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Priming the Arabic dative: Evidence for syntactic abstractness and implicit learning

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Language speakers are more likely to reuse a recently experienced syntactic structure, a phenomenon known as syntactic priming. However, empirical evidence for syntactic priming comes primarily from a small subset of Indo-European languages. Using a comprehension-to-production priming task, this preliminary study examined immediate and cumulative syntactic priming in Arabic, a language with a different typology than studied thus far. Nine native speakers of Arabic were primed to the Arabic double object (DO) dative construction. Results from a logistic regression model indicate that there were significant priming effects across all priming phases, with increased productions of the DO dative (a) during the priming task, (b) immediately after, (c) and 2 weeks later. These findings provide some support for the proposal that syntactic priming arises from an abstract syntactic level as well as the idea that priming is a form of implicit learning.

KEYWORDS

syntactic priming, Arabic priming, dative priming, priming in production, implicit learning, language production

Introduction

One robust psycholinguistic finding is that language users tend to reuse a syntactic structure that has been recently encountered or produced (Mahowald et al., 2016). In other words, someone who has just read or uttered a sentence that employs a passive voice construction like "the cake was eaten by Mary," is more likely to produce another passive construction in their next utterance than an active structure. This phenomenon is known as syntactic priming or structural priming (Pickering and Ferreira, 2008), and has garnered researchers' attention since Bock's landmark work in the mid-1980s (1986). It has been empirically observed for different syntactic alternations, including the dative alternation "The seller gave the farmer the potatoes vs. the seller gave the potatoes to the farmer" (Rowland et al., 2012; van Gompel et al., 2022), the passive/active alternation

"the man is pushing the box vs. the box is being pushed by the man" (Bidgood et al., 2020; Messenger, 2021), the fronted/non-fronted adverbial phrase "In the park, the dog chased the cat vs. the dog chased the cat in the park" (Ruf, 2011; Coumel et al., 2022), and the transitive/intransitive constructions "Lisa dropped the ball to the floor vs. the ball dropped to the floor" (Bidgood et al., 2021). Another type of evidence for syntactic priming comes from the analysis of natural conversational speech (Jaeger and Snider, 2008, 2013; Chia et al., 2020).

However, most of the established properties of syntactic priming are based on evidence from studies conducted on a small group of typologically similar languages such as Dutch (Bernolet and Hartsuiker, 2010; Segaert et al., 2013; Bernolet et al., 2014, 2016; Zhang et al., 2020, 2022; Chen and Hartsuiker, 2021), German (Pappert and Pechmann, 2013, 2014; Chang et al., 2014; Köhne et al., 2014), as well as English (Savage et al., 2006; Bock et al., 2007; Santesteban et al., 2010; Kaschak et al., 2011a; Kidd, 2012; Rowland et al., 2012; Bunger et al., 2013; Jaeger and Snider, 2013; Tooley and Bock, 2014; Branigan and McLean, 2016; Branigan and Messenger, 2016; Hardy et al., 2017, 2020; Carminati et al., 2019; Litcofsky and van Hell, 2019; Bidgood et al., 2020; Chia et al., 2020; Messenger, 2021; Heyselaar and Segaert, 2022; van Gompel et al., 2022). Interestingly, sometimes findings differ even between closely related languages. For example, Chang et al. (2014) reported that structural priming is sensitive to the verb's tense, aspect, and position in German but not in English. Chang et al. (2014) primed German speakers to Prepositional object (PO) and Double object (DO) dative sentences. Half of these sentences included verbs in the second-order position "Die Großmutter schickt ihrem Enkel ihr Testament" which had a present or simple past tense, and the other half presented verbs in the final position "Die Großmutter wird ihrem Enkel ihr Testament schicken" which had a perfect or future tense. When participants heard a prime with a final verb and then were asked to produce a verb final target sentence, they tended to reproduce the prime structure with a verb final order. Likewise, primes with a verb in a second-order position tended to increase priming for targets with a second-order verb. Chang et al. (2014) found that there were larger priming effects when the verb position was the same in the prime and target sentences. Nevertheless, no verb-position effect was reported in earlier English findings (Pickering and Branigan, 1998). More recent research also indicates that structural priming in Japanese follows different trends from what is observed in English (Chang et al., 2022).

Taken together, these studies suggest that it is likely that syntactic priming is influenced by different factors in different languages. These differences call for further investigation of structural priming in typologically different languages. Attention to cross-linguistic variation in syntactic priming will be critical to the development of accurate priming models. This study provides two main contributions to our understanding of syntactic priming. First, it expands the evidence base for the syntactic priming literature by examining a typologically different language than investigated so far, namely Arabic. One consistent finding in the literature is that syntactic priming effects arise largely due to the repetition of abstract linguistic structure, not because the prime and target share lexical items, a phonological structure or semantic information (Mahowald et al., 2016; Branigan and Pickering, 2017). Until there is evidence drawn from a much larger subset of languages, however, the universality of such claims for the abstractness of syntactic priming effects remains limited (e.g., Branigan and Pickering, 2017). Second, it tests the proposal that syntactic priming is a form of implicit learning for speakers of Arabic by examining priming effects in a 2-week delayed post-test.

Literature review

Structural priming models

The many models that have been proposed to explain the mechanism underlying syntactic priming can be divided into three groups: (a) lexicalist models, (b) connectionist (or implicit) learning models, and (c) hybrid models. One prominent lexicalist model is the residual activation model that explains priming in terms of activation at the lemma stratum (Pickering and Branigan, 1998). For instance, suppose that a language speaker encounters the verb "give" in a DO construction like "he gave the buyer the book" and shortly after is asked to use "give" in a sentence. The residual activation model explains that speaker's increased likelihood to use "give" in a DO structure over an alternative that uses a PO construction like "the swimmer gave the towel to the boy" as the effect of the activation of the verb lemma "give" along with its combinatorial nodes (NP + NP) in the speaker's memory. This activation rapidly decays, and lexicalist models are consistent with findings about the lexical boost effect, i.e., structural priming is stronger when lexical items are repeated in the prime and target sentences (Hartsuiker et al., 2008; Rowland et al., 2012; Branigan and McLean, 2016; Scheepers et al., 2017; Carminati et al., 2019; Zhang et al., 2020). Nevertheless, the residual activation model fails to explain how priming effects persist over time (e.g., over many trials, several days, weeks), a finding that is also well-established (Savage et al., 2006; Hartsuiker et al., 2008; Jaeger and Snider, 2008; Kaschak et al., 2011b, 2014; Branigan and Messenger, 2016; Kaan and Chun, 2017; Kutta et al., 2017; Messenger, 2021; Coumel et al., 2022).

The implicit learning model is an alternative to the lexicalist model and explains priming as a form of learning (Chang et al., 2006, 2012; Chang and Fitz, 2014). Chang et al. (2006) used a Recurrent Neural Network (RNN) and trained it to predict the next word in a sentence. The RNN model encountered a large number of English-like sentences, and over time, the model became better at predicting the actual input. It was

observed that the model eventually adjusts its predictions with each experience of a syntactic structure. Adjustments occur when there is a mismatch between the predicted and observed input, i.e., when there is a prediction error. Based on their findings from the computational model, Chang et al. (2006) proposed that priming occurs because language users use an error-based implicit learning mechanism. Error-based implicit learning happens when a language user makes predictions about the following words. When this prediction does not match the actual linguistic input, then a prediction error occurs, making the language speaker adjusts or updates her prediction in the direction of the input.

The following example illustrates how implicit learning gives rise to syntactic priming. Most English speakers are more likely to read, hear and produce ditransitive events (e.g., give, buy, award) using a DO structure (e.g., the mother gives the child an apple) than a PO structure (e.g., the mother gives an apple to the child). As such, English speakers expect a ditransitive event to be expressed using the DO dative. According to the implicit learning account, if English speakers encounter a ditransitive verb in a PO sentence, they will experience a prediction error. This prediction error is the result of a mismatch between what was expected (a DO structure) and what was actually observed in the input (a PO structure). This prediction error will lead speakers to adjust their expectations of ditransitive events so that they would expect to encounter a PO structure in subsequent sentences. Adjustment of expectations (i.e., learning) occurs each time when a language comprehender encounters a less expected structure. These changes in expectations are believed to be implicit, occurring without the awareness of the speaker. Thus, when syntactic priming studies present participants with less frequent structures (causing more prediction errors), the participants are thought to experience implicit error-based learning, leading to a priming effect.

The implicit learning model largely fits well with experimental data. First, it could explain the observed persistence of structural priming effects over days and weeks (as cited above) since it hypothesizes that structural priming is a case of learning A second strength of this approach is that it could also explain immediate abstract priming effects, which occur when people use the prime structure in the next utterance quickly after being exposed to that structure without the presence of a lexical overlap between the prime and target (e.g., Jaeger and Snider, 2013). Despite the advantages of the implicit-learning model, it falls short in accounting for the lexical boost effect in syntactic priming. Unlike abstract priming effects, the lexical boost effect is transient and decays rapidly.

The difference between abstract and lexically-mediated priming effects has been explained by subsequent hybrid accounts (Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020; Heyselaar et al., 2021). Hybrid accounts posit that two mechanisms underlie syntactic priming. One mechanism explains short-lived lexically-mediated priming effects (the lexical boost effect), and the second tackles long-term abstract priming. Most hybrid approaches maintain that the two mechanisms belong to different memory systems (Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020), while some view them as components of the same memory system (Heyselaar et al., 2021). For instance, Hartsuiker et al. (2008) proposed that short-lived priming is due to a spreading activation mechanism while the longer-term abstract priming arises from an implicit learning mechanism. The spreading activation mechanism is thought to rely on the explicit memory system, whereas the learning mechanism is carried out by the implicit memory system. A similar proposal is put forward by Reitter et al. (2011) and Segaert et al. (2016) as well as Zhang et al. (2020). On the other hand, Heyselaar et al. (2021) non-declarative based model posits that short-term lexically mediated priming is supported by the perceptual memory component in the non-declarative memory system, while long-term abstract priming is supported by the conceptual memory component in the same system. Heyselaar et al. (2021) model offers a simpler explanation than the earlier hybrid accounts which proposed a role for both declarative and non-declarative memory systems.

Most of the reviewed syntactic priming models agree on two points. First, almost all existing priming accounts suppose that there is an independent syntactic representation layer in language processing (Pickering and Branigan, 1998; Chang et al., 2006; Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020; Heyselaar et al., 2021). Second, all of these accounts, except for the residual activation account, posit a role of implicit learning in syntactic priming.

Related empirical research

Existing data on syntactic priming are heavily influenced by the properties of the limited number of predominantly Indo-European languages on which research has been conducted, primarily English, Dutch, and German. Although in the past 5 years several priming studies have added to our understanding by investigating a small range of typologically distinct languages, namely Mandarin (Chen et al., 2019; Wang et al., 2020; Zhang et al., 2021), and Japanese (Chang et al., 2022), there is still a need to consider other languages. Over the last three decades, several priming properties have been repeatedly observed in experimental research, including the abstractness and cumulativity of priming effects. The following will review related syntactic priming studies to assess whether such findings are supported across typologically distinct languages.

Abstract syntactic priming

A distinguishing property of syntactic priming is that it occurs without shared lexical, phonological, or semantic

information between the prime and target structures. Some have took this observation to argue that there is a syntactic representation independent from other linguistic levels (Branigan and Pickering, 2017). Under this modular view of syntactic representations, syntactic priming arises due to the presence of a separate syntactic level of representation which specifies the constituents' linear order and hierarchical relations. For instance, a PO dative utterance such as "the man gives the book to the woman" would have the syntactic representation: [S [NP] [VP [V] [NP] [PP [P] [NP]]]]. This modular approach holds that language speakers store an abstract "syntactic level of representation includes syntactic category information, but not semantic information (e.g., thematic roles) or lexical content" (Branigan and Pickering, 2017, pp. 24–25). Several pieces of evidence suggest that it is the abstract syntactic representation that leads to syntactic priming without an additional contribution from the other linguistic levels. In a pioneering study, Bock (1986) asked participants to repeat sentences in the active or passive structure and then required them to describe pictures showing transitive events. There was a higher likelihood to use an active target sentence (e.g., the cat chased the mouse") after repeating an active prime sentence ("the farmer killed the duckling") than after repeating a passive ("the duckling was killed by the farmer"). These findings suggest a separate syntactic representation responsible for priming and are confirmed by works on such Indo-European languages as English (Messenger et al., 2012; Rowland et al., 2012; Branigan and Messenger, 2016; Hardy et al., 2020), German (Chang et al., 2014), Dutch (Hartsuiker et al., 2008; Bernolet et al., 2016), French (Coumel et al., 2022), and Italian (Vernice and Hartsuiker, 2019) as well as Mandarin (Huang et al., 2016; Chen et al., 2019).

Since priming is observed when there is no lexical overlap, one can argue that the speaker has abstract syntactic representations. Priming works in English (Rowland et al., 2012; Tooley and Bock, 2014; Hardy et al., 2020; Foltz et al., 2021), Dutch (Hartsuiker et al., 2008; Segaert et al., 2013), and French (Coumel et al., 2022) found that syntactic priming during language production occurs due to structure repetition alone while holding lexical information constant. Yet, the magnitude of abstract syntactic priming increases when lexical items overlap in the prime ("the cat chased the mouse") and target ("the dog chased the boy"), a finding known as the lexical boost effect. The lexical boost effect has been observed in Indo-European languages when the prime and target share verbs (Schoonbaert et al., 2007; Hartsuiker et al., 2008; Rowland et al., 2012; Branigan and McLean, 2016; Scheepers et al., 2017; Carminati et al., 2019; Weber et al., 2019), nouns (Ruf, 2011; Scheepers et al., 2017), and adverbial phrases e.g., in winter/in the garden (Ruf, 2011; Coumel et al., 2022). However, this lexical boost rapidly decays, disappearing after one or two intervening filler sentences between the prime and target (Hartsuiker et al., 2008; Branigan and McLean, 2016).

Although the lexical boost effect dissipates quickly, the lexically-dependent syntactic priming effect suggests the impact of the word level on the abstract syntactic level. The strong modular view of syntactic representations outlined above suggested that other linguistic levels play no role in the syntactic layer. How can this strong approach, then, account for the observed lexical boost effect? A more lenient modular version was put forward by Branigan and Pickering (2017) to explain the lexical boost effect while taking into account the independence of syntactic representations. Branigan and Pickering (2017) suggested that there is an intermediate layer that "encodes a binding between constituent structure and the lemma (syntactic component) of the lexical entry for the head" (p. 36). Under a lenient modular view of syntactic representations, the utterance "the man gives the book to the woman" would have the following representation: [V[give] NP PP]VP where the verb lemma "give" is included in the syntactic layer. The lemma is an abstract syntactic component that does not encode the word's semantic and phonological information. The lenient modular version still maintains that there is a separate syntactic layer for sentences but adds that this layer may interact with syntactic heads such as the verb for a verb phrase.

Syntactic priming is observed even when phonological information changes (e.g., Bock and Loebell, 1990), with increased effects when there is a phonological similarity between the prime and target (i.e., the homophone boost). Studies on Dutch and Mandarin found a homophone boost to syntactic priming (Santesteban et al., 2010; Bernolet et al., 2012; Wang et al., 2020; Zhang et al., 2021), equivalent to the lexical boost effect. This suggests that abstract syntactic priming occurs based only on syntactic representations, but its magnitude increases with a homophone boost. A five experiment study by Santesteban et al. (2010) found stronger priming effects when the prime and target shared a homophone (prime: "the [cricket] bat that's red," target: "the bat [animal] that's red) than when there was no shared homophone (prime: "the pool that's red," target: "the bat [animal] that's red"). Similar effects were reported in research on Mandarin. For instance, Wang et al. (2020) found larger structural priming effects in Mandarin when the prime and target shared homophone verbs that were written using different characters (prime verb: 搬[ban1, carry], target verb: 颁[ban1, award]) as well as those written in the same character (prime verb: 扛[da3, fetch], target verb: 扛[da3, knit]). Zhang et al. (2021) also observed a homophone boost when verbs in prime and target shared segmental and tonal information but not the character (prime verb: 拖[tuo1], target verb: 脱[tuo1]).

The evidence is mixed when it comes to the influence of thematic roles and meaning on syntactic priming in different languages. While research on English (Messenger et al., 2012; Ziegler and Snedeker, 2018) and Mandarin (Huang et al., 2016; Chen et al., 2019) showed that syntactic priming is independent of semantic information, priming in Japanese was dependent on

sentence meaning (Chang et al., 2022). For instance, differences in animacy features did not play a role in syntactic priming in Mandarin (Chen et al., 2019), while differences in thematic roles did not impact syntactic priming in English (Messenger et al., 2012). In a study by Chen et al. (2019), Mandarin-speaking participants were primed to three structures: DO, typical PO and reversed animacy PO. A typical PO sentence includes an inanimate theme followed by an animate recipient (e.g., the nun posted the scripture to the master), whereas a reversed animacy PO includes an animate theme followed by an inanimate recipient (e.g., the nun gave the child to the temple). Results showed that reversed animacy PO was as successful as typical PO at priming both PO conditions. This suggests that animacy features did not affect the magnitude of priming. On the other hand, Messenger et al. (2012) primed English-speaking children and adults to the passive and active structures. Three verb types were used for both structures: agent-patient verbs (e.g., hit, bite, carry), experiencer–theme verbs (e.g., love, ignore, like) and theme-experiencer verbs (e.g., annoy, shock, surprise). Across two experiments, participants were more likely to repeat the prime syntax irrespective of verb type. For instance, agent-patient passives (e.g., a girl is being hit by a sheep) were as effective as theme-experiencer passives (e.g., a girl is being shocked by a sheep) and experiencer-theme passives (e.g., the girl is being loved by the sheep) at priming agent-patient passives. Together, these studies point to the presence of a separate syntactic representation in sentence processing that does not integrate semantic information.

However, Chang et al. (2022) recently challenged the claim that syntactic representations operate without semantics by manipulating meaning in DO priming in Japanese. In two experiments, the DO structure (e.g., "the postman delivers the housewife the craft beer") was primed by using two structure that are superficially similar to DO datives in terms of case marking but differ in their meaning, namely non-compositional idioms (e.g., "the fireman kept in mind the colleague's story"), and transitives (e.g., "the fireman recorded his colleague's story with the old man"). Whereas transitives primed the DO structure, the idioms did not. Chang et al.'s (2022) findings suggest that priming in Japanese may depend on the compositional meaning of transitive events and supports the call for more research on under-examined languages with different characteristics.

Cumulativity of syntactic priming

Another well-known characteristic of syntactic priming is that abstract syntactic priming effects could occur immediately and cumulatively. Immediate priming effects usually refer to when the speaker produces the target structure immediately following exposure to that structure. Immediate priming effects have been demonstrated experimentally in a number of studies on English and Dutch (Bernolet and Hartsuiker, 2010; Rowland et al., 2012; Bernolet et al., 2014; Carminati et al., 2019; Zhang et al., 2020). Cumulative priming effects describe when the speaker produces the target structure following repeated exposure to that structure in the experiment. Previous works have the reported the cumulativity of priming effects; an incremental increase in the magnitude of priming effects with increasing exposure to the prime structure (Hartsuiker et al., 2008; Jaeger and Snider, 2008; Kaschak et al., 2011a; Ruf, 2011; Bernolet et al., 2016; Branigan and Messenger, 2016; Kaan and Chun, 2017; Kutta et al., 2017; Chen and Hartsuiker, 2021; Messenger, 2021; Coumel et al., 2022).

One study that reported cumulative priming effects is Kaan and Chun (2017) who examined the priming of DO (e.g., The clown showed the cowboy the hat) and PO datives (e.g., The clown showed the hat to the cowboy) among L1 and L2 speakers of English. Cumulative priming effects were defined as the increased production of the primed structure across task trials (i.e., the incremental increase of priming effects with each additional exposure to the primed structure within the experiment). Using a visual, written, web-based questionnaire, the two participant groups had to complete prime trials, which included images with sentence fragments that either forced a PO completion (The nurse gave the medicine.), a DO completion (The nurse gave the patient.), or intransitive sentences acting as fillers (e.g., The girl. . ..). In the target trials, participants had to complete a sentence fragment that did not force any type of completion (e.g., the clown showed. . ..). The results revealed cumulative priming effects for both alternate structures, with each speaker group showing larger effects for the less frequent alternation in their input. In other words, L2 English speakers, who were less experienced with the DO construction, demonstrated stronger priming effects for the DO dative, whereas the L1 English speakers, who were less exposed to the PO structure, showed stronger priming effects for PO construction. These findings are consistent with the inverse frequency effect observed by Jaeger and Snider (2008).

Cumulative priming effects were reported as well in Chen and Hartsuiker's (2021) study. The Dutch DO/PO structure containing particle verbs ("meegeven"/give to someone leaving, the equivalent root verb: "geven"/give) were primed in three comprehension-to-production priming experiments. There were stronger cumulative priming effects when the same verb appeared (meegeven-meegeven) in the prime and target compared to a partial overlap in root (geven-meegeven) or particle (meebrengen-meegeven). Such cumulative priming effects could persist for 1 week (Kaschak et al., 2011b, 2014; Branigan and Messenger, 2016), 1 month (Savage et al., 2006), and even for 9 months (Kroczek and Gunter, 2017).

The present study

The existing literature on syntactic priming indicates that what contributes to syntactic priming is likely different in

different languages and that the long-term effects of priming are also likely part of learning. The present study aims to answer the two research questions:

1) Are there abstract priming effects in Arabic?
2) Can syntactic priming effects in Arabic be sustained for 2 weeks?

The first question investigates the supposed universalism of abstract syntactic priming by investigating the phenomenon in Arabic. Most existing priming accounts posit that an abstract syntactic layer is implicated in syntactic priming (Pickering and Branigan, 1998; Chang et al., 2006; Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020; Heyselaar et al., 2021). However, these models are largely informed by findings from a small group of languages, and it is still unknown whether the abstractness of syntactic priming is shared across typologically different languages. Modern Standard Arabic (MSA) has a flexible word order due to its rich inflectional morphology (Ryding, 2005). For this reason, the DO structure in MSA can have a canonical order or a scrambled one (Al-Jadani, 2016) as demonstrated in the following examples:

1. (a) a'ṭa al-rajul-u al-sadiq-a al-kitab-a (canonical)
   Give-past the man-nominative the friend-accusative the book-accusative
   The man gave the friend the book

1. (b) a'ṭa al-rajul-u al-kitab-a al-sadiq-a (scrambled)
   Give-past the man-nominative the book-accusative the friend-accusative
   *The man gave the book the friend.

Both DO word orders are acceptable in MSA, but only the canonical order is acceptable in English. It should be noted that the dative alternation in MSA has two main structures: DO (canonical and scrambled) as well as PO, which is signaled by the preposition li-, equivalent to the English "to" preposition (Ryding, 2011). Canonical and scrambled DO sentences do not include the preposition li-. The examples also show that syntactic function in the Arabic DO structure is tied to case-marking and not to position in the sentence. In contrast, syntactic function in English is largely tied to position. It is worthwhile to investigate whether abstract priming occurs in the Arabic canonical DO structure in line with what was observed in other languages. The second question tests the validity of the implicit learning model (Chang et al., 2006) that explains syntactic priming as a learning mechanism. Based on the implicit learning account, it is hypothesized that DO priming effects will persist for 2 weeks among Arabic speakers.

Materials and methods

Participants

This study recruited nine native Arabic-speaking participants with a mean age of 28 (SD = 4.8, range = 23–38) all of whom were college graduates. Three participants were males, and six were females. Convenience sampling was used to recruit native speakers through text messages and emails. Only nine of the contacted native speakers (N = 51) showed interest in the study. A small sample size was used due to limited time and funding. All participants were informed about the task, and their consent was obtained prior to completing the task.

Materials

The priming task

A visual comprehension-to-production syntactic priming was designed and administered using the online experiment builder Gorilla.sc (Anwyl-Irvine et al., 2020). A web-based picture description syntactic priming was used to increase the level of control on the participants' production (McDonough and Trofimovich, 2009). Unlike the confederate priming technique (e.g., Messenger et al., 2012), a web-based priming task does not involve a face-to-face interaction between an interlocutor and the participant, minimizing intervening talk during the task. A web-based priming task provides relatively higher control on what the participant would produce compared to the confederate priming technique. The full sentence stimuli and R scripts can be found at https://osf.io/jsp49/.

The priming task had four phases: a baseline phase, a priming phase, an immediate post-test, and a delayed post-test. The priming task started with a short practice session to familiarize participants with the task. The three priming phases, the baseline, priming, and the immediate post-test were completed as a single continuous task in one setting. Thus, the participants would not be aware that they completed three different priming phases, a common practice in syntactic priming research (e.g., Coumel et al., 2022).

The baseline phase asked participants to describe pictures using ditransitive verbs that allow both PO and DO completions without hearing experimental prime sentences that contain the target DO structure. Existing works suggest that the PO structure is more common in MSA literature than the DO structure (Wilmsen, 2012). Thus, only the DO structure was primed to elicit observable priming effects in the task. The baseline phase assessed participants' preferences for using PO or DO to describe a ditransitive event. The second phase had participants both hear and read DO prime sentences and then were asked to describe a picture with the target structure. The immediate post-test was completed immediately after the priming phase and asked participants to describe target pictures

without the experimental DO primes to assess cumulative priming effects. The delayed-post-test was administered 2 weeks after the priming phase. In the delayed post-test, participants described pictures without hearing DO primes, similar to what was done in the baseline and immediate post-test. The delayed post-test assessed long-term cumulative priming effects.

A 2-week time interval between the priming task and the delayed post-tests is an optimal time span to measure cumulative priming effects without compromising on participant attrition, a methodological challenge common in longitudinal studies that limits the generalizability of results because the characteristics of participants who drop out are likely to differ from those who complete the study (Gustavson et al., 2012).

Sample trials for the priming task are provided in **Figures 1**, **2**. There were two task conditions which differed only in the priming phase. During the priming phase, participants in condition 1 were asked to predict the language production of a virtual native Arabic speaker called "Sara" (e.g., Grüter et al., 2021), whereas participants in condition 2 were not asked to predict. In the other task phases, participants in both conditions had to do the same task: write a picture description using the target DO structure. Six participants completed condition 1, and only three completed condition 2. Both conditions had similar DO production frequencies across the four phases (condition 1 = 140, condition 2 = 69) considering the number of participants in each condition. The combined results from the two conditions were analyzed since the participants performed similarly across these conditions.

Sentence stimuli

Sentence stimuli were specifically designed for this study following previous research practice (e.g., Branigan and Gibb, 2018; Jackson and Hopp, 2020). A list of 24 Arabic ditransitive verbs that accept both DO and PO completions was created based on previous lists (Mahmoud, 2006; Al-Jadani, 2016) and by consulting Arabic dictionaries. Thirty-six experimental and 62 filler sentences were created that each used four words. Only the canonical DO structure was primed, and the target trials could elicit canonical DO, scrambled DO, or PO. Six DO verbs were used three times throughout the task phases: once in the baseline (6 sentences), another in the immediate post-test (6 sentences), and once again in the delayed post-test (6 sentences) due to the limited number of Arabic DO verbs that accept both DO and PO completions. The repeated six double-object verbs were used each time with different arguments to mitigate practice effects (e.g., Grüter et al., 2021; Coumel et al., 2022). No verbs or any lexical items were shared between the experimental sentences in the same phase to minimize lexical overlap effects. All subjects and indirect objects were animate and definite, while all direct objects were inanimate and (in)definite in the experimental sentences (e.g., Jackson and Hopp, 2020). The filler four-word sentences had either transitive or intransitive verbs which had all animate subjects. Thirty-one (in)transitive verbs were used twice in the filler sentences to detract the participants' attention from the repeated DO structure. Each filler verb appeared only once in each task phase. Sentences were pseudo-randomized so that each experimental sentence is followed by one or two fillers.

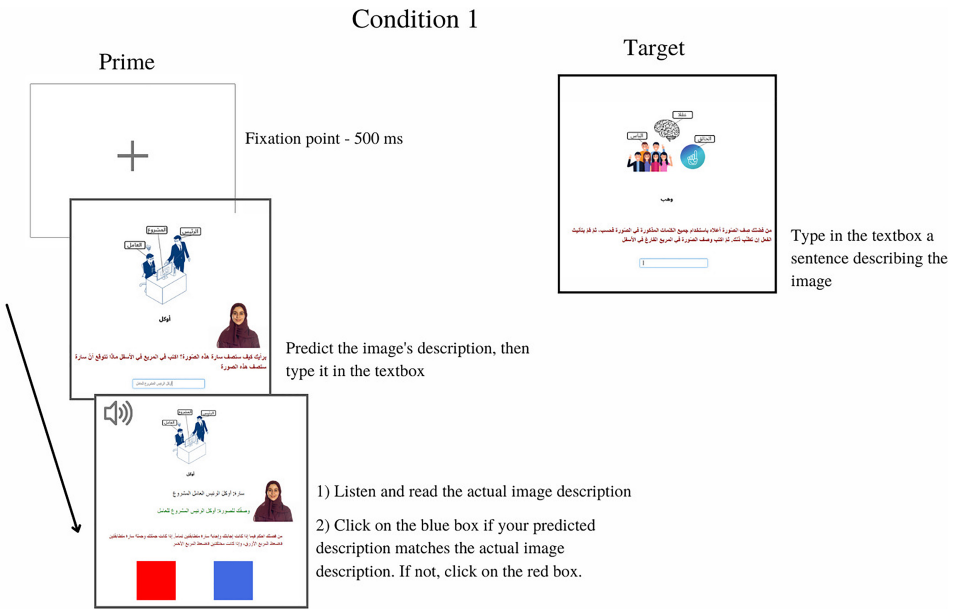

FIGURE 1
A sample trial from condition 1. Progress is self-paced.

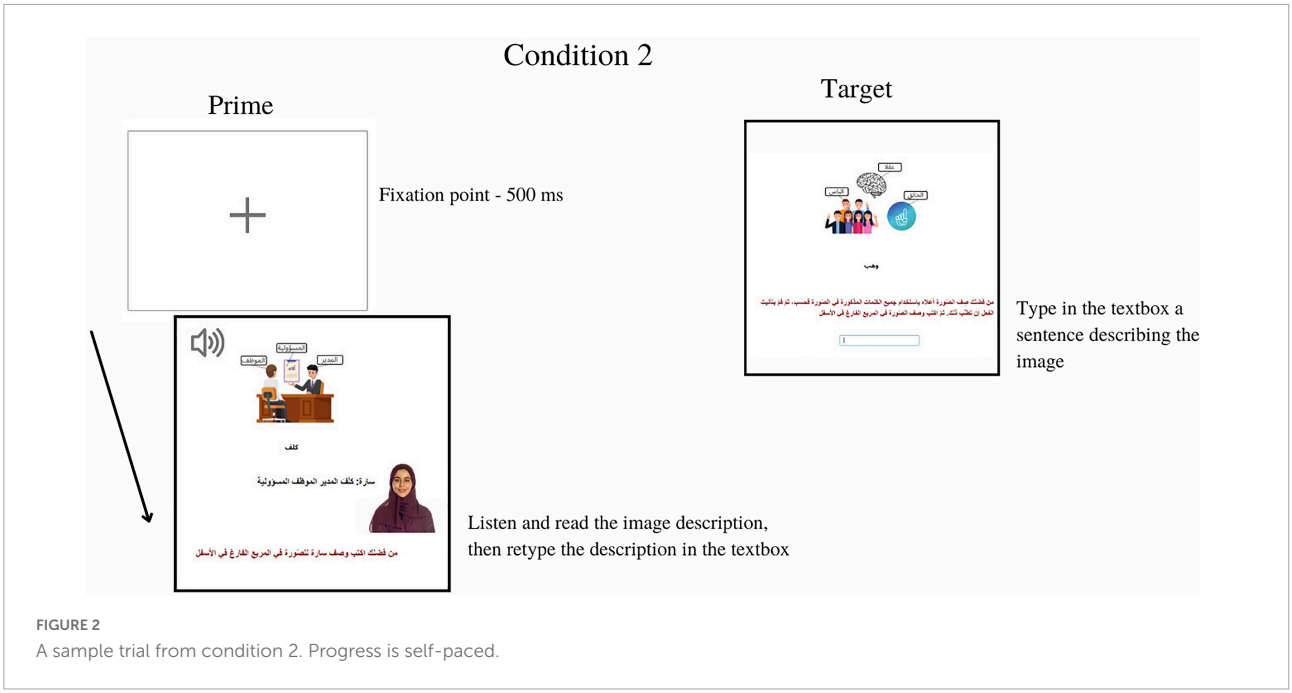

FIGURE 2
A sample trial from condition 2. Progress is self-paced.

Picture and audio stimuli

The priming task included both pictures and audio stimuli. Colored clip-are images illustrating the meaning of each experimental and filler sentence were constructed. All the pictures in the priming task were labeled with the appropriate vocabulary, with the infinitive form of the verb included in bold below each picture to limit the production of unrelated structures (Branigan and Gibb, 2018). The infinitive form of verbs in Arabic is also the 3rd person, singular, masculine, past tense of the verb; thus, participants were required to mark the verb for gender whenever the subject was feminine. The position of the agent, them, and recipient was not counterbalanced in the pictures since DO priming studies do not control for this effect (e.g., Grüter et al., 2021; experiment 3 in Jaeger and Snider, 2013; Kaschak et al., 2014; Peter et al., 2015) while passive priming studies usually do (Messenger et al., 2012; Heyselaar and Segaert, 2022). As for audio stimuli, all prime sentences were voice-recorded by a professional female native Arabic speaker who was instructed to use MSA and to read the sentences as naturally as possible.

Procedure

Participants were individually emailed a link to the Gorilla-hosted experiment and were asked to start the task as soon as possible. The experiment began with general instructions introducing participants to the task which were as follows: "In this experiment, you will be asked to write a sentence describing the image that will appear on your screen. You will see several images in this experiment. For example, you might see an image of 'a boy drinking juice' like the one appearing on the left of this screen. As you can see, the components of this image are labeled with the appropriate vocabulary. All the images in this experiment will be like this one. In addition to seeing images, you will sometimes listen to a female speaker called 'Sarah' who will orally describe some of the images." Then, participants had to complete two practice trials. A priming trial started with a fixation point in the center of the computer screen lasting for 500 ms. A step-by-step description of the sequencing of the two conditions is presented next.

In Condition 1, the priming trial consisted of three additional screens. In screen one, participants saw a labeled image and were asked to guess how "Sarah" would describe it. When participants have finished typing the image description into a textbox, they pressed enter to progress to the next screen. In screen two, participants simultaneously heard and read the prime sentence. Also, participants saw their image description sentence and Sarah's actual description and were subsequently asked to "judge whether your sentence and Sarah's sentence are exactly the same. Click on the blue box if the two sentences are exactly the same. Click on the red box if they are different." This remained on screen until participants clicked on either box to progress to the next screen. In screen three, participants saw only a labeled image and were asked to type their own description into a textbox. When finished typing, participants pressed enter to go to the next priming trial.

In condition 2, the priming trial consisted only of two additional screens. In screen one, a labeled image was shown, and participants simultaneously heard and read the prime sentence. While the written prime sentence remained on screen,

participants were asked to retype the prime sentence in the textbox and press enter to move to the next screen. In screen two, similar to condition 1, participants were shown a labeled image and were asked to type a description into a textbox. Then, participants pressed enter to progress to the remaining trials.

Across both conditions, it took participants 25 min to complete the first three phases of the task and approximately 7 min to complete the delayed priming phase.

Coding and analysis

The variables were coded as follows. The "DO" dependent variable consisted of dummy codes (1, 0). Participants' productions of DO in target trials were coded 1 while productions of other structures were coded 0. The independent variable "phase" was dummy coded with the baseline phase as the reference level. The independent variable "condition" was contrast coded such that "condition 1" was coded as −0.5 and "condition 2" as 0.5. Analysis was conducted in RStudio version 4.0.3 (R Studio Team, 2022) using lme4 package (Bates et al., 2015) and brglm package (Kosmidis and Firth, 2021). The glmer function in lme4 was used to create a binary logistic model with both fixed and random effects. Demographic data were not included in the model because most participants (n = 6) had similar background profiles (college graduates in their mid-twenties). The regression model was created using the maximal approach. A maximal approach to model fitting calls for adding all fixed effects and their interactions, random effects, as well as all random intercepts and slopes justified by the study design (Barr et al., 2013). The simplest maximal model was determined by Akaike's Information Criteria (AIC) scores which included priming phases and condition as fixed effects and random intercepts for participants and items. Condition was added as a fixed effect in the lme4 model to establish that it did not produce any confounding effects.

Results

Table 1 presents the proportion of DO sentences produced by participants in target trials across the four phases. The production of DO sentences was moderate at baseline [M = 0.51, SD = 0.50, *95% CIs* = (0.37, 0.65)], then sharply increased in the priming phase [M = 0.94, SD = 0.24, *95% CIs* = (0.88, 0.99)], reaching a peak in the immediate post-test phase [M = 1, SD = 0.00, *95% CIs* = (1, 1)]. DO production slightly dropped but remained steady in the 2-week delayed post-test [M = 0.96, SD = 0.19, *95% CIs* = (0.91, 1)].

The likelihood of producing a DO (dummy coded) was analyzed in a mixed-effects logistic regression model with task phase (dummy coded) as well as condition (contrast coded) as fixed effects and participants and items as random effects.

TABLE 1 Proportion of DO responses in target trials across the task phases.

Phase	DO production	Non-DO production	
		PO	Other
Baseline	27	26	1
Priming	76	5	0
Immediate post-test	54	0	0
Delayed post-test	52	2	0

Odds ratio was reported as an effect size metric for the fixed effects coefficients. The performance of the model was measured using the function "r.squaredGLMM" in the MuMIn package (Barton, 2019) which calculated marginal pseudo-R^2 (R^2m) and conditional pseudo-R^2 (R^2c) values. R^2m accounts for the variance explained by the fixed effects, while R^2c accounts for the variance explained by both the fixed and random effects. Higher pseudo-R^2 values indicate a better model performance.

The fitted model is presented in **Table 2**. Overall, the fixed effects in the model explain 92% of the variation in the dependent variable, whereas the fixed and random effects explain 95% of that variation. The table shows that there was a significant increase in DO sentence production in both the priming session (b = 3.66, $p < 0.001$) and the 2-week delayed post-test (b = 4.25, $p < 0.001$) compared to DO production in the baseline. However, there was no significant effect in the immediate post-test, which had as well extremely large Standard Errors (SE) (b = 22.1, SE = 563, p = 0.99). Further, there was no significant difference in the production of DO between condition 1 and 2 (b = 0.22, $p < 0.84$). The addition of participants and items as random effects slightly improved the model performance as indicated by the small difference between marginal and conditional pseudo-R^2 values (0. 92 vs. 0.95, respectively).

A reviewer suggested the addition of a random slope to reduce the large *SE*s for the immediate post-test phase. A random slope for task phases over participants was added to the random effects structure in another model. The new model still generated large *SE*s for the immediate post-test (b = 18.9, SE = 1,250, p = 0.98), and was not able to detect significant increases in DO production for this phase. Another way to handle this issue was to use the brglm R package (Kosmidis, 2020). The lack of a significant effect in the immediate post-test could be due to a separation problem that occurs in binary logistic regression models when one of the predictor variables has only one type of response, i.e., all 1 or all 0 responses (Mansournia et al., 2018). A look at the dataset suggests that all participants produced DO structures to describe target trials in the immediate post-test, leading to large estimates for this variable level. To solve the separation problem, another regression model was created using the "brglm" package

TABLE 2 Summary of the best-fit logistic regression model for DO production using lme4; glmer (N = 243).

	Fixed effects					Random effects			
						By subject		By item	
Parameters	**Estimate**	***SE***	***Z***	***p***	***OR***	**Variance**	***SD***	**Variance**	***SD***
Intercept	−0.07	0.63	−0.11	0.90	9.28	1.96	1.40	0.26	0.51
Phase 2 (baseline vs. priming)	3.66	0.72	5.03	<0.001	3.89				
Phase 3 (baseline vs. post-test)	22.1	563	0.00	0.99	4.03				
Phase 4 (baseline vs. delayed)	4.25	1.02	4.24	<0.001	7.07				
Condition 1	0.22	1.12	0.19	0.84	1.25				

Model formula: DO ~ phase + condition + (1| item) + (1| participant), control = glmerControl [optimizer = "bobyqa," optCtrl = list (maxfun = 2e5)], dativenativeitem, family = binomial. OR stands for Odds Ratio. R^2m = 0.92, R^2c = 0.95. AIC = 129.

which reduces large estimates for binary variables that lack variability in responses.

As shown in **Table 3**, the second fitted model for DO revealed that there was a significant effect for producing a DO structure in the immediate post-test (b = 4.65, p < 0.001) compared to the baseline. However, the brglm model is limited because it does not account for individual- and item-level variation (the brglm package does not support random effects). The glmer model explained 43% of the variation in the dependent variable, with a lower AIC score compared to the lme4 model [not advised to use methods of model comparison with brglm models (Kosmidis, 2020)]. Together, these values suggest that the lme4 model outperforms the brglm model. Yet, the non-inclusion of random effects in the brglm model might not have greatly affected its results since the random effects slightly contributed to the lme4 model. The lme4 model showed that the fixed effects alone explained a great deal of variation in the production of DO (R^2m = 0.92) and that the addition of random effects slightly improved the model performance (R^2c = 0.95).

Discussion

The aim of this study was to examine (a) whether abstract syntactic representations underlie syntactic priming in Arabic as it had been in Indo-European languages and (b) whether abstract priming in Arabic can be sustained for a long enough period of time to support the implicit learning model suggested by Chang et al. (2006).

There were significant DO-DO priming effects (a) during the priming task, (b) in the immediate post-test, and (c) in the 2-week delayed post-test compared to the baseline phase (all p < 0.001). The fact that the prime and target sentences in the current study did not share content words, meaning, or homophones suggests that the observed syntactic priming occurred due to similarity in the syntactic representation between prime and target sentences (DO prime: VP-NP-NP-NP, DO target: VP-NP-NP-NP). This finding is in line with previous works on Indo-European languages (Hartsuiker et al., 2008; Messenger et al., 2012; Rowland et al., 2012; Bernolet et al., 2016; Branigan and Messenger, 2016; Vernice and Hartsuiker, 2019; Hardy et al., 2020; Coumel et al., 2022) as well as on Mandarin (Huang et al., 2016; Chen et al., 2019) but differs from data on Japanese (Chang et al., 2022). The difference from Japanese data is because Chang et al. (2022) manipulated meaning in their experimental design, while no similar manipulation was done in the current study.

The present study extended the finding that syntactic priming arises from a distinct level of syntactic representation to Arabic. The priming task in the present study included prime and target sentences that shared the same DO structure but did not share lexical items or phonological aspects. For instance, the participants read the prime sentence "The aunt lent the girl a shirt" and then were asked to produce the target sentence "The dean handed the graduate a certificate." Although primes and targets did not overlap in lexical and phonological content, the thematic structure was the same across DO primes and targets: agent, followed by a recipient then a theme. Overlap in thematic structure may explain to some extent the DO priming effects during the priming phase in which the participants heard DO primes. However, this thematic overlap cannot explain the full range of priming effects including the effects found during the immediate and

TABLE 3 Summary of the best-fit logistic regression model for DO production using the "brglm" package (N = 243).

Parameters	**Estimate**	***SE***	***z***	***p***
(Intercept)	−0.02	0.28	−0.08	0.92
Phase 2 (baseline vs. priming)	2.61	0.51	5.04	<0.001
Phase 3 (baseline vs. post-test)	4.67	1.44	3.23	<0.001
Phase 4 (baseline vs. delayed)	3.02	0.70	4.30	<0.001
Condition 1	0.15	0.45	0.33	0.73

Model formula: brglm (DO ~ phase + condition, data = dativenativeitem, family = binomial). R^2m = 0.43. AIC = 138.

2-week delayed phases. Assuming the presence of a distinct syntactic level helps explain how Arabic-speaking participants successfully reproduced DO sentences in the immediate and delayed priming phases even though they did not encounter DO primes in these phases. Overall, the reported DO priming effects provide some support to the proposal that there is a level of abstract syntactic structure.

The idea that syntactic priming arises from an independent syntactic representation is assumed by the majority of priming models. Accounts that attribute syntactic priming to a spreading activation mechanism (Branigan and Pickering, 2017), an implicit learning mechanism (Chang et al., 2006), or to both mechanisms (Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020; Heyselaar et al., 2021), posit that speakers create a syntactic layer for utterances. The observation that the Arabic-speaking participants created an abstract syntactic representation to encode the syntax of the prime is compatible with most existing priming accounts. Although these priming models suggest that there is a syntactic layer, they do not specify whether this layer is purely independent or partially interactive with the other linguistic layers (except for the pro-independence residual activation account). As such, the observed DO priming effects provide tentative support for the general view that speakers build syntactic representations of experienced sentences but could not provide support for more nuanced views on this issue (purely independent, partially interactive).

It also extends findings on abstract syntactic priming by showing that increased syntactic priming effects occur even when the exposure is not mixed (all experimental primes were DO) rather than the usual presentation of two structure alternations (e.g., PO and DO) in prime trials (e.g., Rowland et al., 2012; Bernolet et al., 2016; Coumel et al., 2022). Increased priming effects when the exposure is not mixed cannot be the result of a carryover effect, with improved performance in subsequent phases due to awareness of the purpose of the task. Participants were asked after task completion whether they could name, describe, give examples of the structures encountered in the task, but none reported noticing the repetition of the DO structure.

This study also demonstrated the durable effect of abstract syntactic priming. The participants significantly increased their use of the primed DO structure during the task (immediate effects) and sustained this increase in the immediate phase (cumulative effects) and up to 2 weeks, as was shown in the delayed priming phase (cumulative effects). The observed immediate priming provides evidence for abstract immediate priming effects in Arabic, supporting previous findings on English and Dutch (Bernolet and Hartsuiker, 2010; Rowland et al., 2012; Bernolet et al., 2014; Carminati et al., 2019; Zhang et al., 2020). Likewise, there were durable cumulative priming effects for the Arabic DO dative, a finding that is compatible with the implicit learning account for syntactic priming (Chang et al., 2006). This account predicts that syntactic priming is a form of implicit, unconscious learning of the prime structure.

This potential explanation fits well with the observed persistence of DO productions for 2 weeks. This finding is line with previous priming in comprehension and production studies (Savage et al., 2006; Kaschak et al., 2011a,b, 2014; Branigan and Messenger, 2016; Kroczek and Gunter, 2017). The present work supports the idea that syntactic priming involves a type of implicit learning by changing speakers' structural preferences to align with what is observed in the input, indicating that language users can rapidly adapt to the surrounding linguistic context. This suggests that what underlies syntactic priming is the same across unrelated languages: English (Savage et al., 2006; Kaschak et al., 2011b, 2014), German (Kroczek and Gunter, 2017), and Arabic.

Therefore, a second contribution of this study is that it provided evidence for the claim that implicit learning derives syntactic priming in Arabic. The reported persistence of DO priming effects is predicted by the implicit learning account and hybrid priming models but not the residual activation account. Like the implicit learning account (Chang et al., 2006), all hybrid models maintain that there is an implicit learning mechanism involved in priming (Hartsuiker et al., 2008; Reitter et al., 2011; Segaert et al., 2016; Zhang et al., 2020; Heyselaar et al., 2021). Within hybrid accounts, it is proposed that abstract priming effects persevere over long periods of time because they involve changes to the syntactic representations stored in long-term memory (as part of the non-declarative memory system). The 2-week persistence of DO priming in the present study is accounted for by both the implicit learning account and hybrid models. On the other hand, the residual activation account (Pickering and Branigan, 1998) fails to explain this persistence since it predicts that the prime structure is stored in short-term memory. Without postulating a role for long-term memory in syntactic priming, the residual activation account cannot explain how the participants in the present study successfully reproduced the DO structure during the immediate priming phase and the 2-week delayed priming phase.

Another point to discuss is the interpretation of the immediate post-test results. This study reported that priming effects were robust in the immediate post-test phase although only the brglm model found these effects while the lme4 model did not. The lme4 model could not find an effect for this phase due to a separation problem which occurs when a predictor perfectly predicts the outcome (for a detailed review, see Mansournia et al., 2018). The descriptive analysis showed that participants only produced DO sentences during the target trials in the immediate post-test phase, but this was not the case in the other phases. Whereas lme4 does not cope with a

variable that has identical responses, the brglm model can cope well by generating bias-corrected estimates (for more technical details, see Kosmidis and Firth, 2021). Another reason for disregarding the lme4 results for this phase is the large SEs which usually indicate unreliable beta estimates (Levshina, 2015; Mansournia et al., 2018). Despite the difference between the two models' results, the study reported a significant effect for the immediate post-test phase since both descriptive data and the brglm model point to a significant increase in the production of DO in this phase.

Meanwhile, the participants' responses in the baseline phase could offer preliminary evidence for DO/PO bias in MSA. Descriptive data showed that there were 50% DO responses and about 50% PO responses in this phase. This baseline finding may indicate that there is no clear bias for the ditransitive verbs that accept both PO and DO structures. A previous corpus study (Wilmsen, 2012) indicated that PO is more preferred in written MSA literature, but this was not the case in the present study. This could be due to register differences. The corpus study analyzed MSA fiction while the present study examined the production of DO in MSA non-fiction writing. A second potential reason could be that the recruited Saudi MSA speakers are influenced by their Saudi-Arabic variety. It is possible that DO/PO preferences may differ among MSA speakers from different Arab countries due to the diglossic nature of Arabic, with the regional Arabic variety slightly affecting some features of the MSA used in that region. Together, these findings may suggest that the frequency of DO/PO structures may differ across different MSA registers with a potential regional effect.

Overall, one implication of the study findings is that syntactic priming is to some extent driven by similar factors (abstract syntactic representation, implicit learning) across languages with unique characteristics such as Indo-European languages (e.g., English, Dutch, German, Italian), Mandarin, and Arabic. Nevertheless, more works on other languages could shed light on different factors that are not present in previously examined languages. While current evidence hints at cross-linguistic similarity in the characteristics of syntactic priming, it is still too early to conclusively establish any universality claims about syntactic priming (e.g., Branigan and Pickering, 2017).

Limitations and future directions

This study is limited in several ways. First, a small number of participants completed the priming task in the current study, which reduces the statistical reliability of the results (Button et al., 2013). Future works should consider recruiting a larger number of participants to avoid this problem (for specific recommendations, see Mahowald et al., 2016). Second, the interactions of any linguistic level (semantic, phonological, lexical) with the syntactic level were beyond the scope of the present work. A promising avenue for further research will be to examine the interaction between two linguistic representation levels on the syntactic priming phenomenon since existing research suggests the presence of some language-specific connections between them (e.g., Chang et al., 2022). Third, most participants (6 out of 9) completed conditions 1 which includes an explicit prediction component that potentially increases priming effects (e.g., Grüter et al., 2021). Although there were no significant differences in priming effects between condition 1 and 2, the results reported here lack generalizability. Future works could avoid this issue by using a traditional priming repetition task. Finally, only the DO structure was investigated to test whether the DO structure findings from European languages do hold for unrelated languages such as Arabic. Other Arabic-unique constructions could exhibit different priming patterns from those reported in the present study. Future works should examine other Arabic-specific structures such the Arabic copula predicate (Al-Dobaian, 2006; Alharbi, 2017; Hardie and Ibrahim, 2021) to determine the generalizability of the current results.

A related topic is the limitations of web-based priming experiments. Conducting an online-based experiment rather than a lab-based one had several benefits and drawbacks. Benefits included increased flexibility in completing the task (anytime, anywhere), increased willingness to participate, reduced financial costs (no need to have an experiment-ready lab), and a shorter data collection period. Drawbacks included technical problems (internet connections issues), inability to ensure a uniform presentation of the trials (e.g., partial overlap between text and image on smaller computer screens), and potential participant inattentiveness. A progress bar was included in the present task to maintain participants' attention. Including comprehension questions that have to be correctly answered before proceeding with the task might have guaranteed better attention. Offering financial compensation may as well increase attention. A reviewer wondered whether different results could have been obtained if the task was completed in a lab. It is difficult to speculate about how much lab-based priming results would differ from online-based ones, and this would remain an open question for future research.

Conclusion

This preliminary work presented evidence that syntactic priming in Arabic, like the other investigated European languages, is motivated by the presence of an abstract syntactic representation of sentences and constitutes a form of implicit learning given its persistence for 2 weeks. More research is needed on Arabic and other non-European languages to assess the characteristics and mechanisms of syntactic priming. A universal account of syntactic priming with language-specific

constraints will only be possible when more investigation of more typologically different languages has been conducted.

Data availability statement

The materials and R scripts can be downloaded via the Open Science Framework at https://osf.io/jsp49/.

Ethics statement

The study was reviewed and approved by the Research Ethics Committee and the Institutional Review Board for Humanities at King Saud University. The participants provided their written informed consent to participate in this study.

Author contributions

AA contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript.

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Conflict of interest

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

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References

Al-Dobaian, A. (2006). A Minimalist analysis of three predicate types: lexical, functional, and null. *Linguist. Res.* 11, 28–52.

Alharbi, B. Y. (2017). *The Syntax of Copular Clauses in Arabic*. Ph.D thesis. Available online at: https://dc.uwm.edu/etd/1573/ (accessed July 6, 2022).

Al-Jadani, A. S. R. (2016). *Second Language Acquisition of the Dative Alternation in English and Arabic: A Bidirectional Study*. Ph.D thesis, Heslington: University of York

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., and Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behav. Res. Methods* 52, 388–407. doi: 10.3758/s13428-019-01237-x

Barr, D. J., Levy, R., Scheepers, C., and Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *J. Mem. Lang.* 68, 255–278. doi: 10.1016/j.jml.2012.11.001

Barton, K. (2019). *MuMIn: Multi-model inference. R package version 1.43.17. Computer software*. Available online at: https://cran.r-project.org/web/packages/MuMIn/index.html (accessed May 3, 2022).

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2015). Fitting-linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Bernolet, S., Colleman, T., and Hartsuiker, R. J. (2014). The "sense boost" to dative priming: Evidence for sense-specific verb-structure links. *J. Mem. Lang.* 76, 113–126. doi: 10.1016/j.jml.2014.06.006

Bernolet, S., Collina, S., and Hartsuiker, R. J. (2016). The persistence of syntactic priming revisited. *J. Mem. Lang.* 91, 99–116. doi: 10.1016/j.jml.2016.01.002

Bernolet, S., and Hartsuiker, R. J. (2010). Does verb bias modulate syntactic priming?. *Cognition* 114, 455–461. doi: 10.1016/j.cognition.2009.11.005

Bernolet, S., Hartsuiker, R. J., and Pickering, M. J. (2012). Effects of phonological feedback on the selection of syntax: Evidence from between-language syntactic priming. *Biling. Lang. Cogn.* 15, 503–516. doi: 10.1017/S1366728911000162

Bidgood, A., Pine, J., Rowland, C., Sala, G., Freudenthal, D., and Ambridge, B. (2021). Verb argument structure overgeneralisations for the English intransitive and transitive constructions: Grammaticality judgments and production priming. *Lang. Cogn.* 13, 397–437. doi: 10.1017/langcog.2021.8

Bidgood, A., Pine, J. M., Rowland, C. F., and Ambridge, B. (2020). Syntactic representations are both abstract and semantically constrained: Evidence from children's and adults' comprehension and production/priming of the English passive. *Cogn. Sci.* 44:e12892. doi: 10.1111/cogs.12892

Bock, J. K. (1986). Syntactic persistence in language production. *Cogn. Psychol.* 18, 355–387. doi: 10.1016/0010-0285(86)90004-6

Bock, J. K., Dell, G. S., Chang, F., and Onishi, K. H. (2007). Persistent structural priming from language comprehension to language production. *Cognition* 104, 437–458. doi: 10.1016/j.cognition.2006.07.003

Bock, J. K., and Loebell, H. (1990). Framing sentences. *Cognition* 35, 1–39. doi: 10.1016/0010-0277(90)90035-I

Branigan, H. P., and Gibb, C. L. (2018). "Structural priming," in *Research Methods in Psycholinguistics and the Neurobiology of Language: A Practical Guide*, eds A. M. B. de Groot and P. Hagoort (Hoboken: Wiley Blackwell), 130–150.

Branigan, H. P., and McLean, J. F. (2016). What children learn from adults' utterances: An ephemeral lexical boost and persistent syntactic priming in adult–child dialogue. *J. Mem. Lang.* 91, 141–157. doi: 10.1016/j.jml.2016.02.002

Branigan, H. P., and Messenger, K. (2016). Consistent and cumulative effects of syntactic experience in children's sentence production: Evidence for error-based implicit learning. *Cognition* 157, 250–256. j.cognition.2016.09.004 doi: 10.1016/j.cognition.2016.09.004

Branigan, H. P., and Pickering, M. J. (2017). An experimental approach to linguistic representation. *Behav. Brain Sci.* 40:e282. doi: 10.1017/s0140525x16002028

Bunger, A., Papafragou, A., and Trueswell, J. C. (2013). Event structure influences language production: Evidence from structural priming in motion event description. *J. Mem. Lang.* 69, 299–323. doi: 10.1016/j.jml.2013.04.002

Button, K. S., Ioannidis, J., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S., et al. (2013). Power failure: Why small sample size undermines the reliability of neuroscience. *Nat. Rev. Neurosci.* 14, 365–376. doi: 10.1038/nrn3475

Carminati, M. N., van Gompel, R. P. G., and Wakeford, L. J. (2019). An investigation into the lexical boost with nonhead nouns. *J. Mem. Lang.* 108:104031. doi: 10.1016/j.jml.2019.104031

Chang, F., Baumann, M., Pappert, S., and Fitz, H. (2014). Do Lemmas Speak German? A Verb Position Effect in German Structural Priming. *Cogn. Sci.* 39, 1113–1130. doi: 10.1111/cogs.12184

Chang, F., Dell, G. S., and Bock, K. (2006). Becoming syntactic. *Psychol. Rev.* 113, 234–272. doi: 10.1037/0033-295X.113.2.234

Chang, F., and Fitz, H. (2014). "Computational models of sentence production: A dual-path approach," in *The Oxford Handbook of Language Production*, eds M. Goldrick, V. S. Ferreira, and M. Miozzo (Oxford: Oxford University Press), 1–30. doi: 10.1093/oxfordhb/9780199735471.013.019

Chang, F., Janciauskas, M., and Fitz, H. (2012). Language adaptation and learning: Getting explicit about implicit learning. *Lang. Linguist. Compass* 6, 259–278. doi: 10.1002/lnc3.337

Chang, F., Tsumura, S., Minemi, I., and Hirose, Y. (2022). Abstract structures and meaning in Japanese dative structural priming. *Appl. Psycholinguist.* 43, 411–433. doi: 10.1017/S0142716421000576

Chen, X., Branigan, H. P., Wang, S., Huang, J., and Pickering, M. J. (2019). Syntactic representation is independent of semantics in Mandarin: Evidence from syntactic priming. *Lang. Cogn. Neurosci.* 35, 211–220. doi: 10.1080/23273798.2019.1644355

Chen, X., and Hartsuiker, R. J. (2021). Do particle verbs share a representation with their root verbs? Evidence from structural priming. *J. Mem. Lang.* 120:104255. doi: 10.1016/j.jml.2021.104255

Chia, K., Hetzel-Ebben, H., Adolph, M., Amaral, M., Arriaga, M., Booth, H., et al. (2020). Examining the factors that affect structural repetition in question answering. *Mem. Cogn.* 48, 1046–1060. doi: 10.3758/s13421-020-01036-2

Coumel, M., Ushioda, E., and Messenger, K. (2022). In prep. Between- and within- group variation in first and second language syntactic priming. *PsyArXiv* [Preprint]. doi: 10.31234/osf.io/wzj7g

Foltz, A., Knopf, K., Jonas, K., Jaecks, P., and Stenneken, P. (2021). Evidence for robust abstract syntactic representations in production before age three. *First Lang.* 41, 3–20. doi: 10.1177/0142723720905919

Grüter, T., Zhu, Y. A., and Jackson, C. N. (2021). "Forcing prediction increases priming and adaptation in second language production," in *Prediction in Second Language Processing and Learning*, eds E. Kaan and T. Grüter (Amsterdam: John Benjamins), 208–231. doi: 10.1075/bpa.12.10gru

Gustavson, K., von Soest, T., Karevold, E., and Røysamb, E. (2012). Attrition and generalizability in longitudinal studies: Findings from a 15-year population-based study and a Monte Carlo simulation study. *BMC Public Health* 12:918. doi: 10.1186/1471-2458-12-918

Hardie, A., and Ibrahim, W. (2021). Exploring and categorising the Arabic copula and auxiliary kāna through enhanced part-of-speech tagging. *Corpora* 16, 305–335. doi: 10.3366/cor.2021.0225

Hardy, S. M., Messenger, K., and Maylor, E. A. (2017). Aging and syntactic representations: Evidence of preserved syntactic priming and lexical boost. *Psychol. Aging* 32, 588–596. doi: 10.1037/pag0000180

Hardy, S. M., Wheeldon, L., and Segaert, K. (2020). Structural priming is determined by global syntax rather than internal phrasal structure: Evidence from young and older adults. *J. Exp. Psychol. Learn. Mem. Cogn.* 46, 720–740. doi: 10.1037/xlm0000754

Hartsuiker, R., Bernolet, S., Schoonbaert, S., Speybroeck, S., and Vanderelst, D. (2008). Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. *J. Mem. Lang.* 58, 214–238. doi: 10.1016/j.jml.2007.07.003

Heyselaar, E., and Segaert, K. (2022). Structural priming persists for (at least) one month in young adults, but not in healthy older adults. *J. Exp. Psychol.: Learn. Mem. Cogn.* [Epub ahead of print]. doi: 10.1037/xlm0001123

Heyselaar, E., Wheeldon, L., and Segaert, K. (2021). Structural priming is supported by different components of nondeclarative memory: Evidence from priming across the lifespan. *J. Exp. Psychol. Learn. Mem. Cogn.* 47, 820–837. doi: 10.1037/xlm0000955

Huang, J., Pickering, M. J., Yang, J., Wang, S., and Branigan, H. P. (2016). The independence of syntactic processing in Mandarin: Evidence from structural priming. *J. Mem. Lang.* 91, 81–98. doi: 10.1016/j.jml.2016.02.005

Jackson, C. N., and Hopp, H. (2020). Prediction error and implicit learning in L1 and L2 syntactic priming. *Int. J. Billing* 24, 895–911. doi: 10.1177/1367006920902851

Jaeger, T. F., and Snider, N. (2008). "). Implicit learning and syntactic persistence: Surprisal and cumulativity," in *Proceedings of the 30th Annual Conference of the Cognitive Science Society*, eds B. C. Love, K. McRae, and V. M. Sloutsky (washington, DC: Cognitive Science Society), 827–812.

Jaeger, T. F., and Snider, N. E. (2013). Alignment as a consequence of expectation adaptation: Syntactic priming is affected by the prime's prediction error given both prior and recent experience. *Cognition* 127, 57–83. doi: 10.1016/j.cognition.2012.10.013

Kaan, E., and Chun, E. (2017). Priming and adaptation in native speakers and second-language learners. *Biling Lang. Cogn.* 21, 228–242. doi: 10.1017/S1366728916001231

Kaschak, M. P., Kutta, T. J., and Coyle, J. M. (2014). Long and short term cumulative structural priming effects. *Lang. Cogn. Neurosci.* 29, 728–743. doi: 10.1080/01690965.2011.641387

Kaschak, M. P., Kutta, T. J., and Jones, J. L. (2011a). Structural priming as implicit learning: Cumulative priming effects and individual differences. *Psychon. Bull. Rev.* 18, 1133–1139. doi: 10.3758/s13423-011-0157-y

Kaschak, M. P., Kutta, T. J., and Schatschneider, C. (2011b). Long-term cumulative structural priming persists for (at least) one week. *Mem. Cogn.* 39, 381–388. doi: 10.3758/s13421-010-0042-3

Kidd, E. (2012). Individual differences in syntactic priming in language acquisition. *Appl. Psycholinguist.* 33, 393–418. doi: 10.1017/S0142716411000415

Köhne, J., Pickering, M. J., and Branigan, H. P. (2014). The relationship between sentence meaning and word order: Evidence from structural priming in German. *Q. J. Exp. Psychol.* 67, 304–318. doi: 10.1080/17470218.2013.807855

Kosmidis, I. (2020). *Brglm: Bias Reduction in Binary-Response Generalized Linear Models*. Available online at: https://cran.r-project.org/package=brglm (accessed April 26, 2022).

Kosmidis, I., and Firth, D. (2021). Jeffreys-prior penalty, finiteness and shrinkage in binomial-response generalized linear models. *Biometrika* 108, 71–82. doi: 10.1093/biomet/asaa052

Kroczek, L. O., and Gunter, T. C. (2017). Communicative predictions can overrule linguistic priors. *Sci. Rep.* 7:17581 doi: 10.1038/s41598-017-17907-9

Kutta, T. J., Kaschak, M. P., Porcellini, A., and Jones, J. L. (2017). Implicit and explicit memory factors in cumulative structural priming. *Collabra Psychol.* 3:13 doi: 10.1525/collabra.59

Levshina, N. (2015). *How to do Linguistics With R: Data Exploration and Statistical Analysis*. Amsterdam: John Benjamins doi: 10.1075/z.195

Litcofsky, K. A., and van Hell, J. G. (2019). Bi-Directional Evidence Linking Sentence Production and Comprehension: A Cross-Modality Structural Priming Study. *Front. Psychol.* 10:1095. doi: 10.3389/fpsyg.2019.01095

Mahmoud, A. T. (2006). Dative shift in Arabic and English: A contrastive study. *Pozn. Stud. Contemp. Linguist.* 42, 191–218.

Mahowald, K., James, A., Futrell, R., and Gibson, E. (2016). A meta-analysis of syntactic priming in language production. *J. Mem. Lang.* 91, 5–27. doi: 10.1016/j.jml.2016.03.009

Mansournia, M. A., Geroldinger, A., Greenland, S., and Heinze, G. (2018). Separation in logistic regression: causes, consequences, and control. *Am. J. Epidemiol.* 187, 864–870. doi: 10.1093/aje/kwx299

McDonough, K., and Trofimovich, P. (2009). *Using Priming Methods in Second Language Research*. Milton Park, UK: Routledge.

Messenger, K. (2021). The Persistence of Priming: Exploring Long-lasting Syntactic Priming Effects in Children and Adults. *Cogn. Sci.* 45:e13005. doi: 10.1111/cogs.13005

Messenger, K., Branigan, H. P., McLean, J. F., and Sorace, A. (2012). Is young children's passive syntax semantically constrained? Evidence from syntactic priming. *J. Mem. Lang.* 66, 568–587. doi: 10.1016/j.jml.2012.03.008

Pappert, S., and Pechmann, T. (2013). Bidirectional structural priming across alternations: Evidence from the generation of dative and benefactive alternation structures in German. *Lang. Cogn. Process.* 28, 1303–1322. doi: 10.1080/01690965.2012.672752

Pappert, S., and Pechmann, T. (2014). Priming word order by thematic roles: No evidence for an additional involvement of phrase structure. *Q. J. Exp. Psychol.* 67, 2260–2278. doi: 10.1080/17470218.2014.918632

Peter, M., Chang, F., Pine, J. M., Blything, R., and Rowland, C. F. (2015). When and how do children develop knowledge of verb argument structure? Evidence from verb bias effects in a structural priming task. *J. Mem. Lang.* 81, 1–15. doi: 10.1016/j.jml.2014.12.002

Pickering, M. J., and Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *J. Mem. Lang.* 39, 633–651. doi: 10.1006/jmla.1998.2592

Pickering, M. J., and Ferreira, V. S. (2008). Structural priming: A critical review. *Psychol. Bull.* 134, 427–459. doi: 10.1037/0033-2909.134.3.427

R Studio Team (2022). *R Studio: Integrated Development for R Studio, PBC*. Boston, MA: RStudio Team.

Reitter, D., Keller, F., and Moore, J. D. (2011). A computational cognitive model of syntactic priming. *Cogn. Sci.* 35, 587–637. doi: 10.1111/j.1551-6709.2010.01165.x

Rowland, C. F., Chang, F., Ambridge, B., Pine, J. M., and Lieven, E. V. (2012). The development of abstract syntax: Evidence from structural priming and the lexical boost. *Cognition* 125, 49–63. doi: 10.1016/j.cognition.2012.06.008

Ruf, H. T. (2011). *An Investigation of Syntactic Priming Among German Speakers at Varying Proficiency Levels*. Ph D thesis. Madison, WI: University of Wisconsin.

Ryding, K. (2005). *A Reference Grammar of modern standard Arabic*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511486975

Ryding, K. (2011). "Arabic datives, ditransitives, and the preposition li," in *The Shadow of Arabic: The Centrality of Language to Arabic Culture*, ed. B. Orfali (Boston: Brill), 283–299. doi: 10.1163/9789004216136_013

Santesteban, M., Pickering, M. J., and McLean, J. F. (2010). Lexical and phonological effects on syntactic processing: Evidence from syntactic priming. *J. Mem. Lang.* 63, 347–366. doi: 10.1016/j.jml.2010.07.001

Savage, C., Lieven, E., Theakston, A., and Tomasello, M. (2006). Structural priming as implicit learning in language acquisition: The persistence of lexical and structural priming in 4-year-olds. *Lang. Learn. Dev.* 2, 27–49. doi: 10.1207/s15473341lld0201_2

Scheepers, C., Raffray, C. N., and Myachykov, A. (2017). The lexical boost effect is not diagnostic of lexically-specific syntactic representations. *J. Mem. Lang.* 95, 102–115. doi: 10.1016/j.jml.2017.03.001

Schoonbaert, S., Hartsuiker, R., and Pickering, M. J. (2007). The representation of lexical and syntactic information in bilinguals: Evidence from syntactic priming. *J. Mem. Lang.* 56, 153–171. doi: 10.1016/j.jml.2006.10.002

Segaert, K., Kempen, G., Petersson, K. M., and Hagoort, P. (2013). Syntactic priming and the lexical boost effect during sentence production and sentence comprehension: An fMRI study. *Brain Lang.* 124, 174–183. doi: 10.1016/j.bandl.2012.12.003

Segaert, K., Wheeldon, L., and Hagoort, P. (2016). Unifying structural priming effects on syntactic choices and timing of sentence generation. *J. Mem. Lang.* 91, 59–80. doi: 10.1016/j.jml.2016.03.011

Tooley, K. M., and Bock, J. K. (2014). On the parity of structural persistence in language production and comprehension. *Cognition* 132, 101–136. doi: 10.1016/j.cognition.2014.04.002

van Gompel, R. P., Wakeford, L. J., and Kantola, L. (2022). No looking back: The effects of visual cues on the lexical boost in structural priming. *Lang. Cogn. Neurosci.* 1–10. doi: 10.1080/23273798.2022.2036782

Vernice, M., and Hartsuiker, R. J. (2019). Mapping thematic roles onto grammatical functions in sentence production: Evidence from structural priming in Italian. *J. Cult. Cogn. Sci.* 3, 39–64. doi: 10.1016/j.jml.2016.06.002

Wang, M., Cai, Z. G., Wang, R., Branigan, H. P., and Pickering, M. J. (2020). How do phonology and orthography feed back to influence syntactic encoding in language production? Evidence from structural priming in Mandarin. *Q. J. Exp. Psychol.* 73, 1807–1819. doi: 10.1177/1747021820932125

Weber, K., Christiansen, M. H., Indefrey, P., and Hagoort, P. (2019). Primed from the start: Syntactic priming during the first days of language learning. *Lang. Learn.* 69, 198–221. doi: 10.1111/lang.12327

Wilmsen, D. (2012). "The Ditransitive Dative Divide in Arabic: Grammaticality assessments and actuality," in *Arabic Language and Linguistics*, eds R. Bassiouney and E. G. Katz (Washington, D.C: Georgetown University Press), 215–232.

Zhang, C., Bernolet, S., and 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 One* 15:e0240909. doi: 10.1371/journal.pone.0240909

Zhang, C., Bernolet, S., and Hartsuiker, R. J. (2021). Are there segmental and tonal effects on syntactic encoding? Evidence from structural priming in Mandarin. *J. Mem. Lang.* 119:104220. doi: 10.1016/j.jml.2021.104220

Zhang, C., Bernolet, S., and Hartsuiker, R. J. (2022). Effects of lexical cues on phrase structure encoding: Evidence from the production of genitives in Dutch. *Lang. Cogn. Neurosci.* 37, 182–208. doi: 10.1080/23273798.2021.1978511

Ziegler, J., and Snedeker, J. (2018). The use of syntax and information structure during language comprehension: Evidence from structural priming, Language, Cognition and Neuroscience. *Lang. Cogn. Neurosci.* 34, 365–384. doi: 10.1080/23273798.2018.1539757