briefcases*) ($n = 23$); only one argument was mentioned ($n = 1$); participants used *full of* instead of a preposition for the verb *stuff* or *pack* ($n = 2$) or omitted the preposition ($n = 3$); they conveyed a non-target meaning ($n = 1$) or used a non-target structure ($n = 1$) or used a non-target verb ($n = 2$); or there was a technical error ($n = 1$). In total, 47 trials (1.8 %) were excluded from analyses.

### 7.2. Results and discussion

Fig. 15 reports the percentages and standard errors of location-theme (*with*-structure) responses relative to theme-location (locative structure) responses (see Appendix 13.16 for count data). As in Experiments 1-3, participants generally produced theme-location orders more frequently than location-theme orders (as confirmed by the negative intercept in Table 9). This contrasts with Experiment 4, where location-theme orders (theme-focused) were generally chosen more frequently in *what*-cleft targets, demonstrating an impact of the use of *what*-cleft construction in the target on thematic role ordering. Importantly, as summarized in Table 9, the analyses, including prime thematic role order (location-theme order vs. theme-location order), prime argument structure (*with*-structure vs. locative structure) and verb repetition (repeated vs. not-repeated) as fixed effects, revealed a main effect of thematic role order as well as a main effect of argument structure. Participants produced more location-theme order simple declarative sentences

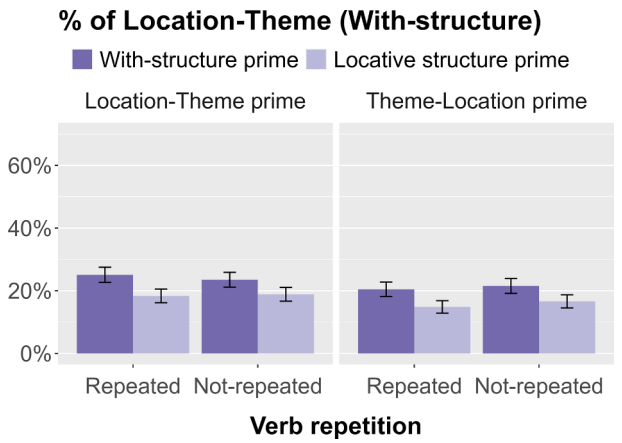


**Fig. 15.** Percentages and standard errors of Location-Theme (*With*-structure) responses relative to Theme-Location (Locative structure) responses in Experiment 5.

**Table 9**
Analyses of structural choice in Experiment 5.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (Intercept) | −2.32 | 0.33 | −7.00 | < .001 |
| Thematic Role Order | 0.15 | 0.06 | 2.43 | .015 |
| Argument Structure (*With* vs. Locative) | 0.27 | 0.07 | 4.02 | < .001 |
| Verb Repetition (Repeated vs. Not-Repeated) | −0.02 | 0.06 | −0.30 | .768 |
| Thematic Role Order × Argument Structure | 0.00 | 0.06 | −0.02 | .987 |
| Thematic Role Order × Verb Repetition | 0.07 | 0.06 | 1.08 | .281 |
| Argument Structure × Verb Repetition | 0.03 | 0.06 | 0.55 | .586 |
| Thematic Role Order × Argument Structure × Verb Repetition | −0.04 | 0.08 | −0.54 | .591 |

(*with*-structures) when *what*-cleft primes had location-theme orders (21.5 %, $SE = 1.2$ %) rather than when they had theme-location orders (18.3 %, $SE = 1.1$ %), demonstrating thematic role order priming from *what*-cleft primes to non-cleft targets. Moreover, participants produced more location-theme orders (*with*-structures) following *with*-structure primes (22.7 %, $SE = 1.2$ %) than following locative structure primes (17.2 %, $SE = 1.1$ %), indicating the persistence of argument structure from *what*-cleft primes. Critically, verb repetition did not enhance the effect of prime thematic role order nor prime argument structure. The Bayes Factors ($BF_{01}$) for the prime argument structure × verb repetition and the prime order × verb repetition interactions were 43.51 and 28.87, respectively, showing strong support for the null hypotheses.

The results of Experiment 5 revealed that argument structure and thematic role order in *what*-cleft primes influence function assignment and thematic role ordering in non-cleft sentences. Importantly, neither effect was reliably enhanced by verb repetition, indicating that verb boost effects do not simply arise from the co-occurrence of the verb and the argument structure or from the co-occurrence of the verb and the thematic role order in the prime. If this were the case, the repetition of the verb should have enhanced argument structure persistence and thematic role order persistence from *what*-cleft primes to non-cleft targets. In contrast, the results align with the interactive structure building account, which suggests that verb repetition boosts structural priming due to the co-occurrence of the verb and either an argument structure or thematic role order selected in the particular construction of the prime. When primes and targets involve different constructions, the link between the structural feature and the target construction is not primed. This reduces the likelihood of verb repetition reliably enhancing the probability of the primed structural feature persisting with the verb, compared to cases where the construction node is also repeated alongside the verb; in such cases, the primed structural feature can receive boosts not only from the verb but also from the construction node.

Additionally, the impact of the argument structure of *what*-cleft primes on argument structure selection in non-cleft targets (5.5 %) (Experiment 5) was smaller compared to that in *what*-cleft targets (21.6 %) (Experiment 4), $Estimate = 0.28$, $SE = 0.04$, $z = 6.39$, $p < .001$ (see Appendix 13.18 for full results). Similarly, the effect of the thematic role order of *what*-cleft primes on thematic role ordering in non-cleft targets (3.2 %) (Experiment 5) was reduced in contrast to *what*-cleft targets (14.7 %) (Experiment 4), $Estimate = 0.40$, $SE = 0.05$, $z = 7.43$, $p < .001$ (see Appendix 13.19 for full results). This cannot be attributed solely to the absence of verb boost effects in Experiment 5. The effects of prime argument structure and thematic role order were smaller in Experiment 5 than in Experiment 4 in both the verb-repeated condition, $Estimate = 0.43$, $SE = 0.07$, $z = 6.59$, $p < .001$ (argument structure); $Estimate = 0.47$, $SE = 0.09$, $z = 5.06$, $p < .001$ (thematic role order), and the not-repeated condition, $Estimate = 0.17$, $SE = 0.06$, $z = 2.97$, $p = .003$ (argument structure); $Estimate = 0.32$, $SE = 0.07$, $z = 4.42$, $p < .001$ (thematic role order). When *what*-cleft primes were followed by non-cleft targets, interactive priming between thematic role ordering and argument structure selection was not reliable, because the thematic role order and the argument structure of the prime were not primed in association with the non-cleft target construction.

Hence, the persistence of a thematic role order in a non-cleft target did not reliably enhance the likelihood of argument structure persistence in the non-cleft target, and vice versa.

## 8. Experiment 6: From *It*-Cleft Prime To Non-Cleft Target

Experiment 5 demonstrated the persistence of thematic role order from *what*-cleft primes to non-cleft targets. One possible interpretation of this finding is that the persistence from the *what*-cleft prime to the non-cleft target is driven by thematic emphasis rather than by thematic role order persistence. This interpretation assumes that the alternation between theme-location and location-theme orders in declarative sentences is largely influenced by the persistence of thematic emphasis (Bernolet et al., 2009). Specifically, a location-theme order *what*-cleft prime such as *What the assistant loaded into the lift was the equipment* can elicit location-theme orders in non-cleft declarative sentences such as *The man loaded the bus with the luggage* because in English, the thematic role of a newly introduced or emphasized entity typically follows that of a previously introduced or de-emphasized entity (e.g., Haviland & Clark, 1974; Givón, 1984; Halliday, 1970; Quirk et al., 1985). Hence, in both *what*-cleft primes and declarative targets, the last-mentioned thematic role (i.e., the theme role in the above examples) is emphasized.

Experiment 6 thus aimed to determine the impact of thematic emphasis within *it*-cleft primes on thematic role ordering in declarative targets. If thematic emphasis in the prime sentence influences the ordering of thematic roles in declarative constructions, we should observe an opposite effect of thematic role ordering from *it*-cleft constructions on non-cleft declarative targets. In *it*-cleft constructions, it is the first-mentioned role that is emphasized. As shown in Table 10, theme-focused *it*-cleft sentences like (11a, 11b, 11e, 11f) place the theme role in the first position, while location-focused *it*-cleft sentences like (11c, 11d, 11g, 11h) place the location role first. Suppose that these *it*-cleft sentences were presented as primes, followed by non-cleft declarative target sentences, such as (12a and 12b). If thematic emphasis indeed drives the alternation of theme-location in declarative sentences, theme-focused *it*-cleft primes (11a, 11b, 11e, 11f) should elicit more location-theme order responses, such as *The man loaded the bus with the luggage* (12a), than location-focused *it*-cleft primes (11c, 11d, 11g, 11h) should.

As shown in Table 10, all the *it*-cleft primes mentioned either the theme role or the location role first, whereas in the non-cleft declarative targets, the agent role was mentioned first. Hence, it was unlikely that these *it*-cleft primes would influence thematic role ordering in the non-cleft target sentences. However, the argument structures of *it*-cleft primes should persist into non-cleft targets because argument structures do not carry ordering information. Specifically, prime sentences (11a, 11c, 11e, 11g) involve *with*-structures, whereas sentences (11b, 11d, 11f, 11h) involve locative structures. Therefore, *with*-structure primes should elicit more location-theme orders (12a, *with*-structures) as opposed to theme-location orders (12b, locative structures) than locative structure primes should. Critically, *it*-cleft primes and non-cleft targets involve different constructions. Hence, according to the interactive structure-building account, similar to Experiment 5, verb repetition is unlikely to boost argument structure persistence from *it*-cleft primes to non-cleft targets.

### 8.1. Method

#### 8.1.1. Participants

A further 80 participants were recruited from the same population as before. An additional participant was recruited but excluded from analyses due to their failure to follow the instructions in the prime trials.

#### 8.1.2. Materials, design, and procedure

These were the same as in Experiment 5, except that prime sentences involved *it*-clefting, shown in Table 10 (11a-11h) (see Appendix 13.8). We manipulated prime argument structure (*with* vs. locative structure), prime thematic role order (emphasis) (location-agent-theme/location-focused vs. theme-agent-location/theme-focused) and verb repetition (repeated vs. not-repeated) as within-

**Table 10**
Example prime sentences and target sentences in Experiment 6.

| Thematic Role Order | Argument Structure | Sentences |
|---|---|---|
| | **Experiment 6 Prime Sentence** | |
| *Verb-Repeated* | | |
| Theme-Agent-Location | *With*-Structure | 11a. It was (the equipment) that the assistant loaded the lift with. |
| (Theme-focused) | Locative Structure | 11b. It was (the equipment) that the assistant loaded into the lift. |
| Location-Agent-Theme | *With*-Structure | 11c. It was (the lift) that the assistant loaded with the equipment. |
| (Location-focused) | Locative-Structure | 11d. It was (the lift) that the assistant loaded the equipment into. |
| *Not-Repeated* | | |
| Theme-Agent-Location | *With*-Structure | 11e. It was (the equipment) that the assistant packed the lift with. |
| (Theme-focused) | Locative Structure | 11f. It was (the equipment) that the assistant packed into the lift. |
| Location-Agent-Theme | *With*-Structure | 11g. It was (the lift) that the assistant packed with the equipment. |
| (Location-Focused) | Locative-Structure | 11h. It was (the lift) that the assistant packed the equipment into. |
| | **Experiment 6 Target Completion** | |
| Agent-Location-Theme | *With*-Structure | 12a. The man loaded (the bus with the luggage) |
| Agent-Theme-Location | Locative Structure | 12b. The man loaded (the luggage onto the bus). |

*Note.* Example completions in brackets.

subjects and within-items variables, leading to a 2 (argument structure) × 2 (verb repetition) × 2 (thematic role order) repeated measure design. The target events and prompts were the same as in Experiments 4 & 5 (Appendix 13.9). The 32 experimental items and 70 filler items were distributed across four lists as before.

#### 8.1.3. Scoring

We scored if participants produced a theme-location response ($n = 1922$) or a location-theme response ($n = 600$) when producing a non-cleft target as before. We excluded cases ($n = 17$) where the response include only one thematic role ($n = 4$); they used *full of* instead of a preposition ($n = 3$) or *in* or *for* in location-theme responses ($n = 5$) or omitted the preposition ($n = 1$); the responses conveyed non-target meanings ($n = 1$), contained an exchange error ($n = 1$) or an additional unnecessary preposition ($n = 1$) or verb ($n = 1$). We also excluded cases (0.8% of total 2560 responses, $n = 21$) where participants had chosen an implausible alternative word in the prime ($n = 15$) or included a redundant preposition (e.g., *It was on the arm that the tourist rubbed with lotion; It was in the boxes that the babysitter crammed with the toys*) ($n = 3$), or additional words that altered the event meanings (e.g., *It was a spoon on the table that the baby splashed with the soup*; $n = 1$) or there were technical errors in the prime trials ($n = 2$). In total, 38 trials (1.5 %) were excluded from analyses.

### 8.2. Results and discussion

Fig. 16 presents the percentages and standard errors of location-theme (*with*-structure) responses relative to theme-location (locative structure) responses by prime thematic role order (emphasis), prime argument structure and verb repetition (see Appendix 13.17 for count data). The analyses included prime thematic role order (emphasis) (theme-agent-location/theme-focused vs. location-agent-theme/location-focused, coded as 1 and 0) respectively), prime argument structure (*with* vs. locative structure, coded as 1 and 0 respectively) and verb repetition (repeated vs. not-repeated, coded as 1 and 0 respectively), which were all mean-centred and standardized. The results are summarized in Table 11. The analyses showed no main effect of thematic role order (emphasis) × verb repetition interaction, with the $BF_{01}$ for this interaction being 50.22, showing very strong support for the null hypothesis. In contrast, as in Experiment 5, there was a main effect of argument structure, with more location-theme order responses (*with*-structures) following a *with*-structure prime (27.0 %, $SE = 1.3$ %) than following a locative structure prime (20.6 %, $SE = 1.1$ %). This effect of prime argument structure was numerically larger when the verb was repeated (8.7 %) than when it was not repeated (4.1 %). However, the effect was only marginal and the $BF_{01}$ for this interaction was 11.33, providing support for the null hypothesis.

Thus, Experiment 6 provided no evidence that the thematic role order of *it*-cleft sentences primes theme-locative alternations in non-cleft sentences. This suggests that the persistence of thematic role order observed in Experiment 5 is unlikely to have resulted from the persistence of thematic emphasis. As Experiment 5, Experiment 6 did find an effect of argument structure priming, where the argument structure of the *it*-cleft prime influenced argument structure selection in non-cleft targets. This effect was marginally larger when the verb was repeated. While this might imply a certain degree of overlap between *it*-cleft constructions and declarative constructions, the Bayes Factor for this effect ($BF_{01}$) favored the null hypothesis. The findings are also in line with those of Experiment 5, where the persistence of both argument structure and thematic role order from *what*-cleft primes to non-cleft targets was not significantly enhanced by verb repetition.

According to the interactive structure building account, the magnitudes of thematic role order priming and argument structure priming should be larger when the construction is repeated from the prime to the target, regardless of verb repetition. In Experiment 1, both primes and targets employed declarative constructions. Therefore, we might anticipate a larger priming effect in Experiment 1 than in Experiments 5 and 6, where primes and targets featured different constructions. However, unlike in Experiments 5/6, argument structure and thematic role order were confounded in Experiment 1. This prevents us from directly comparing Experiment 1 with

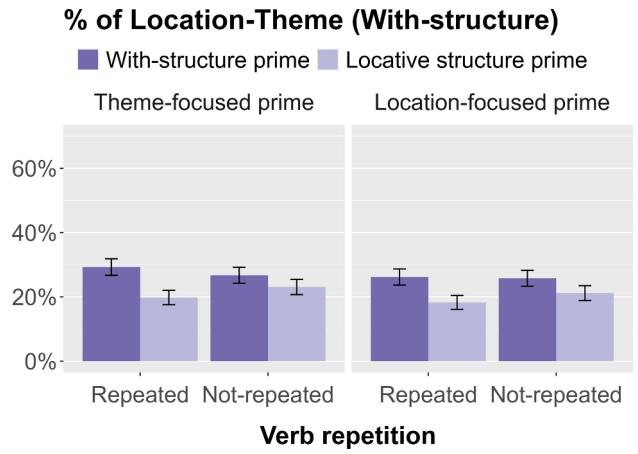


**Fig. 16.** Percentages and standard errors of Location-Theme (*With*-structure) responses relative to Theme-Location (Locative structure) responses in Experiment 6.

**Table 11**
Analyses of structural choice in Experiment 6.

| Fixed Effect | *Estimate* | *SE* | *z* | *p* |
|---|---|---|---|---|
| (Intercept) | −1.85 | 0.30 | −6.27 | < .001 |
| Thematic role order (Emphasis) | 0.07 | 0.06 | 1.29 | .197 |
| Argument Structure (*With* vs. Locative) | 0.26 | 0.07 | 4.01 | < .001 |
| Verb Repetition (Repeated vs. Not-Repeated) | −0.06 | 0.06 | −0.97 | .333 |
| Thematic role order × Argument Structure | 0.03 | 0.06 | 0.44 | .663 |
| Thematic role order × Verb Repetition | 0.00 | 0.06 | 0.01 | .995 |
| Argument Structure × Verb Repetition | 0.10 | 0.06 | 1.76 | .078 |
| Thematic role order × Structure × Verb Repetition | 0.05 | 0.06 | 0.88 | .382 |

Experiments 5/6, as we cannot discern to what extent the priming effect in Experiment 1 was influenced by the thematic role order, argument structure of the prime, or both. To enable valid comparisons between *it*-cleft primes and non-cleft primes, investigating a language that permits the independent manipulation of argument structure and thematic role order in declarative sentences would be necessary. Additionally, it is worth noting that Experiment 1 showed a verb boost effect, which was not present in Experiments 5–6. When verb repetition strongly cues the primed structure, the priming effect might decrease in conditions without verb repetition (cf., MacWhinney, 1987). Consistent with this possibility, in the not-repeated condition, the effect of prime was marginally smaller in Experiment 1 (5.1 %), where there was a verb boost effect, than in Experiments 2 and 3 (8.5 %), where there was no verb boost effect (see Appendix 13.11).

In summary, the results from Experiments 4–6 collectively indicate that verb repetition enhances structural priming by increasing the probabilities of repeating the primed argument structure and thematic role order within the same construction as in the prime; when the constructions in the prime and target differ, verb repetition is unlikely to enhance the priming effects. As discussed earlier, the interactive structure-building account proposes that a prime sentence like *What the assistant loaded the lift with was the equipment* not only activates links from the *with*-structure and the A-L-T order to the verb but also to the node representing the *what*-cleft construction (Wh-cleft node) in Fig. 7A. If the verb and the Wh-cleft construction node is subsequently repeated in the target and their activation then spreads through the network, the *with*-structure node and the A-L-T node receive strong activation due to the prior activation of their links to both the verb and the Wh-cleft node. This robustly increases the chances of the *with*-structure and the A-L-T order persisting when the verb and the *what*-cleft construction are repeated in the target. However, if the verb is repeated in a declarative target sentence, the *with*-structure node only gains a boost from the verb-argument structure link, insufficient to enhance the likelihood of the *with*-structure appearing in the declarative sentence. In Experiments 5 and 6, cleft primes were followed by non-cleft targets, whereas in Experiment 4, both primes and targets featured the same Wh-cleft constructions. This explains the absence of significant verb boost effects in Experiments 5 and 6, in contrast with their presence in Experiment 4.

## 9. General discussion

### 9.1. Summary

The current study examined the representations underpinning structural priming, focusing on understanding the locus of the lexical boost effect. Three accounts were evaluated. The first two hypotheses were derived from the two-stage grammatical encoding account (e.g., Bock & Levelt, 1994), which posits a strict sequential process of grammatical encoding, with function assignment (involving the assignment of syntactic functions to thematic roles) preceding constituent assembly (determining the linear order based solely on abstract syntactic information rather than on thematic information). The first account, the **verb-constituent structure account**, assumes that verb selection is associated with the syntactic representations underpinning constituent assembly. On this view, verb repetition is not expected to enhance structural priming with *spray-load* verbs in declarative sentences, where the structural variants share same constituent structure. On the other hand, the second account, the **verb-argument structure account**, proposes that verb selection is associated with the selection of argument structures, underpinning thematic role-syntactic function mappings during function assignment. In this view, verb repetition can enhance structural priming with *spray-load* verbs, increasing the probability of repeating the primed argument structure in the target. However, because function assignment precedes constituent assembly, the persistence of argument structure should be independent of whether the order of constituents (and the thematic role order) is also maintained in the target or not, and the constituent structure of the prime can persist separately from its argument structure and thematic role order.

The third account is the **interactive structure-building account**. According to this account, structural building proceeds in a single stage, where the selection of a thematic role order, which drives linear ordering, is selected along with an argument structure and other structurally relevant information, such as the verb's semantic and syntactic properties and a sentence construction. This is interactive, because combinations of various structural features are affected by their co-occurrence in prior utterances. Specifically, when the verb and the construction are repeated from the prime in the target, it increases the probability of repeating other associated features, namely, the thematic role order and the argument structure of the prime. Likewise, when the argument structure of the prime is repeated in the same construction in the target, it increases the likelihood of the associated thematic role order being repeated, and vice versa.

Experiments 1–3 revealed that the repetition of verbs, but not nouns fulfilling the theme or location roles, produced a larger

structural priming effect on the theme-location alternation in declarative sentences, providing evidence against the verb-constituent structure account. Using *what*-cleft constructions for both primes and targets, Experiment 4 extended this finding by demonstrating that verb repetition leads to larger likelihoods of argument structure persistence and thematic role order persistence. In addition, the persistence of argument structure was found to interact with the persistence of thematic role order. When participants repeated the same thematic role order from *what*-cleft primes to *what*-cleft targets, they were more likely to repeat the argument structure of the prime, and vice versa. These findings were in line with the interactive structure-building account, according to which verb selection is associated with both thematic role ordering and argument structure selection, which also interact with each other. In contrast, the results were inconsistent with the verb-argument structure account, according to which verb repetition should only enhance the persistence of argument structure, and the persistence of argument structure should be unrelated to the persistence of thematic role order persistence. Further evidence against the verb-argument structure account came from the finding that the constituent structure of the prime does not persist independently from the thematic role order nor the argument structure of the prime, whereas both the thematic role order and argument structure of the prime perseverate in the absence of its counterpart persisting. These findings suggest that abstract constituent structure is not a determining factor in structural choices beyond what is determined by the argument structure or thematic role order of the prime.

Experiments 5 and 6 further examined whether the verb boost effects observed in Experiments 1 and 4 would be diminished when primes and targets involve different constructions, as suggested by the interactive structure-building account. Experiment 5 found that both the thematic role order and the argument structure of *what*-cleft primes can influence structural alternations in non-cleft declarative targets, indicating that thematic role orders and argument structures are shared across different constructions. However, these priming effects were not enhanced by verb repetition. Experiment 6 corroborated this finding: While the argument structure of an *it*-cleft prime persisted into a non-cleft target, verb repetition did not reliably boost this effect, despite a numerical tendency pointing in this direction. Moreover, we observed no evidence that thematic emphasis in *it*-cleft primes can influence structural choice in non-cleft targets, indicating that thematic role order persistence from *what*-cleft primes to non-cleft targets is unlikely to be due to the persistence of thematic emphasis. Instead, the effect is likely to be driven by the persistence of abstract thematic role order shared across different constructions.

### 9.2. Implications for theories of structural priming

All in all, the current findings have significant implications for theories of structural priming. We showed that structural priming is primarily driven by the persistence of argument structures that underpin thematic role-function mappings as well as the persistence of thematic role orders that underpin thematic role-position mappings. Importantly, both priming effects are enhanced by verb repetition and appear to interact. In contrast, the persistence of constituent structure represents a combined effect of these two forces. We found no evidence that abstract syntax, more specifically, the orders of syntactic categories and functions, plays an independent role in driving structural alternations. While abstract syntax (e.g., whether a verb is followed by a noun phrase representing a direct object or a prepositional object phrase) might be represented, such information does not appear to drive structural alterations. This contrasts with the residual activation model (Pickering & Branigan, 1998; Pickering et al., 2002), which focused on the persistence of abstract constituent structure as the driving force behind structural priming and verb boost effects.

Moreover, the results from our experiments suggest that verb boost effects reflect general interactive structure-building processes, wherein various structural features, including thematic role orders and argument structures, are selected interactively, guided by their prior co-occurrence and associations. Specifically, when two structural features from a prime are repeated in a target, this increases the likelihood of a third feature that co-occurred with them in the prime being repeated in the target. For instance, when both the verb and a *what*-cleft construction are repeated from the prime, the probabilities of the argument structure and the thematic role order also persisting along with them increase. Similarly, when the primed thematic role order is repeated in the same *what*-cleft construction, it enhances the probability of the primed argument structure being repeated in that construction, thus reinforcing the overall structural persistence. However, it is important to note that interactive priming does not necessarily require the repetition of all the structural features that occurred in the prime. In Experiment 4, a verb boost effect on argument structure persistence was observed independently of whether the thematic role order was also repeated or not. This finding suggests that tracking the co-occurrence of all four features (verb, argument structure, construction, and thematic role order) is not a prerequisite for boosting structural persistence.

The current findings, indicating that verb repetition, but not noun repetition, enhances theme-location alternations, provide evidence against hypotheses suggesting that structural priming can be enhanced not only by verb repetition but also by noun repetition, given that both are content words (Chang et al., 2006; Reitter et al., 2011; Scheepers et al., 2017), or that the theme-location alternation functions differently from the dative alternation (Chang et al., 2006). In contrast, the current findings align with recent studies (Carminati et al., 2019; Kantola et al., 2023; Huang et al., 2023; Van Gompel et al., 2023) which found that only verb repetition enhances structural priming involving the dative alternation. However, these results were interpreted based on the traditional residual activation model (Pickering & Branigan, 1998; Pickering et al., 2002), which assumes that verb repetition enhances the persistence of abstract syntax, without involving thematic role information. The current study's demonstration of verb boost effects on both thematic role ordering and argument structure selection provides evidence against this assumption.

Although our results are compatible with Fukumura and Zhang (2023), who showed that syntactic priming of noun phrases is specifically enhanced by head noun repetition, in their study, conceptual category order priming was enhanced not only by noun repetition but also by the repetition of adjectives, which are non-heads. This leads to the question of why noun repetition does not enhance thematic role order priming. It is important to recognize that thematic roles are not inherent features of the concepts bearing those roles. For instance, the role of an object, such as car, can be a theme (e.g., being loaded into a truck) or a location (e.g., being

loaded with boxes), depending on its function within the action or event, which is expressed by the verb's meaning. Therefore, the representation of thematic role orders is more closely tied to the verb's meaning than to the noun concepts. This contrasts with adjective conceptual category orders. Conceptual categories like color and pattern are the attributes of individual adjective concepts; for instance, BLUE is a color and STRIPED is a pattern. Hence, adjective category orders are associated with individual adjective concepts because the category orders must correspond to the order of the individual category tokens, the activation of which enables the selection of those categories.

The current findings have significant implications for the ongoing debates surrounding the temporal dynamics of verb boost effects. Researchers have proposed that the lexical boost effect is contingent on explicit short-term memory, yielding transient effects, whereas abstract priming—structural priming devoid of lexical repetition—stems from implicit learning and thus exhibits longer-lasting effects (e.g., Bock & Griffin, 2000; Chang et al., 2006; 2012). However, although lexical repetition can enhance the rate of recall of the primed structure (Zhang et al., 2020), explicit memory may also contribute to abstract priming (Bernolet et al., 2016; Zhang et al., 2020; but see Bock et al., 1992; V. Ferreira et al., 2008). Evidence from aphasia studies is somewhat inconsistent. Man et al. (2019) observed no lexical boost effect in aphasic patients with lexical–semantic short-term memory deficits. On the other hand, Yan et al. (2018) found a verb boost effect in aphasic individuals with explicit short-term memory deficits, without a correlation between the magnitude of the lexical boost effect and short-term memory deficits. The temporal durations of different priming effects are difficult to estimate, as they might be influenced by various factors such as experimental tasks, the type of stimuli, the strength of the association, the level of exposure, and others. However, there is evidence suggesting that abstract priming is longer-lasting compared to the lexical boost effect (Bock & Griffin, 2000; Hartsuiker et al., 2008; Branigan & McLean, 2016; see also Bernolet et al., 2016). The difference in duration may not necessarily stem from the lexical boost effect's reliance on explicit memory, as posited by certain theories (e.g., Bock & Griffin, 2000; Chang et al., 2006; 2012). Instead, the lexical boost effect may rely on short-term associative memory traces, which are not necessarily explicit but decay faster than abstract priming, which relies on adjustments in the base-level activation of the primed structure (Malhotra et al., 2008).

Another reason why the lexical boost effect may decay faster than abstract priming could be attributed to the complexity of the representations underpinning the lexical boost effect. The current findings suggest that whereas abstract priming relies on the persistence of a single structural feature, either the primed thematic role order or argument structure, the lexical boost effect involves more features and interconnected links. Specifically, verb boost effects rely not only on the verb, the primed structural feature (thematic role order or argument structure) and the construction, but also the links connecting them. If the memory traces for any of these nodes and links become disrupted, the occurrence of a verb boost effect is unlikely. The same principle applies to interactive priming between argument structure and thematic role order, which also relies on multiple features and interconnected links. Consequently, both interactive priming and the lexical boost effect may have shorter-lasting durations compared to abstract priming, owing to a higher likelihood of at least one feature or link being disrupted during intervening trials, as compared to the persistence of an abstract priming effect. Thus, while associations between multiple features can indeed form through exposure to a single prime sentence, one-shot exposures might not be sufficient to establish lasting connections between structural features. A promising avenue for future research lies in the testing of these hypotheses, investigating the temporal dynamics of the priming effects observed in the current study, with a specific focus on examining the relative durations of the persistence of argument structure, thematic role order, their interaction, and the verb boost effect.

The current study highlights the role of 'construction' as an additional structural element in moderating the verb boost effect. In this study, prime sentences appeared in three distinct constructions: *What*-cleft constructions, *it*-cleft constructions, and declarative constructions. We have assumed that construction nodes encompass information such as illocutionary force (e.g., making a request, asking a question, giving a command, making a statement) (cf. Searle, 1979), along with global syntactic information (e.g., forms of different cleft constructions) associated with different constructions. What other information might be encoded in these construction nodes? The findings from Chang et al. (2015) suggest that these construction nodes might include information about verb position. They reported that the likelihood of German ditransitive priming increased not only due to verb repetition but also with the repetition of verb position from the prime to the target. In contrast to English, in German, verb position in declarative sentences can vary based on tense and aspect. In their study, prime sentences featured either a simple past tense (e.g., *Die Geliebte sendete dem Kavalier die Rechnung*, The mistress sent the gentleman the bill), where a finite verb (sendete) occupied the second position, or a present perfect tense (*Die Geliebte hat dem Kavalier die Rechnung gesandt*, The mistress has sent the gentleman the bill), where an auxiliary (*hat*) appeared in the second position while the participle (*gesandt*) was positioned at the end of the sentence. The targets were always in the simple past tense, so they had the finite verb in the second position. Chang et al. found that the prime structure (double object dative vs. prepositional dative) persisted in the target, regardless of whether the verb position in the prime was the same (i.e., second position) or different (i.e., final position), or whether the verb was repeated or not repeated. However, the verb boost effect was reliable only when the verb occurred in the second position in the prime, as was the case in the target. Hence, these findings indicate that the declarative construction node may be represented differently depending on verb position in German. This suggests that the construction nodes examined in the current study, representing declarative sentences, *what*-cleft sentences, and *it*-cleft sentences, might also include information relating to the relative position of the verb in the sentence.

Until recently, closed-class words have been assumed to play no role in structural priming (e.g., Branigan & Pickering, 2017). This is because studies have shown, using dative alternations, that structural priming is unaffected by preposition overlap between prime and target; a prepositional object sentence can be elicited by another prepositional object sentence regardless of whether the preposition is the same (as in *The student brought a cake to the teacher*) or different (as in *The student brought a cake for the teacher*) (Bock, 1989; Chang et al., 2003; Ziegler & Snedeker, 2018). However, Ziegler et al. (2019) recently reported that *the airplane is landing by the control tower* primed passive sentences, as reported in Bock and Loebell (1990), but *the airplane is landing next to the control tower* did not prime passives.

One possibility is that lexical priming of the preposition *by* influenced the rates of passive responses. On this view, structural priming in the current study could be explained by lexical repetition of prepositions: While location-theme orders almost always involve *with*, theme-location orders can take different prepositions. Chang et al. (2003) argued against this possibility, pointing out that in their study, locative variants (theme-location orders) primed locative variants just as effectively as *with*-structure (location-theme) primes elicited *with*-structure responses. If the lexical priming of *with* is the driving force behind the structural alternations, structural priming should be more pronounced following *with*-structure primes than following locative structure primes. In the current study, *with* variants (31 %) were repeated *less* frequently than locative variants (80 %), making it unlikely for the lexical priming of *with* to be the source of the priming effects.

An alternative possibility is that the prepositions are part of the argument structures, as assumed under the interactive structure-building account (cf. Pinker, 1989; Rappaport & Levin, 1988). Specifically, the argument structure for *with* variants involves the preposition *with*, whereas the argument structure for locative variants involves locative prepositions. Likewise, the preposition *by* is represented as part of the argument structure underlying a passive sentence, with *by* specifying the agent role of the prepositional object. Hence, the selection of an argument structure for a passive form was influenced by the prior encounter of *by* in *The airplane is landing by the control tower* in Ziegler et al.'s study. This does not conflict with the finding mentioned above, where *for*-prepositional object dative primes elicit *to*-prepositional object datives to the same extent as *to*-prepositional object dative primes do. Both prepositions, *for* and *to*, can specify the role that implies receiving or possessing the theme due to the action denoted by the verb (Pinker, 1989). Therefore, both *to*-datives and *for*-datives may be construed to have equivalent thematic role orders and argument structures, whereby both *to* and *for* specify a similar role, as in the case of the locative in the theme-location alternation, which can take different location prepositions (e.g., on, in, onto) to specify the location role.

Although the current study investigated thematic role ordering, an important question is whether the current findings generalize across different types of word order priming reported in the literature. For instance, Hartsuiker and Westenberg (2000) demonstrated that in Dutch, language users produce auxiliary-final responses more often following an auxiliary-final prime such as *omdat de weg geblokkeerd was* (because the road was blocked) than following a participle-final prime such as *omdat de weg was geblokkeerd*. The findings from Konopka and Bock (2009) suggest that this type of word order priming effect can be enhanced by verb repetition. In their study, the position of the particle in phrasal verbs such as *broke down the door* or *broke the door down* persisted from the prime to the target, and the effect was larger when the verb and particle were both repeated from the prime to the target. Moreover, the probability of this verb boost effect might also be contingent on the repetition of the construction. Momma (2022) recently showed that the priming of an optional English complementizer *that*, as in *The mechanic mentioned (that) the car could use a tune-up* (V. Ferreira, 2003), can be boosted by verb repetition. Momma found that participants were more likely to mention *that* in their responses after encountering prime sentences containing the complementizer. Interestingly, the verb boost effect was found only when the prime and target either both involved or neither involved a filler-gap dependency (e.g., *Who did the director announce (that) he nominated?*), while the presence or absence of *that* was primed across different constructions. Momma proposed that the priming of optional *that* occurs due to the persistence of the mapping between the use of *that* and its associated conceptual feature, whereas the verb boost effect is driven by the residual activation of the tree structure in which *that* is embedded. This is consistent with our proposal that verb selection is associated with the argument structure and thematic role order implemented in a specific construction.

### 9.3. Implications for theories of sentence production

The findings from the present study challenge the fundamental assumptions of the two-stage grammatical encoding account, which posits a strictly serial process of grammatical encoding and the independence of constituent structure from thematic information. However, it may be argued that the two-stage account has received support not only from the structural priming literature but also from other domains of language production research. For instance, the two-stage account originates from Garrett's (1975, 1990) analysis of speech errors, suggesting that word exchange errors (such as *I left the briefcase in my cigar*, where *cigar in my briefcase* was intended) occur at the functional stage, while sound exchange errors (such as *easy enoughly* when *easily enough* was intended) are associated with a positional stage, with no interaction between these stages. Similarly, some studies on verb agreement errors have provided evidence supporting the two-stage model. For instance, Vigliocco and Nicol (1998) reported that verb agreement errors occur regardless of linear proximity to the attractor noun (**The helicopter for the flights <u>are</u> safe* vs. **<u>Are</u> the helicopter for the flights safe*?). This finding was regarded as evidence in favor of the two-stage grammatical encoding account, which posits that hierarchical relations relevant to verb agreement are computed prior to constituent assembly (Bock & Miller, 1991; Bock & Cutting, 1992; Garrett, 1980).

However, these interpretations have been controversial. Dell and colleagues (Dell, 1986; Dell & Reich, 1981) examined other error patterns that indicate interactions between different types of representations, which led to the proposal of a word production model that allowed for interactive parallel processing. As for verb agreement errors, other studies have shown that linear proximity can influence verb agreement processes (Franck et al., 2006; Haskell & MacDonald, 2005; Santesteban et al., 2013). For instance, Haskell and MacDonald (2005) found that when producing sentences with disjunctive subject noun phrases in English, participants tend to make the verb agree with the number of the noun nearest to the verb both when the verb follows (e.g., *The clock or the horses is/are red*) and when it precedes the noun (e.g., *Is/Are the horses or the clock red?*). Similarly, Santesteban et al. (2013) found that speakers of Basque, a language in which the verb agrees in number with both the subject and object, exhibited a higher frequency of verb agreement errors when the noun was positioned further away from the verb (i.e., the subject in subject-object-verb word order sentences, where the subject is distant from the verb, and the object in object-subject-verb word order sentences, where the object is distant from the verb). It was suggested that syntactic agreement is made over a linearly specified representation, possibly during the mapping process between semantic and syntactic representations. Such a proposal aligns with the interactive structure-building

account, according to which the selection of an argument structure underpinning function assignment operates in parallel with the ordering of thematic roles, which allows for the possibility that linear order can interfere with agreement processes.

In addition to speech errors and verb agreement errors, some findings on accessibility effects on sentence production have been interpreted as supporting the two-stage account. For instance, some studies (Bock & Warren, 1985; McDonald et al., 1993) indicated that conceptual accessibility due to animacy or imageability influences word order via function assignment, rather than influencing linear order directly. Using a sentence recall task, McDonald et al. (1993) reported that participants were more likely to recall sentences by assigning the subject role to an animate entity rather than to an inanimate entity (e.g., *The child was soothed by the music* rather than *The music soothed the child*). This animacy effect was not observed when the subject comprised a conjoined noun phrase where an animate and an inanimate noun shared the subject function (e.g., *The key and the manager were nowhere to be found* vs. *The manager and the key were nowhere to be found*). These findings led to the suggestion that conceptual accessibility impacts structural choice through function assignment rather than through constituent assembly, aligning with the two-stage grammatical encoding account (e.g., Bock et al., 1992; Bock & Warren, 1985).

However, those interpretations have been called into question following findings that the higher accessibility of an entity due to *givenness* (V. Ferreira & Yoshita, 2003; Prat-Sala & Branigan, 2000) or animacy (Branigan et al., 2008; Kempen & Harbusch, 2004; Prat-Sala & Branigan, 2000; Tanaka et al., 2011; cf. Christianson & F. Ferreira, 2005; Van Nice & Dietrich, 2003) can influence linear ordering as well as function assignment in freer word order languages. For example, Prat-Sala and Branigan (2000) demonstrated in Spanish that when the referent of the noun with the patient role is more accessible due to its prior mention or animacy status, the likelihoods of producing patient-initial actives (*A la mujer la atropelló el tren*, to the woman she ran over the train, meaning that the train ran over the woman) as well as patient-initial passives (*La mujer fué atropellada por el tren*, The woman was run over by the train) increase, relative to all alternatives, including agent-initial actives (*El tren atropelló a la mujer*, The train ran over the woman). Patient-initial actives and agent-initial actives differ in their linear order, but they share the function assignment. The finding thus challenges the assumption of the two-stage models, which suggests that conceptual accessibility affects structural choice exclusively through function assignment. Moreover, in a series of experiments, McDonald et al. (1993) found that when conjoined noun phrases were presented in isolation (i.e., they were not a part of a sentence), participants did tend to recall animate nouns before inanimate nouns (e.g., *bachelor and spoon* rather than *spoon and bachelor*), suggesting that animacy *can* influence linear ordering for conjoined noun phrases. Similarly, conceptual accessibility has been shown to impact the order of both conjoined and non-conjoined adjectives (Fukumura, 2018), with a general preference for color-before-pattern orders (e.g., *green and spotted bow* rather than *spotted and green bow*). Therefore, it is not the case that conceptual accessibility solely influences linear order through function assignment, contrary to the two-stage grammatical encoding account.

Therefore, we propose that prior interpretations based on the two-stage model should be re-evaluated in light of the current findings and other available evidence. Specifically, the interactive structure-building account can offer an alternative interpretation of accessibility effects. According to this view, accessibility influences linear ordering at the conceptual level, impacting the selection of an abstract conceptual order, which interfaces with syntactic selection. Fukumura and Zhang (2023) first demonstrated the presence of such interactions, showing speakers repeat a primed relative clause (such as *green bow that's spotted* as opposed to a simpler alternative structure such as *green spotted bow*) more often when they also repeat the primed adjective order (i.e., a color-before-pattern order) than when they use a different adjective order (e.g., a pattern-before-color order as in *spotted bow that's green*) from the prime. In the present study, we observed that in sentence production, thematic role ordering can interact with the selection of argument structure. This leads us to propose that accessibility-based structure building occurs because speakers choose a syntactic structure in conjunction with an abstract conceptual order, such as a thematic role order and an adjective category order, so that a most accessible concept can be placed early, thereby promoting incremental production processes. Thus, by positing that speakers formulate a syntactic structure in tandem with a conceptual order, the interactive structure-building account can explain both accessibility-based grammatical encoding and structural priming in a unified production process.

## 10. Conclusions

The current research provides novel insights into interactions between thematic and syntactic representations in sentence production. Overall, our findings demonstrate that the argument structure underpinning thematic role-syntax mappings as well as the order of thematic roles of the preceding sentence can independently influence structural choice across different constructions, while the interaction between them strengthens the magnitude of persistence: The likelihood of argument structure persistence in the target is higher with the same thematic role order than with a different thematic role order from the prime, reflecting a tendency to repeat the same argument structure for the same thematic role order selected in the same construction as in the prime. Verb boost effects arise from the same interactive mechanism, wherein the co-occurrence of different structural features in the preceding sentence influences structural combinations in the upcoming utterance. Thus, verb repetition increases the probabilities of the primed thematic role order as well as the primed argument structure being repeated for the same type of construction. Importantly, while both the argument structure and thematic role order of the preceding sentence can independently influence the structural choice across different constructions, the abstract constituent structure of the preceding sentence cannot be primed separately from its thematic role nor argument structure.

These results are incompatible with traditional two-stage grammatical encoding accounts, and we propose the interactive structure-building account as an alternative. While two-stage accounts have been adopted to explain findings in other areas of language production research, we propose that those interpretations should be re-evaluated in light of the new evidence. We must also acknowledge that the current proposed account and hypotheses require further refinement and revision through future investigations,

encompassing not only the domain of structural priming but also other aspects of human language production processes. By stimulating such future investigations, we believe that our work can make a significant contribution to advancing the understanding of structural priming and human sentence production processes.

## 11. 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

Data and R scripts are available via https://osf.io/m5whg/?view_only=86f83d06ab1a444581cea1b3aa57e4fe.

## 12. Acknowledgements

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## 13. Appendix

Each prime sentence appeared across two items, once as a not-repeated prime and once as a repeated prime. Location-theme primes had the reversed order of the post-verbal noun phrases with the preposition *with* in between them. In Experiments 4–6, location-focused primes were created by reversing the order of the theme and location roles.

### *13.1. Experiment 1: Prime sentences*

1–2. The assistant loaded/packed the boxes into the van.
3–4. The hiker loaded/packed the camping gear into the car.
5–6. The tourist rubbed/dabbed lotion onto her arm.
7–8. The actress rubbed/dabbed moisturiser onto her ankle.
9–10. The pensioner smeared/slathered butter on the toast.
11–12. The chef smeared/slathered the mustard sauce on the chicken breast.
13–14. The baby splashed/splattered soup on the table.
15–16. The cyclist splashed/splattered water on the bench.
17–18. The manager drizzled/sprayed vinegar on the salad.
19–20. The cook sprayed/drizzled lime juice on the grilled fish.
21–22. The babysitter stuffed/crammed the toys into the chest.
23–24. The lawyer stuffed/crammed banknotes into the briefcase.
25–26. The novelist stacked/piled books on the desk.
27–28. The waiter stacked/piled plates on the countertop.
29–30. The granny dusted/sprinkled sugar onto the donuts.
31–32. The barista dusted/sprinkled cinnamon on the coffee.

### *13.2. Experiment 1: Target events*

1. Boy packing stationery into bag.
2. Man loading luggage onto trolley.
3. Woman packing clothes into suitcase.
4. Man loading bins into lorry.
5. Boy dabbing watercolours onto canvas.
6. Man rubbing wax onto shoes.
7. Woman dabbing antiseptic onto wound.
8. Boy rubbing soap onto hands.
9. Girl slathering jam on a piece of bread.
10. Girl smearing glue on paper.
11. Boy slathering sunscreen on body.
12. Woman smearing icing on cake.
13. Girl splattering paint on wall.
14. Woman splashing water on face.
15. Girl splattering mud on trousers.
16. Boy splashing milk on floor.

17. Girl spraying liquid on window.
18. Boy drizzling syrup on pancakes.
19. Man spraying pesticide on crops.
20. Man drizzling olive oil on dish.
21. Woman cramming junk into wardrobe.
22. Woman stuffing onions into turkey.
23. Man cramming furniture into van.
24. Woman stuffing files into drawer.
25. Boy stacking cups onto table.
26. Boy piling t-shirts into laundry basket.
27. Man stacking tins on shelves.
28. Boy piling leaves into wheelbarrow.
29. Man sprinkling pepper on stew.
30. Man dusting flour on bread.
31. Woman sprinkling herbs onto pasta.
32. Woman dusting cocoa powder on tiramisu.

### *13.3. Experiment 2: Prime sentences*

1–2. The assistant loaded explosives/boxes into the vehicle.
3–4. The traveller packed skis/suitcases into the car.
5–6. The actress rubbed moisturiser/lotion onto her ankle.
7–8. The hiker dabbed sunscreen/antiseptic onto her elbow.
9–10. The pensioner smeared peanut butter/jam on the bagel.
11–12. The guest slathered clotted cream/icing on the sponge.
13–14. The child splashed milk/paint on the table.
14–16. The cyclist splattered water/mud on the pavement.
17–18. The manager sprayed dressing/vinegar on the salad.
19–20. The chef drizzled olive oil/lime juice on the grilled fish.
21–22. The tenant crammed vegetables/burgers into the fridge.
23–24. The lawyer stuffed junk/furniture into the attic.
25–26. The student piled tins/bottles onto the countertop.
27–28. The manager stacked books/folders in the cabinet.
29–30. The pâtissier sprinkled cocoa powder/icing sugar on the brownies.
31–32. The baker dusted spices/cinnamon onto the pie.

### *13.4. Experiment 2: Target events*

1. Woman packing boxes into van.
2. Man packing explosives into (car) boot.
3. Man loading suitcases onto trolley.
4. Woman loading skis into cable car.
5. Woman dabbing lotion onto shoulder.
6. Man dabbing moisturiser onto hand.
7. Woman rubbing antiseptic onto leg.
8. Man rubbing sunscreen on neck.
9. Girl slathering jam on a piece of bread.
10. Boy slathering peanut butter on toast.
11. Woman smearing icing on cake.
12. Man smearing clotted cream on scone.
13. Girl splattering paint on wall.
14. Boy splattering milk on floor.
14. Boy splashing mud onto bench.
16. Woman splashing water onto face.
17. Girl drizzling vinegar on dish.
18. Boy drizzling dressing on prawns.
19. Girl spraying lime juice on oysters.
20. Man spraying olive oil on roast chicken.
21. Man stuffing burgers into mouth.
22. Woman stuffing vegetables into turkey.
23. Man cramming furniture into truck.

24. Woman cramming junk into wardrobe.
25. Woman stacking bottles on wine rack.
26. Man stacking tins on shelves.
27. Man piling folders onto desk.
28. Girl piling books onto armchair.
29. Boy dusting icing sugar on donuts.
30. Woman dusting cocoa powder on tiramisu.
31. Woman sprinkling cinnamon on coffee.
32. Man sprinkling spices on stew.

### *13.5. Experiment 3: Prime sentences*

1–2. The assistant loaded explosives into the car/van.
3–4. The tour operator packed rucksacks onto the sledge/trolley.
5–6. The hiker rubbed sunscreen onto her neck/arm.
7–8. The athlete dabbed antiseptic onto his leg/hand.
9–10. The pensioner smeared hummus onto the toast/bread.
11–12. The guest slathered jam on the scone/cake.
13–14. The child splashed water on the floor/wall.
15–16. The cyclist splattered mud onto the pavement/bench.
17–18. The manager sprayed coconut oil on the beans/prawns.
19–20. The chef drizzled mustard sauce on the mushrooms/oysters.
21–22. The deliveryman crammed furniture into the lorry/garage.
23–24. The teenager stuffed chocolates into her drawer/mouth.
25–26. The student piled magazines on the desk/shelf.
27–28. The waiter stacked bowls on the table/countertop.
29–30. The pâtissier sprinkled cocoa powder on the brownies/donuts.
31–32. The baker dusted cinnamon on the pie/loaf.

### *13.6. Experiment 3: Target events*

1. Man packing boxes into van.
2. Woman packing shopping bags into car.
3. Man loading suitcases onto trolley.
4. Girl loading gifts into sledge.
5. Girl dabbing lotion onto arm.
6. Man dabbing cologne on neck.
7. Boy rubbing Vaseline onto hand.
8. Woman rubbing moisturiser onto leg.
9. Girl slathering marmalade onto a piece of bread.
10. Boy slathering peanut butter on toast.
11. Woman smearing icing onto cake.
12. Man smearing clotted cream on scone.
13. Girl splattering paint on wall.
14. Boy splattering milk on the floor.
15. Woman splashing disinfectant onto bench.
16. Man splashing Champagne onto pavement.
17. Boy drizzling dressing over prawns.
18. Girl drizzling vinegar over beans.
19. Woman spraying lime juice on oysters.
20. Man spraying olive oil on mushrooms.
21. Man stuffing junk into garage.
22. Woman stuffing plants into lorry.
23. Man cramming burgers into mouth.
24. Woman cramming files into drawer.
25. Man stacking tins on shelf.
26. Woman stacking books on desk.
27. Woman piling plates on countertop.
28. Man piling cups onto table.
29. Boy dusting icing sugar onto donuts.
30. Woman dusting ginger powder on brownies.

31. Man sprinkling flour onto loaf.
32. Woman sprinkling nutmeg on pie.

### 13.7. Experiments 4 & 5: Prime sentences

1–2. What the assistant loaded/packed into the lift was the equipment.
3–4. What the hiker loaded/packed into the car was the camping gear.
5–6. What the tourist rubbed/dabbed onto her arm was the lotion.
7–8. What the actress rubbed/dabbed onto her ankle was the moisturiser.
9–10. What the pensioner smeared/slathered on the toast was peanut butter.
11–12. What the chef smeared/slathered on the chicken breast was the mustard sauce.
13–14. What the baby splashed/splattered on the table was the soup.
15–16. What the cleaner splattered/splashed on the bench was the disinfectant.
17–18. What the manager drizzled/sprayed on the salad was the dressing.
19–20. What the cook drizzled/sprayed on the grilled fish was lime juice.
21–22. What the babysitter stuffed/crammed into the boxes were the toys.
23–24. What the lawyer stuffed/crammed into the briefcases were the banknotes.
25–26. What the novelist piled/stacked on the armchairs were the books.
27–28. What the waiter piled/stacked on the trollies were the plates.
29–30. What the granny dusted/sprinkled on the mince pie was icing sugar.
31–32. What the barista dusted/sprinkled on the coffee was cinnamon.

### 13.8. Experiment 6: Prime sentences

1–2. It was the equipment that the assistant loaded/packed into the lift.
3–4. It was the camping gear that the hiker loaded/packed into the car.
5–6. It was lotion that the tourist rubbed/dabbed onto her arm.
7–8. It was moisturiser that the actress rubbed/dabbed onto her ankle.
9–10. It was the peanut butter that the pensioner smeared/slathered on the toast.
11–12. It was the mustard sauce that the chef smeared/slathered on the chicken breast.
13–14. It was the soup that the baby splashed/splattered on the table.
15–16. It was disinfectant that the cleaner splashed/splattered on the bench.
17–18. It was the dressing that the manager drizzled/sprayed on the salad.
19–20. It was lime juice that the cook drizzled/sprayed on the grilled fish.
21–22. It was the toys that the babysitter stuffed/crammed into the boxes.
23–24. It was the banknotes that the lawyer stuffed/crammed into the briefcases.
25–26. It was the books that the novelist piled/stacked on the armchairs.
27–28. It was the plates that the waiter piled/stacked on the trollies.
29–30. It was icing sugar that the granny dusted/sprinkled on the mince pie.
31–32. It was cinnamon that the barista dusted/sprinkled on the coffee.

### 13.9. Experiments 4, 5, 6: Target events

1. Boy packing stationery into bag.
2. Man loading luggage onto bus.
3. Woman packing hat into suitcase.
4. Man loading rubbish into lorry.
5. Man dabbing Cologne onto neck.
6. Man rubbing wax onto shoe.
7. Woman dabbing antiseptic onto wound.
8. Boy rubbing Vaseline onto hand.
9. Girl slathering jam on a piece of bread.
10. Girl smearing glue on paper.
11. Boy slathering sunscreen on body.
12. Woman smearing icing on cake.
13. Girl splattering paint on wall.
14. Woman splashing water on face.
15. Man splattering Champagne on pavement.
16. Boy splashing milk on floor.
17. Girl spraying bleach on window.
18. Boy drizzling syrup on pancake.

19. Man spraying pesticide on plant.
20. Man drizzling olive oil on dish.
21. Woman cramming junk into wardrobe.
22. Woman stuffing onions into turkeys.
23. Man cramming furniture into van.
24. Woman stuffing files into drawers.
25. Boy stacking cups onto tables.
26. Boy piling clothes into laundry baskets.
27. Man stacking tins on shelves.
28. Boy piling leaves into wheelbarrows.
29. Man sprinkling pepper on stew.
30. Man dusting flour on bread.
31. Woman sprinkling basil onto pasta.
32. Woman dusting cocoa powder on tiramisu.

### *13.10. Frequencies of target responses in Experiments 1–3*

| | **Target** | | | |
|---|---|---|---|---|
| **Prime** | LT | TL | % of LT | *SE* |
| | **Experiment 1: Verb Repetition** | | | |
| *Verb Repeated* | | | | |
| Location-Theme (LT) order | 223 | 414 | 35.0 % | 1.9 % |
| Theme-Location (TL) order | 110 | 521 | 17.4 % | 1.5 % |
| *Not-Repeated* | | | | |
| Location-Theme order | 172 | 462 | 27.1 % | 1.8 % |
| Theme-Location order | 139 | 492 | 22.0 % | 1.6 % |
| | **Experiment 2: Theme Repetition** | | | |
| *Theme Repeated* | | | | |
| Location-Theme order | 154 | 478 | 24.4 % | 1.7 % |
| Theme-Location order | 107 | 521 | 17.0 % | 1.5 % |
| *Not-Repeated* | | | | |
| Location-Theme order | 169 | 466 | 26.6 % | 1.8 % |
| Theme-Location order | 107 | 530 | 16.8 % | 1.5 % |
| | **Experiment 3: Location Repetition** | | | |
| *Location Repeated* | | | | |
| Location-theme order | 129 | 506 | 20.3 % | 1.6 % |
| Theme-location order | 80 | 547 | 12.8 % | 1.3 % |
| *Not-Repeated* | | | | |
| Location-theme order | 123 | 511 | 19.4 % | 1.6 % |
| Theme-location order | 76 | 546 | 12.2 % | 1.3 % |

### *13.11. Experiments 1–3 combined analyses 13 (with supplementary likelihood ratio tests)*

| Fixed Effect | *Estimate* | *SE* | *z* | *p* | $\chi^2$ (1) |
|---|---|---|---|---|---|
| | **Combined Analysis for Experiments 2 and 3** | | | | |
| (Intercept) | −2.17 | 0.19 | −11.49 | < .001 | |
| Prime Structure | 0.37 | 0.05 | 7.35 | < .001 | 35.76, $p < .001$ |
| Repetition (Repeated vs. Not-Repeated) | −0.01 | 0.04 | −0.14 | .892 | 0.02, $p = .896$ |
| Experiment (Theme vs. Location Repetition) | 0.18 | 0.19 | 0.98 | .330 | 0.94, $p = .333$ |
| Prime Structure × Repetition | −0.02 | 0.04 | −0.42 | .672 | 0.17, $p = .680$ |
| Prime Structure × Experiment | 0.02 | 0.05 | 0.31 | .760 | 0.09, $p = .767$ |
| Repetition × Experiment | −0.04 | 0.04 | −0.86 | .392 | 0.69, $p = .406$ |
| Prime Structure × Repetition × Experiment | −0.02 | 0.04 | −0.53 | .595 | 0.27, $p = .605$ |
| | **Experiment 1 vs. Experiment 2/3** | | | | |
| (Intercept) | −1.99 | 0.15 | 13.01 | < .001 | |
| Prime Structure | 0.39 | 0.04 | 9.09 | < .001 | 58.55, $p < .001$ |
| Repetition (Repeated vs. Not-Repeated) | 0.01 | 0.04 | 0.17 | .863 | 0.03, $p = .867$ |
| Experiment (Verb vs. Noun Repetition)[a] | 0.59 | 0.32 | 1.84 | .065 | 3.35, $p = .067$ |
| Prime Structure × Repetition | 0.06 | 0.03 | 1.80 | .072 | 3.07, $p = .080$ |
| Prime Structure × Experiment | 0.05 | 0.09 | 0.53 | .597 | 0.26, $p = .608$ |
| Repetition × Experiment | 0.04 | 0.07 | 0.58 | .563 | 0.32, $p = .572$ |
| Prime Structure × Repetition × Experiment | 0.24 | 0.07 | 3.42 | .001 | 11.15, $p < .001$ |

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| Fixed Effect | *Estimate* | *SE* | *z* | *p* | $\chi^2$ (1) |
|---|---|---|---|---|---|
| *Repeated condition* | | | | | |
| (Intercept) | −1.95 | 0.15 | −12.64 | < .001 | |
| Prime Structure | 0.44 | 0.05 | 8.32 | < .001 | 61.26, $p < .001$ |
| Experiment (Verb vs. Noun Repetition) | 0.67 | 0.32 | 2.11 | .035 | 4.36, $p = .037$ |
| Prime Structure × Experiment | 0.27 | 0.11 | 2.51 | .012 | 5.87, $p = .015$ |
| *Not-repeated condition* | | | | | |
| (Intercept) | −2.02 | 0.17 | −12.19 | < .001 | |
| Prime Structure | 0.34 | 0.05 | 6.54 | < .001 | 32.40, $p < .001$ |
| Experiment (Verb vs. Noun Repetition) | 0.47 | 0.34 | 1.38 | .169 | 1.86, $p = .173$ |
| Prime Structure × Experiment | −0.19 | 0.11 | −1.75 | .080 | 2.76, $p = .097$ |

[a] Experiment 1 was assigned a weight of 0.6666667, while both Experiments 2 and 3 were assigned a weight of −0.3333333.

### 13.12. Frequencies of target responses in Experiment 4

| *What*-Cleft Prime | | | *What*-Cleft Target | | | |
|---|---|---|---|---|---|---|
| | | | Location-Theme (Theme-focused) | | Theme-Location (Location-focused) | |
| Prime order | Prime structure | Constituent structure | *With* NP-first | Locative PP-first | *With* PP-first | Locative NP-first |
| **Verb Repeated** | | | | | | |
| Location-Theme | *With* | NP-first | 128 (45 %, *SE* = 3 %) | 149 (52 %, *SE* = 3 %) | 3 (1 %, *SE* = 1 %) | 6 (2 %, *SE* = 1 %) |
| Location-Theme | Locative | PP-first | 30 (11 %, *SE* = 2 %) | 240 (85 %, *SE* = 2 %) | 7 (3 %, *SE* = 1 %) | 6 (2 %, *SE* = 1 %) |
| Theme-Location | *With* | PP-first | 83 (30 %, *SE* = 3 %) | 146 (54 %, *SE* = 3 %) | 23 (8 %, *SE* = 2 %) | 21 (8 %, *SE* = 2 %) |
| Theme-Location | Locative | NP-first | 38 (14 %, *SE* = 2 %) | 165 (59 %, *SE* = 3 %) | 0 | 76 (27 %, *SE* = 3 %) |
| **Not-Repeated** | | | | | | |
| Location-Theme | *With* | NP-first | 93 (33 %, *SE* = 3 %) | 170 (60 %, *SE* = 3 %) | 3 (1 %, *SE* = 1 %) | 17 (6 %, *SE* = 1 %) |
| Location-Theme | Locative | PP-first | 44 (15 %, *SE* = 2 %) | 226 (79 %, *SE* = 2 %) | 6 (2 %, *SE* = 1 %) | 9 (3 %, *SE* = 1 %) |
| Theme-Location | *With* | PP-first | 71 (26 %, *SE* = 3 %) | 164 (59 %, *SE* = 3 %) | 15 (5 %, *SE* = 1 %) | 28 (10 %, *SE* = 2 %) |
| Theme-Location | Locative | NP-first | 49 (18 %, *SE* = 2 %) | 172 (62 %, *SE* = 3 %) | 3 (1 %, *SE* = 1 %) | 52 (19 %, *SE* = 2 %) |

Note. NP = Noun Phrase; PP = Prepositional Phrase.

### 13.13. Frequencies of argument structure choice in Experiment 4

| *What*-Cleft Prime | *What*-Cleft Target Verb repeated | | | | Not-repeated | | | |
|---|---|---|---|---|---|---|---|---|
| | *With*-Structure | Locative Structure | % of *With* | *SE* | *With*-Structure | Locative Structure | % of *With* | *SE* |
| **Location-Theme Order (Theme-focused)** | | | | | | | | |
| *With*-Structure | 131 | 155 | 45.8 % | 2.9 % | 96 | 187 | 33.9 % | 2.8 % |
| Locative Structure | 37 | 246 | 13.1 % | 2.0 % | 50 | 235 | 17.5 % | 2.3 % |
| **Theme-Location Order (Location-focused)** | | | | | | | | |
| *With*-Structure | 106 | 167 | 38.8 % | 2.9 % | 86 | 192 | 30.9 % | 2.8 % |
| Locative Structure | 38 | 241 | 13.6 % | 2.1 % | 52 | 224 | 18.8 % | 2.4 % |
| **Same Thematic Role Order** | | | | | | | | |
| *With*-Structure | 151 | 170 | 47.0 % | 2.8 % | 108 | 198 | 35.3 % | 2.7 % |
| Locative Structure | 30 | 316 | 8.7 % | 1.5 % | 47 | 278 | 14.5 % | 2.0 % |
| **Different Thematic Role Order** | | | | | | | | |
| *With*-Structure | 86 | 152 | 36.1 % | 3.1 % | 74 | 181 | 29.0 % | 2.8 % |
| Locative Structure | 45 | 171 | 20.8 % | 2.8 % | 55 | 181 | 23.3 % | 2.8 % |

### 13.14. Frequencies of thematic role order choice in Experiment 4

| *What*-Cleft Prime | *What*-Cleft Target | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Verb Repeated | | | | Not-Repeated | | | |
| | LT | TL | % of LT | *SE* | LT | TL | % of LT | *SE* |
| ***With*-Structure** | | | | | | | | |
| Location-Theme (LT) | 277 | 9 | 96.9 % | 1.0 % | 263 | 20 | 92.9 % | 1.5 % |
| Theme-Location (TL) | 229 | 44 | 83.9 % | 2.2 % | 235 | 43 | 84.5 % | 2.2 % |
| **Locative Structure** | | | | | | | | |

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| *What*-Cleft Prime | *What*-Cleft Target | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Verb Repeated | | | | Not-Repeated | | | |
| | LT | TL | % of LT | *SE* | LT | TL | % of LT | *SE* |
| Location-Theme | 270 | 13 | 95.4 % | 1.2 % | 270 | 15 | 94.7 % | 1.3 % |
| Theme-Location | 203 | 76 | 72.8 % | 2.7 % | 221 | 55 | 80.1 % | 2.4 % |
| **Same Argument Structure** | | | | | | | | |
| Location-Theme | 368 | 9 | 97.6 % | 0.8% | 319 | 12 | 96.4 % | 1.0 % |
| Theme-Location | 248 | 99 | 71.5 % | 2.4 % | 243 | 67 | 78.4 % | 2.3 % |
| **Different Argument Structure** | | | | | | | | |
| Location-Theme | 179 | 13 | 93.2 % | 1.8 % | 214 | 23 | 90.3 % | 1.9 % |
| Theme-Location | 184 | 21 | 89.8 % | 2.1 % | 213 | 31 | 87.3 % | 2.1 % |

### 13.15. Frequencies of constituent structure in Experiment 4

| *What*-Cleft Prime | *What*-Cleft Target | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Verb repeated | | | | Not-repeated | | | |
| | NP-first | PP-first | % of NP-first | *SE* | NP-first | PP-first | % of NP-first | *SE* |
| **Same Thematic Role Order** | | | | | | | | |
| NP-first | 204 | 149 | 57.8 % | 2.6 % | 145 | 173 | 45.6 % | 2.8 % |
| PP-first | 51 | 263 | 16.2 % | 2.1 % | 72 | 241 | 23.0 % | 2.4 % |
| **Different Thematic Role Order** | | | | | | | | |
| NP-first | 44 | 168 | 20.8 % | 2.8 % | 66 | 175 | 27.4 % | 2.9 % |
| PP-first | 89 | 153 | 36.8 % | 3.1 % | 80 | 170 | 32.0 % | 3.0 % |
| **Same Argument Structure** | | | | | | | | |
| NP-first | 204 | 168 | 54.8 % | 2.6 % | 145 | 175 | 45.3 % | 2.8 % |
| PP-first | 89 | 263 | 25.3 % | 2.3 % | 80 | 241 | 24.9 % | 2.4 % |
| **Different Argument Structure** | | | | | | | | |
| NP-first | 44 | 149 | 22.8 % | 3.0 % | 66 | 173 | 27.6 % | 2.9 % |
| PP-first | 51 | 153 | 25.0 % | 3.0 % | 72 | 170 | 29.8 % | 2.9 % |

*Note.* NP = Noun Phrase, PP = Prepositional Phrase.

### 13.16. Frequencies of target responses in Experiment 5

| *What*-Cleft Prime | Non-Cleft Target | | | |
|---|---|---|---|---|
| | Location-Theme (*With*-Structure) | Theme-Location (Locative Structure) | % of Location-Theme | *SE* |
| | | **Verb Repeated** | | |
| **Location-Theme Order** | | | | |
| *With*-Structure | 80 | 239 | 25.1 % | 2.4 % |
| Locative Structure | 58 | 258 | 18.4 % | 2.2 % |
| **Theme-Location Order** | | | | |
| *With*-Structure | 62 | 241 | 20.5 % | 2.3 % |
| Locative Structure | 47 | 270 | 14.8 % | 2.0 % |
| | | **Not-Repeated** | | |
| **Location-Theme Order** | | | | |
| *With*-Structure | 75 | 244 | 23.5 % | 2.4 % |
| Locative Structure | 60 | 258 | 18.9 % | 2.2 % |
| **Theme-Location Order** | | | | |
| *With*-Structure | 65 | 237 | 21.5 % | 2.4 % |
| Locative Structure | 53 | 266 | 16.6 % | 2.1 % |

*13.17. Frequencies of target responses in Experiment 6*

| *It*-Cleft Prime | Non-Cleft Target | | | |
|---|---|---|---|---|
| | Location-Theme (*With*-Structure) | Theme-Location (Locative-Structure) | % of Location- Theme | *SE* |
| | | **Verb Repeated** | | |
| **Theme-Agent-Location (Theme-focused)** | | | | |
| *With*-Structure | 92 | 222 | 29.3 % | 2.6 % |
| Locative Structure | 63 | 255 | 19.8 % | 2.2 % |
| **Location-Agent- Theme (Location-focused)** | | | | |
| *With*-Structure | 81 | 228 | 26.2 % | 2.5 % |
| Locative Structure | 58 | 259 | 18.3 % | 2.2 % |
| | | **Not-Repeated** | | |
| **Theme-Agent-Location (Theme-focused)** | | | | |
| *With*-Structure | 85 | 233 | 26.7 % | 2.5 % |
| Locative Structure | 73 | 243 | 23.1 % | 2.4 % |
| **Location-Agent- Theme (Location-focused)** | | | | |
| *With*-Structure | 81 | 233 | 25.8 % | 2.5 % |
| Locative Structure | 67 | 249 | 21.2 % | 2.3 % |

*13.18. Experiment 4 vs. Experiment 5 comparison on argument structure priming (with supplementary likelihood ratio test analyses)*

| Fixed Effect | *Estimate* | *SE* | *z* | *p* | $\chi^2$ (1) |
|---|---|---|---|---|---|
| (Intercept) | −1.93 | 0.25 | −7.78 | < .001 | |
| Argument Structure | 0.53 | 0.05 | 9.67 | < .001 | 45.60, $p < .001$ |
| Verb Repetition | 0.01 | 0.04 | 0.16 | .875 | 0.02, $p = .877$ |
| Experiment (*What*-Cleft vs. Non-Cleft Target) | 0.30 | 0.13 | 2.29 | .022 | 5.17, $p = .023$ |
| Argument Structure × Verb Repetition | 0.15 | 0.05 | 3.14 | .002 | 7.96, $p = .005$ |
| Argument Structure × Experiment | 0.28 | 0.04 | 6.39 | < .001 | 39.46, $p < .001$ |
| Verb Repetition × Experiment | 0.02 | 0.04 | 0.56 | .575 | 0.30, $p = .583$ |
| Argument Structure × Verb Repetition × Experiment | 0.13 | 0.04 | 3.02 | .003 | 8.78, $p = .003$ |
| | *Verb-Repeated Condition* | | | | |
| (Intercept) | −1.91 | 0.26 | −7.42 | < .001 | |
| Argument Structure | 0.69 | 0.08 | 8.48 | < .001 | 41.79, $p < .001$ |
| Experiment | 0.30 | 0.14 | 2.23 | .026 | 5.01, $p = .025$ |
| Argument Structure × Experiment | 0.43 | 0.07 | 6.59 | < .001 | 45.30, $p < .001$ |
| | *Not-Repeated Condition* | | | | |
| (Intercept) | −1.80 | 0.23 | −7.72 | < .001 | |
| Argument Structure | 0.36 | 0.06 | 6.16 | < .001 | 37.14, $p < .001$ |
| Experiment | 0.17 | 0.10 | 1.67 | .095 | 2.69, $p = .101$ |
| Argument Structure × Experiment | 0.17 | 0.06 | 2.97 | .003 | 8.45, $p = .004$ |

*13.19. Experiment 4 vs. Experiment 5 comparison on thematic role order priming (with supplementary likelihood ratio test analyses)*

| Fixed Effect | *Estimate* | *SE* | *z* | *p* | $\chi^2$ (1) |
|---|---|---|---|---|---|
| (Intercept) | 0.21 | 0.21 | 0.97 | .331 | |
| Thematic Role Order | 0.53 | 0.05 | 9.88 | < .001 | 50.68, $p < .001$ |
| Verb Repetition | 0.02 | 0.05 | 0.36 | .717 | 0.31, $p = .575$ |
| Experiment (*What*-Cleft Target vs. Non-Cleft Target) | 2.54 | 0.17 | 14.62 | < .001 | 75.48, $p < .001$ |
| Thematic Role Order × Verb Repetition | 0.13 | 0.05 | 2.58 | .010 | 6.08, $p = .014$ |
| Thematic Role Order × Experiment | 0.40 | 0.05 | 7.43 | < .001 | 58.11, $p < .001$ |
| Verb Repetition × Experiment | 0.03 | 0.05 | 0.66 | .512 | 0.59, $p = .443$ |
| Thematic Role Order × Verb Repetition × Experiment | 0.08 | 0.05 | 1.41 | .159 | 2.30, $p = .130$ |
| | *Verb-Repeated Condition* | | | | |
| (Intercept) | 0.24 | 0.20 | 1.19 | .235 | |
| Thematic Role Order | 0.64 | 0.08 | 7.87 | < .001 | 36.14, $p < .001$ |
| Experiment | 2.53 | 0.20 | 12.56 | < .001 | 66.60, $p < .001$. |
| Thematic Role Order × Experiment | 0.47 | 0.09 | 5.06 | < .001 | 18.99, $p < .001$ |
| | *Not-Repeated Condition* | | | | |
| (Intercept) | 0.26 | 0.24 | 1.08 | .279 | |
| Thematic Role Order | 0.40 | 0.07 | 5.47 | < .001 | 31.87, $p < .001$ |
| Experiment | 2.52 | 0.17 | 14.98 | < .001 | 82.35, $p < .001$ |
| Thematic Role Order × Experiment | 0.32 | 0.07 | 4.42 | < .001 | 20.64, $p < .001$ |

### 13.20. Supplementary likelihood ratio tests

#### 13.20.1. Experiments 1–3: Analyses of structural choice

| | Experiment 1 | | Experiment 2 | | Experiment 3 | |
|---|---|---|---|---|---|---|
| Fixed Effect | $\chi^2(1)$ | $p$ | $\chi^2(1)$ | $p$ | $\chi^2(1)$ | $p$ |
| Prime Structure | 22.41 | < .001 | 21.28 | < .001 | 20.56 | < .001 |
| Lexical Repetition | 0.42 | .516 | 0.46 | .497 | 0.13 | .720 |
| Prime Structure × Lexical Repetition | 13.33 | < .001 | 0.51 | .474 | 0.01 | .928 |
| *Repeated* | | | | | | |
| Prime Structure | 31.65 | < .001 | 9.71 | .002 | 13.44 | < .001 |
| *Not-Repeated* | | | | | | |
| Prime Structure | 5.50 | .019 | 16.96 | < .001 | 13.33 | < .001 |

#### 13.20.2. Experiment 4: Analyses of argument structure selection

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| **(1) Argument Structure × Verb Repetition** | | |
| Argument Structure | 85.96 | < .001 |
| Thematic Role Order | 0.77 | .381 |
| Verb Repetition | 0.39 | .535 |
| Argument Structure × Thematic Role Order | 2.75 | .097 |
| Argument Structure × Verb Repetition | 12.73 | < .001 |
| Thematic Role Order × Verb Repetition | 0.25 | .615 |
| Argument Structure × Thematic Role Order × Verb Repetition | 0.02 | .887 |
| *Verb Repeated* | | |
| Argument Structure | 53.20 | < .001 |
| *Not-Repeated* | | |
| Argument Structure | 39.09 | < .001 |
| **(2) Argument Structure × Thematic Role Order Congruence** | | |
| Argument Structure | 90.28 | < .001 |
| Order Congruence | 4.01 | .045 |
| Verb Repetition | 0.18 | .671 |
| Argument Structure × Order Congruence | 35.04 | < .001 |
| Argument Structure × Verb Repetition | 13.75 | < .001 |
| Order Congruence × Verb Repetition | 0.37 | .543 |
| Argument Structure × Order Congruence × Verb Repetition | 1.40 | .237 |
| *Same Thematic Role Order* | | |
| Argument Structure | 184.29 | < .001 |
| *Different Thematic Role Order* | | |
| Argument Structure | 16.59 | < .001 |

#### 13.20.3. Experiment 4: Analyses of thematic role order choice

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| **(1) Thematic Role Order × Verb Repetition** | | |
| Thematic Role Order | 43.60 | < .001 |
| Argument Structure | 2.54 | .111 |
| Verb Repetition | 0.34 | .558 |
| Thematic Role Order × Argument Structure | 2.01 | .156 |
| Thematic Role Order × Verb Repetition | 4.59 | .032 |
| Argument Structure × Verb Repetition | 1.82 | .177 |
| Thematic Role Order × Argument Structure × Verb Repetition | 0.22 | .638 |
| *Verb Repeated* | | |
| Thematic Role Order | 29.05 | < .001 |
| *Not-Repeated* | | |
| Thematic Role Order | 33.92 | < .001 |
| **(2) Thematic Role Order × Structure Congruence** | | |
| Thematic Role Order | 40.86 | < .001 |
| Argument Structure Congruence | 0.01 | .943 |
| Verb Repetition | 0.37 | .546 |
| Thematic Role Order × Structure Congruence | 32.27 | < .001 |
| Thematic Role Order × Verb Repetition | 2.19 | .139 |
| Structure Congruence × Verb Repetition | 0.85 | .355 |
| Thematic Role Order × Structure Congruence × Verb Repetition | 0.60 | .438 |

(*continued on next page*)

(*continued*)

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| *Same Argument Structure* | | |
| Thematic Role Order | 49.48 | < .001 |
| *Different Argument Structure* | | |
| Thematic Role Order | 4.16 | .041 |

### 13.20.4. Experiment 4: Analyses of constituent structure choice

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| **(1) Constituent Structure × Thematic Role Order Congruence** | | |
| Constituent Structure | 63.53 | < .001 |
| Thematic Role Order Congruence | 2.77 | .096 |
| Verb Repetition | < 0.01 | .951 |
| Constituent Structure × Order Congruence | 139.43 | < .001 |
| Constituent Structure × Verb Repetition | 1.65 | .199 |
| Thematic Role Order Congruence × Verb Repetition | 0.12 | .730 |
| Constituent Structure × Order Congruence × Verb Repetition | 12.70 | < .001 |
| *Same Thematic Role Order* | | |
| Constituent Structure | 57.71 | < .001 |
| Verb Repetition | 0.11 | .742 |
| Constituent Structure × Verb Repetition | 12.72 | < .001 |
| *Different Thematic Role Order* | | |
| Constituent Structure | 13.82 | < .001 |
| Verb Repetition | 0.12 | .732 |
| Constituent Structure × Verb Repetition | 3.41 | .065 |
| **(2) Constituent Structure × Argument Structure Congruence** | | |
| Constituent Structure | 60.00 | < .001 |
| Argument Structure Congruence | 12.19 | < .001 |
| Verb Repetition | 0.15 | .702 |
| Constituent Structure × Structural Congruence | 27.45 | < .001 |
| Constituent Structure × Verb Repetition | 0.79 | .375 |
| Argument Structure Congruence × Verb Repetition | 2.80 | .094 |
| Constituent Structure × Structural Congruence × Verb Repetition | 0.65 | .422 |
| *Same Argument Structure* | | |
| Constituent Structure | 113.70 | < .001 |
| *Different Argument Structure* | | |
| Constituent Structure | 0.07 | .792 |

### 13.20.5. Experiment 5: From what-cleft primes to non-cleft targets

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| Thematic Role Order | 5.61 | .018 |
| Argument Structure | 13.03 | < .001 |
| Verb Repetition | 0.08 | .774 |
| Thematic Role Order × Argument Structure | < 0.01 | .988 |
| Thematic Role Order × Verb Repetition | 1.10 | .293 |
| Argument Structure × Verb Repetition | 0.28 | .595 |
| Thematic Role Order × Argument Structure × Verb Repetition | 0.28 | .598 |

### 13.20.6. Experiment 6: From it-cleft primes to non-cleft targets

| Fixed Effect | $\chi^2(1)$ | $p$ |
|---|---|---|
| Thematic Role Order (Emphasis) | 1.60 | .206 |
| Argument Structure | 12.06 | .001 |
| Verb Repetition | 0.90 | .344 |
| Emphasis × Argument Structure | 0.18 | .672 |
| Emphasis × Verb Repetition | < 0.01 | .996 |
| Argument Structure × Verb Repetition | 2.98 | .084 |
| Emphasis × Structure × Verb Repetition | 0.73 | .393 |

## References


Anderson, S. R. (1971). On the role of deep structure in semantic interpretation. *Foundations of Language, 7*, 387–396.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modelling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390–412.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015a). *Parsimonious mixed models.* arXiv preprint. arXiv:1506.04967.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48.

Bernolet, S., Hartsuiker, R. J., & Pickering, M. J. (2009). Persistence of emphasis in language production: A cross-linguistic approach. *Cognition, 112*, 300–317.

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

Bock, J. K. (1982). Toward a cognitive psychology of syntax: Information processing contributions to sentence formulation. *Psychological Review, 89*, 1–47.

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

Bock, J. K., & Cutting, J. C. (1992). Regulating mental energy: Performance units in language production. *Journal of Memory and Language, 31*, 99–127.

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

Bock, J. K., & Miller, C. A. (1991). Broken agreement. *Cognitive Psychology, 23*, 45–93.

Bock, J. K., Loebell, H., & Morey, R. (1992). From conceptual roles to structural relations: Bridging the syntactic cleft. *Psychological Review, 99*, 150–171.

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

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

Bock, J. K., & Warren, R. K. (1985). Conceptual availability and syntactic structure in sentence formulation. *Cognition, 21*, 47–67.

Bock, K., & Levelt, W. (1994). Language production: Grammatical encoding. In M. Gernsbacher (Ed.), *Handbook of Psycholinguistics* (pp. 945–984). New York: Academic Press.

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

Branigan, H., & Pickering, M. J. (2017). An experimental approach to linguistic representation. *Behavioral and Brain Sciences, 40*, E282.

Branigan, H. P., Pickering, M. J., & Tanaka, M. (2008). Contributions of animacy to grammatical function assignment and word order during production. *Lingua, 118*, 172–189.

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

Cai, Z. G., Pickering, M. J., & Branigan, H. P. (2012). Mapping concepts to syntax: Evidence from structural priming in Mandarin Chinese. *Journal of Memory and Language, 66*, 833–849.

Carminati, M. N., Van Gompel, R. P., & Wakeford, L. J. (2019). An investigation into the lexical boost with nonhead nouns. *Journal of Memory and Language, 108*, Article 104031.

Chang, F., Bock, K., & Goldberg, A. E. (2003). Can thematic roles leave traces of their places? *Cognition, 90*, 29–49.

Chang, F., Dell, G. S., & Bock, K. (2006). Becoming syntactic. *Psychological Review, 113*, 234–272.

Chang, F., Baumann, M., Pappert, S., & Fitz, H. (2015). Do Lemmas Speak German? A verb position effect in German structural priming. *Cognitive Science, 39*, 1113–1130.

Chang, F., Janciauskas, M., & Fitz, H. (2012). Language adaptation and learning: Getting explicit about implicit learning. *Language and Linguistics Compass, 6*, 259–278.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, Massachusetts: MIT Press.

Cho-Reyes, S., Mack, J. E., & Thompson, C. K. (2016). Grammatical Encoding and Learning in Agrammatic Aphasia: Evidence from Structural Priming. *Journal of memory and language, 91*, 202–218.

Christianson, K., & Ferreira, F. (2005). Conceptual accessibility and sentence production in a free word order language (Odawa). *Cognition, 98*, 105–135.

Cleland, A. A., & Pickering, M. J. (2003). The use of lexical and syntactic information in language production: Evidence from the priming of noun-phrase structure. *Journal of Memory and Language, 49*, 214–1213.

Dell, G. S. (1986). A spreading activation theory of retrieval in sentence production. *Psychological Review, 93*, 283–1232.

Dell, G. S., & Reich, P. A. (1981). Stages in sentence production: An analysis of speech error data. *Journal of Verbal Learning and Verbal Behavior, 20*, 611–629.

Ferreira, V. S. (2003). The persistence of optional complementizer production: Why saying "that" is not saying "that" at all. *Journal of Memory and Language, 48*, 379–398.

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

Ferreira, V. S., & Yoshita, H. (2003). Given-New Ordering Effects on the Production of Scrambled Sentences in Japanese. *Journal of Psycholinguistic Research, 32*(6), 669–692.

Ferreira, V. S., Slevc, L. R., & Rogers, E. S. (2005). How do speakers avoid ambiguous linguistic expressions? *Cognition, 96*, 263–284.

Ferreira, V. S., Bock, K., Wilson, M. P., & Cohen, N. J. (2008). Memory for syntax despite amnesia. *Psychological science, 19*, 940–946.

Fleischer, Z., Pickering, M. J., & McLean, J. F. (2012). Shared information structure: Evidence from cross-linguistic priming. *Bilingualism: Language and Cognition, 15*, 568–579.

Franck, J., Lassi, G., Frauenfelder, U. H., & Rizzi, L. (2006). Agreement and movement: A syntactic analysis of attraction. *Cognition, 101*, 173–216.

Fukumura, K. (2018). Ordering adjectives in referential communication. *Journal of Memory and Language, 10*, 37–135.

Fukumura, K., & Zhang, S. (2023). The interplay between syntactic and non-syntactic structure in language production. *Journal of Memory and Language, 128*, Article 104385.

Fukumura, K., Pozniak, C., & Alario, F. X. (2022). Avoiding gender ambiguous pronouns in French. *Cognition, 218*, Article 104909.

Garrett, M. F. (1975). The analysis of sentence production. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 9, pp. 133–177). New York: Academic Press.

Garrett, M. F. (1980). Levels of processing in sentence production. In B. Butterworth (Ed.), *Language production* (Vol. 1, pp. 177–220). London: Academic Press.

Garrett, M. F. (1990). Sentence processing. In D. N. Osherson, & H. Lasnik (Eds.), *Language: An invitation to cognitive science* (Vol. 1, pp. 133–175). The MIT Press.

Gelman, A., & Hill, J. (2007). *Data Analysis using regression and multilevel/hierarchical models*. Cambridge: Cambridge University Press.

Givón, T. (1984). *Syntax: A functional-typological introduction* (Vol. I). Amsterdam: John Benjamins.

Goldberg, A. E. (1995). *Constructions: A construction grammar approach to argument structure*. Chicago, IL: University of Chicago Press.

Grimshaw, J. (1990). *Argument structure*. Cambridge, MA: MIT Press.

Gropen, J., Pinker, S., Hollander, M., & Goldberg, R. (1991). Affectedness and direct objects: The role of lexical semantics in the acquisition of verb argument structure. *Cognition, 41*, 153–1119.

Halliday, M.A.K. (1970). Language structure and language function. In J. Lyons (Ed.), *New Horizons in Linguistics* (pp.128-169). Harmondsworth: Penguin.

Hare, M. L., & Goldberg, A. E. (1999). In *Structural priming: Purely syntactic?* (pp. 208–211). Mahwah, NJ: Erlbaum.

Hartsuiker, R. J., & Kolk, H. H. J. (1998). Syntactic persistence in Dutch. *Language and Speech, 41*, 143–184.

Hartsuiker, R. J., & Westenberg, C. (2000). Word order priming in written and spoken sentence production. *Cognition, 75*, B27–B39.

Hartsuiker, R. J., Bernolet, S., Schoonbaert, S., Speybroeck, S., & Vanderelst, D. (2008). Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. *Journal of Memory and Language, 58*, 214–238.

Haskell, T. R., & MacDonald, M. C. (2005). Constituent structure and linear order in language production: Evidence from subject agreement. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 891–904.

Haviland, S. E., & Clark, H. (1974). What's new? Acquiring new information as a process in comprehension. *Journal of Verbal Learning and Verbal Behavior, 13*, 512–521.
Heydel, M., & Murray, W. S. (2000). Conceptual effects in sentence priming: A cross-linguistic perspective. In M. De Vincenzi, & V. Lombardo (Eds.), *Cross-linguistic Perspectives on Language Processing* (pp. 227-254). Dordrecht: Springer. *horizons in linguistics*. Harmondsworth: Penguin.
Huang, J., Liu, X., Lu, M., Sun, Y., Wang, S., Branigan, H., & Pickering, M. J. (2023). The head constituent plays a key role in the lexical boost in syntactic priming. *Journal of Memory and Language*.
Ivanova, I., Pickering, M. J., McLean, J. F., Costa, A., & Branigan, H. P. (2012). How do people produce ungrammatical utterances? *Journal of Memory and Language, 67*, 355–370.
Ivanova, I., Wardlow, L., Warker, J., & Ferreira, V. S. (2017). The effect of anomalous utterances on language production. *Memory & Cognition, 45*, 308–319.
Jackendoff, R. S. (1983). *Semantics and cognition*. Cambridge, MA: MIT Press.
Jeffreys, H. (1961). *Theory of Probability* (3rd edn.). Oxford, UK: Oxford University Press.
Kantola, L., van Gompel, R. P., & Wakeford, L. J. (2023). The head of the verb: Is the lexical boost restricted to the head verb? *Journal of Memory and Language, 129*, Article 104388.
Kempen, G., & Harbusch, K. (2004). A corpus study into word order variation in German subordinate clauses: Animacy affects linearization independently of grammatical function assignment. In T. Pechmann, & C. Habel (Eds.), *Multidisciplinary approaches to language production* (pp. 173–181). Berlin: Mouton de Gruyter.
Kempen, G., & Hoenkamp, E. (1987). An incremental procedural grammar for sentence formulation. *Cognitive Science, 11*, 201–258.
Kliegl, R. (2014). Reduction of complexity of linear mixed models with double-bar syntax. https://rpubs.com/Reinhold/22193.
Köhne, J., Pickering, M. J., & Branigan, H. P. (2014). The relationship between sentence meaning and word order: Evidence from structural priming in German. *Quarterly Journal of Experimental Psychology, 67*, 304–318.
Konopka, A. E., & Bock, K. (2009). Lexical or syntactic control of sentence formulation? Structural generalizations from idiom production. *Cognitive Psychology, 58*, 68–101.
Lee, M. D., & Wagenmakers, E.-J. (2013). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.
Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: The MIT Press.
Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22*, 1–38.
Levin, B. (1993). *English verb classes and alternations: A preliminary investigation*. Chicago, IL: University of Chicago Press.
Levin, B., & Rappaport Hovav, M. (2005). *Argument Realization*. Cambridge: Cambridge University Press.
MacWhinney, B. (1987). The competition model. In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 249–308). Hillsdale, NJ: Lawrence Erlbaum.
Mahowald, K., James, A., Futrell, R., & Gibson, E. (2016). A meta-analysis of syntactic priming in language production. *Journal of Memory and Language, 91*, 5–27.
Malhotra, G., Pickering, M. J., Branigan, H. P., & Bednar, J. A. (2008). On the persistence of structural priming: Mechanisms of decay and influence of word-forms. In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.). *Proceedings of the 30th annual conference of the cognitive science society* (pp. 657–662). Austin, TX: Cognitive Science Society.
Makowski, D., Ben-Shachar, M. S., & Lüdecke, D. (2019). bayestestR: Describing Effects and their Uncertainty, Existence and Significance within the Bayesian Framework. *Journal of Open Source Software, 4*, 1541.
Man, G., Meehan, S., Martin, N., Branigan, H., & Lee, J. (2019). Effects of verb overlap on structural priming in dialogue: Implications for syntactic learning in aphasia. *Journal of speech, language, and hearing research : JSLHR, 62*(6), 1933–1950.
Marantz, A. (1984). *On the nature of grammatical relations*. MIT Press.
Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing type I error and power in linear mixed models. *Journal of Memory and Language, 94*, 305–315.
McDonald, J., Bock, K., & Kelly, M. H. (1993). Word and world order: Semantic, phonological, and metrical determinants of serial position. *Cognitive Psychology, 25*, 188–1123.
Momma, M. (2022). Producing filler-gap dependencies: Structural priming evidence for two distinct combinatorial processes in production. *Journal of Memory and Language, 126*, Article 104349.
Pappert, S., & Pechmann, T. (2014). Priming word order by thematic roles: No evidence for an additional involvement of phrase structure. *The Quarterly Journal of Experimental Psychology, 67*, 2260–2278.
Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language, 39*, 633–651.
Pickering, M. J., Branigan, H. P., & McLean, J. F. (2002). Constituent structure is formulated in one stage. *Journal of Memory and Language, 46*, 586–605.
Pinker, S. (1989). *Learnability and cognition: The acquisition of argument structure*. Cambridge, MA: MIT Press.
Potter, M. C., & Lombardi, L. (1998). Syntactic priming in immediate recall of sentences. *Journal of Memory and Language, 38*, 265–282.
Prat-Sala, M., & Branigan, H. P. (2000). Discourse constraints on syntactic processing in language production: A cross-linguistic study in English and Spanish. *Journal of Memory and Language, 42*, 168–182.
Quirk, R., Greenbaum, S., Leech, G., & Svartvik, J. (1985). *A comprehensive grammar of the English language*. London: Longman.
R Core Team. (2021). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/.
Rappaport, M., & Levin, B. (1988). What to do with θ-roles. In W.Wilkins (Ed.), *Syntax and semantics, vol. 21: Thematic relations* (pp.7-36). San Diego: Academic Press.
Reitter, D., Keller, F., & Moore, J. D. (2011). A computational cognitive model of syntactic priming. *Cognitive Science, 35*, 587–637.
Salamoura, A., & Williams, J. N. (2007). Processing verb argument structure across languages: Evidence for shared representations in the bilingual lexicon. *Applied Psycholinguistics, 28*, 627–666.
Santesteban, M., Pickering, M. J., & Branigan, H. P. (2013). The effects of word order on subject–verb and object–verb agreement: Evidence from Basque. *Journal of Memory and Language, 68*, 160–179.
Scheepers, C., Raffray, C. N., & Myachykov, A. (2017). The lexical boost effect is not diagnostic of lexically-specific syntactic representations. *Journal of Memory and Language, 95*, 102–115.
Searle, J. R. (1979). *Expression and Meaning: Studies in the theory of speech acts*. Cambridge: Cambridge University Press.
Segaert, K., Kempen, G., Petersson, K. M., & Hagoort, P. (2013). Syntactic priming and the lexical boost effect during sentence production and sentence comprehension: An fMRI study. *Brain and Language, 124*, 174–183.
Singmann, H., & Kellen, D. (2020). An Introduction to Mixed Models for Experimental Psychology. In D. H. Spieler, & E. Schumacher (Eds.), *New Methods in Cognitive Psychology* (pp. 4–31). New York: Routledge.
Tanaka, M. N., Branigan, H. P., Mclean, J. F., & Pickering, M. J. (2011). Conceptual influences on word order and voice in sentence production: Evidence from Japanese. *Journal of Memory and Language, 65*, 318–333.
Van Gompel, R. P., Wakeford, L. J., & Kantola, L. (2023). No looking back: The effects of visual cues on the lexical boost in structural priming. *Language, Cognition and Neuroscience, 38*, 1–10.
Van Nice, K. Y., & Dietrich, R. (2003). Task sensitivity of animacy effects: Evidence from German picture descriptions. *Linguistics, 41*, 825–849.
Vernice, M., Pickering, M. J., & Hartsuiker, R. J. (2012). Thematic emphasis in language production. *Language and Cognitive Processes, 27*, 631–664.
Vigliocco, G., & Nicol, J. (1998). Separating hierarchical relations and word order in language production: Is proximity concord syntactic or linear? *Cognition, 68*, 13–29.
Yan, H., Martin, R. C., & Slevc, L. R. (2018). Lexical overlap increases syntactic priming in aphasia independently of short-term memory abilities: Evidence against the explicit memory account of the lexical boost. *Journal of Neurolinguistics, 48*, 76–89.

Ziegler, J., & Snedeker, J. (2018). How broad are thematic roles? Evidence from structural priming. *Cognition, 179*, 221–224.
Zhang, C., Bernolet, S., & Hartsuiker, R. J. (2020). The role of explicit memory in syntactic persistence: Effects of lexical cueing and load on sentence memory and sentence production. *PLoS One1, 15*, e0240909.
Ziegler, J., Bencini, G. M., Goldberg, A. E., & Snedeker, J. (2019). How abstract is syntax? *Evidence from structural priming. Cognition, 193*, Article 104045.