Are there segmental and tonal effects on syntactic encoding? Evidence from structural priming in Mandarin

Chi Zhang[a]

Sarah Bernolet[b]

Robert J. Hartsuiker[a]

[a]Department of Experimental Psychology, Ghent University

[b]Department of Linguistics, University of Antwerp

Address for correspondence: Chi Zhang

Department of Experimental Psychology

Ghent University

Henri Dunantlaan 2

B-9000 Gent

Belgium

Tel. +32 (0)465 38 65 30

chi.zhang@ugent.be

Abstract

Numerous studies have established that speakers tend to form utterances by reusing previously experienced sentence structures (i.e., structural priming). It was also frequently found that the repetition of lexical items enhances structural priming (i.e., lexical boost). This facilitation effect occurs not only when there is a full overlap of verbs, but also when one level of the lexical representation (semantic or phonological representation) overlaps between the prime and the target. In the current study, we further scrutinize the phonological overlap effect on structural priming. We asked whether the phonological effect is independent of orthographic overlap, and whether it is driven by overlap of segments, tone, or both. In five structural priming experiments (three lab-based, two web-based experiments), native Mandarin speakers were instructed to describe transitive pictures after receiving SVO or SOV "ba" prime sentences. In Experiment 1, prime and target verbs had lexical overlap (e.g., *脱[tuo1, to take off]-脱[tuo1]*), semantic overlap (e.g., *卸[xie4, to remove]-脱[tuo1]*), phonological overlap (e.g., *拖[tuo1, to mop]-脱[tuo1]*), or no overlap (e.g., *打[da3, to beat]-脱[tuo1]*) while similarities at other levels were carefully avoided. There were structural priming and lexical boost effects, but semantic or phonological overlap did not boost priming. In two further lab-based experiments and their large-scale online replications, verbs in prime and target had full phonological overlap (segmental+tonal, e.g., *拖[tuo1]-脱[tuo1]*), syllabic overlap only (e.g., *驮[tuo2, to carry]-脱[tuo1]*), tonal overlap only (*称[cheng1, to weigh]-脱[tuo1]*), or no overlap. All four experiments showed structural priming, which was boosted by full phonological overlap. The syllabic overlap exerted a significant facilitation effect on structural priming, whereas no tonal effect was found. Together, these results indicate that processing at the phonological level feeds back to syntactic encoding in sentence production, which further supports an interactive view of language production.

Keywords: structural priming; lexical boost; phonological feedback; segmental processing; tonal processing

Introduction

Sentence production requires speakers to formulate words into meaningful strings. This process involves the encoding of representations at the lexical level, such as meaning, sound, and spelling of the words, as well as the encoding of representations at the sentential level, such as the structure of the sentences. A plethora of studies concurred that speakers construct the syntactic structure of sentences they produce under the influence of properties of the words they intend to utter. This led to the assumption that access to lexical representations guides the formulation of sentence structure (Bock, 1982; Vigliocco & Hartsuiker, 2002). While effects of semantic processing on sentence structure encoding have been clearly established (e.g., Bock, 1986a; Bock, Loebell, & Morey, 1992; McDonald, Bock, & Kelly, 1993), considerably less is known on how phonological processing affects this process. In this study, we further explore the interplay between phonological processing (in particular tonal and segmental processing) and syntactic encoding in sentence production in Mandarin.

Most models of production envisage a speech generation process that starts from the formulation of a non-linguistic message (conceptualization). This is followed by the selection of a lemma (a representation that entails the lexical and grammatical feature of a word), the formulation of morphological and phonological forms, and ends with physical articulation (Bock & Levelt, 1994; Levelt, Roelofs, & Meyer, 1999; Vigliocco & Hartsuiker, 2002). These models are, nevertheless, equivocal about whether the processing at the word-form level interacts with the preceding processes (see Rapp & Goldrick, 2000 for a review). Whereas some models postulated that the flow of activation is strictly unidirectional from lexical selection to word-form processing (e.g., Levelt et al., 1999), others champion an interactive view that allows both cascading of activation and feedback of activation from lower levels to higher levels (e.g., Dell, 1986; Rapp & Goldrick, 2000; Vigliocco & Hartsuiker, 2002). In the current study, we take a closer look at the phonological effect on syntactic processing. Specifically, we asked whether there is an effect of phonological relatedness - independent from orthographic overlap - on grammatical encoding. Furthermore, we examine the locus of any such feedback effect: Does it come from segmental processing, tonal processing, or both?

Phonological effects in lexical access and sentence formulation

Before discussing whether phonological processing influences sentence production, we first consider the effects of phonological feedback on lexical access in production. Several empirical studies demonstrated bottom-up effects of phonological encoding on lexical retrieval. Many of these studies employed homophones (i.e., words with the same sound but different meaning, e.g., *pair*-*pear*) as one of the critical manipulations. Homophones are arguably represented by separate lemmas but a shared word-form (Dell, 1990; Jescheniak & Levelt, 1994; Jescheniak, Meyer, & Levelt, 2003; Levelt et al., 1999; but see Caramazza, Costa, Miozzo, & Bi, 2001). On this account, it was assumed that the shared word-form representation between homophones influences the processing in lexical production of the homophonic twins (see Q. Chen & Mirman, 2012 for a review). For example, in experiments that elicited phonological errors, Dell (1990) showed that a low-frequency word (e.g., *witch*) was as immune to sound misordering as its high-frequency homophonic counterpart (e.g., *which*), even though it is well-documented that low-frequency words are more prone to speech errors, Dell suggested that a high-frequency homophonic counterpart might bestow processing advantage to a low-frequency word. Meanwhile, Ferreira and Griffin (2003) asked participants to name target pictures (e.g., a priest) that were preceded by a visually presented cloze sentence that either induced a homophonic counterpart of the semantic distractor of that target picture (e.g., *I thought there would still be some cookies left, but there were*…, likely inducing *none*) or an unrelated noun (e.g., *Debbie returned the blouse to the store because the colors just didn't …*, likely inducing *match*). They found that participants were more susceptible to semantic substitution error in picture naming (e.g., choosing *nun* over *priest*) when the cloze sentence induced *none* rather than *match.* The authors interpreted the results as a possible contribution of phonological feedback in picture naming.

Consistent with interactive models of language production, one interpretation of these homophone effects on spoken word production is the effect of word-form feedback. Take the finding from Dell (1990) as an example. The activation of the lemma node spreads to the word-form node that is shared between the homophone counterparts. The activation of the word-form node then feeds back to the lemma node of its homophone counterpart (i.e., the high-frequency word). This way, both words are activated and the activation spreads downwards again to the shared word-form. In effect, the activation of the target word is jointly determined by the inherited activation level of both the target word and its homophone counterpart. Note that a lexeme-level account is also compatible with the homophone effect on sound misordering (Jescheniak & Levelt, 1994), and an account that encompasses feedforward-only cascading of activation and monitoring mechanisms is consistent with the homophone effect on semantic substitution (Ferreira & Griffin, 2003; Roelofs, 2004). Whether these phonological effects are interpreted as production-internal or comprehension-based, they can nevertheless be taken as evidence that the homophone status in phonological processing modulates the efficiency and accuracy of lexical retrieval in sentence production.

Evidence was also found for a phonological effect on structure processing in sentence production. Some researchers examined how phonological repetition mediates the accessibility of certain arguments in a sentence, thus influencing the construction of the sentence structure. Bock (1987) investigated lexical priming in sentence production. Speakers described pictures after reading aloud (or listening to) a prime word that shares the phonological onset with the agent or the patient of the target picture. For example, before speakers described a picture of a bee stinging a man, they would first read a prime word *beet* (related to the agent) or *mat* (related to the patient). Bock found that the lexical prime influenced picture description in such a way that speakers tended to put the phonologically primed word later in the sentence (e.g., *The man was stung by a bee* when the prime word was *beet*). The results were interpreted in terms of the conceptual accessibility hypothesis in sentence production (Bock, 1982). This hypothesis posits that conceptually more accessible words (e.g., words that are easier to be imagined or that are given by the context) tend to be mentioned earlier in the sentence. In line with this hypothesis, Bock argued that the access to a phonological cohort neighbour might induce competition between phonological or articulation forms, thereby reducing the accessibility of the primed target word and delaying its production. This hypothesis was supported by a more recent study on unscripted sentence production (Jaeger, Furth, & Hilliard, 2012). Jaeger and colleagues demonstrated that speakers avoided the production of two consecutive nouns that share their onset (e.g., *gave the gauge*). They preferred a constituent structure with the interpolation of another argument noun between two phonologically similar arguments (e.g., *Hanna gave the boy a gauge* relative to *Hanna gave a gauge to the boy*). Both studies supported the hypothesis that the accessibility of the lexical items is reduced by the activation of the phonological representation that is related to these items, which further mediates speakers' choice of the argument order in a sentence.

Important for our present purposes, several studies examined the influence of lexical processing on grammatical encoding by investigating the effect of shared lexical representation on the persistence of syntactic choice. These studies used a structural priming paradigm, which examines the speakers' tendency to spontaneously reuse the syntactic choice of a previously experienced sentence. For example, Bock (1986b) found that speakers were more likely to choose a double object structure (DO structure, e.g., *A rock star sold an undercover agent some cocaine*) over a prepositional object structure (PO structure, e.g., *A rock star sold some cocaine to an undercover agent*) to describe a picture after they heard a DO sentence. Many studies on structural priming have shown that syntactic persistence is independent of the overlap of semantic or prosodic representations (Bock, 1986b; Bock & Loebell, 1990; Scheepers, 2003; but see J. Ziegler, Snedeker, & Wittenberg, 2018). Nevertheless, it was also found that lexical overlap considerably enhances the magnitude of structural priming (i.e., lexical boost). Pickering and Branigan (1998) demonstrated that the priming effect was much larger when the verb of the target sentence completion task (e.g., *show* in *The patient showed…*) matched with the verb in the prime sentence completion task (e.g., *show* in *The racing driver showed the helpful mechanic…*) relative to when the verbs were unmatched (*e.g., give-show*). Lexical overlap has been shown to be the strongest modulator of structural priming in a recent meta-analysis of structural priming studies (Mahowald, James, Futrell, & Gibson, 2016). This evident modulation effect led to an extensive inquiry with regard to the role of lexical factors in structural priming (e.g., Carminati, van Gompel, & Wakeford, 2019; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Pickering & Branigan, 1998; Scheepers, Raffray, & Myachykov, 2017).

Several studies employing a structural priming paradigm manipulated overlap between the lexical items in prime and target sentence with respect to phonology (Bernolet, Hartsuiker, & Pickering, 2012; Cleland & Pickering, 2003; Santesteban, Pickering, & McLean, 2010; Schoonbaert, Hartsuiker, & Pickering, 2007). In Experiment 3 of Cleland and Pickering (2003), the researchers asked participants to describe pictures that induce a prenominal construction (e.g., *the red sheep*) or a postnominal construction with a relative clause (e.g., *the sheep that's red*), while manipulating the overlap of phonemes between the head of the prime sentence and of the target sentence. They found that the priming effect was not stronger when the onset and coda of the heads overlapped (e.g., *ship-sheep*) than when the phonemes were totally different (e.g., *ball-sheep*), thus providing no evidence for a phonological boost to structural priming. Cleland and Pickering suspected that one possible reason for the lack of a phonological overlap effect was that the phonemes only partially overlapped between the prime head and the target head (i.e., in the onset and the coda) and that consequently the phonological feedback was not strong enough to facilitate the structural priming effect.

Indeed, phonological effects on structural priming have been observed in studies that matched phonological representations to a greater extent. Santesteban and colleagues (2010) used a similar design to Cleland and Pickering (2003) to examine the homophone effect on structural priming. They found that the priming effect was larger when the prime head and target head were homophones (e.g., *bat [as a cricket bat]-bat [as an animal]*) in comparison with a control condition where no phonological representation was shared (e.g., *bat-knob*). The boost effect did not dissipate when the participants were able to disambiguate the meaning of the words before listening to the primes, indicating that the locus of the effect was phonological. Furthermore, Bernolet and colleagues (2012) found a similar effect in a cross-language priming experiment. They instructed Dutch-English bilingual speakers to comprehend either a Dutch s-genitive sentence (e.g., *Het meisje haar appel is blauw [literally: The girl her apple is blue]*) or a Dutch of-genitive sentence (e.g., *De appel van het meisje is blauw [literally: The apple of the girl is blue]*) and then describe a picture in English that induced a genitive expression (e.g., a wizard with a blue apple). The prime head and target head were either cognates (i.e., words in two languages with similar meaning and word form, e.g., *appel-apple*) or translation equivalents (e.g., *eend-duck*). Bernolet and colleagues found that structural priming was stronger with cognates than with translation equivalents. This indicates that the additional repetition of the word form yielded a facilitation effect on cross-language structural priming. These studies further corroborated that a feedback effect of word-form encoding influences syntactic choice in sentence production.

Taken together, the empirical evidence seems to demonstrate an interaction between phonological processing and syntactic encoding. However, it is not yet clear at what specific level of word-form processing this interaction takes place. First, it is likely that there are (reciprocal) connections between orthographic and phonological representations. Orthographic properties of the lexical items arguably modulate the online processing of phonological information (Perre, Pattamadilok, Montant, & Ziegler, 2009). This raises the question of whether the phonological feedback effect on grammatical encoding is independent of orthographic processing. Previous studies, using alphabetic languages like Dutch and English, could not disentangle these effects because of the strong confound between phonology and orthography in these languages. Second, we do not yet know whether the activation at each sublevel of the phonological processing (e.g., segmental processing and metrical processing) is sufficient to influence grammatical encoding. In earlier studies that used homophones or cognates, there was always overlap in both the segments and the metrical structure, as it is difficult to manipulate these properties orthogonally. In the current study, we tried to answer these two research questions, exploiting two important properties of Mandarin: that there can be phonological overlap in the absence of orthographic overlap, and that a word’s segments can be dissociated from a key aspect of metrical structure, namely tone. We will further elaborate on the research questions in the next section.

Entanglement between orthographic and phonological processing

Some authors argued for bi-directional activation between orthographic and phonological representations (Van Orden & Goldinger, 1994; Van Orden, Pennington, & Stone, 1990). Studies on spoken word comprehension suggested that activation at the orthographic level feeds to phonological processing. Specifically, several studies demonstrated that the phonology-to-spelling consistency (i.e., the number of orthographic forms corresponding to a phonological form) affects the accuracy and speed of lexical decision (e.g., Pattamadilok, Morais, Ventura, & Kolinsky, 2007; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; J. C. Ziegler & Ferrand, 1998; J. C. Ziegler, Ferrand, & Montant, 2004; J. C. Ziegler, Muneaux, & Grainger, 2003). Further behavioral and neuroimaging studies supported a hypothesis that during the process of learning to read and write, phonological representations are remodeled to include orthographic information (Montant, Schön, Anton, & Ziegler, 2011; Perre et al., 2009; J. C. Ziegler & Muneaux, 2007). This suggests that orthographic representations might be activated along with the activation of phonological representations. If this is the case, the orthographic properties of the lexicon might mediate the phonological effect on lexical retrieval.

Importantly, orthographic effects were also found in spoken word production (Bürki, Spinelli, & Gaskell, 2012; Damian & Bowers, 2003; Rastle, McCormick, Bayliss, & Davis, 2011). In a series of implicit priming tasks, Damian and Bowers (2003) asked participants to memorize a few triads of words (i.e., response words) and recall them later on. In the critical blocks, the onset of the response words in each triad was the same, but the spelling of the words was the same in some blocks (e.g., *kennel, kayak, kidney*) and different in the other (e.g., *kennel, camel, kidney*). Damian and Bowers showed that in the critical blocks, speakers prepared the onset of the response words for the target production (i.e., showed an implicit priming effect) only when the spelling was also consistent. They suggested that orthographic representations are mandatorily activated during phonological processing in production. Although the methodology of Damian and Bowers (2003) was initially criticized (Alario, Perre, Castel, & Ziegler, 2007; Roelofs, 2006), converging evidence for their hypothesis was later found in studies employing a novel word learning paradigm (Bürki et al., 2012; Rastle et al., 2011). It thus seems that phonological processing and orthographic processing are hardwired in speech production.

Specific to the research question of the current study, the entanglement between phonological processing and orthographic processing raises the issue of whether the phonological boost of structural priming is genuinely a phonological effect or whether orthographic representations play a role as well. One hypothesis is that word-form processing influences grammatical encoding only when all representations at the word-form level (both phonological and orthographic representations) are activated. In this case, we should not observe a phonological boost effect when phonemes, but not graphemes, are repeated between prime and target. An alternative hypothesis is that the activation at one level of word-form processing is strong enough to influence grammatical encoding. In this case, the mere overlap of phonemes can induce a boost effect on structural priming. As discussed above, previous studies on the phonological feedback effect on grammatical encoding mostly employed homophones or phonological neighbours that shared not only phonemes but also most of their graphemes. As the graphemes can be activated even when processing a spoken word, these studies do not rule out the possibility that the feedback effect might (also) come from repeated access of the orthographic representation of the preceding prime. It is necessary therefore to disentangle any effect at the orthographic level from an effect at the phonological level when investigating the phonological feedback to higher level processing. This seems difficult to accomplish in an alphabetic language.

In the current study, we investigated the phonological feedback effect on grammatical encoding in a logographic language (i.e., Mandarin), which can minimize the connection between phonemes and graphemes. There is a large store of homophonic words in Mandarin (Tan & Perfetti, 1998). As a consequence of the logographic nature of Mandarin, many of the homophones display evident orthographic differences (e.g. *tuo1[拖, mop]-tuo1[脱, take off]*). The rich repertoire of heterographic homophones in Mandarin allows us to manipulate the phonological overlap between verbs without necessarily tapping into orthographic similarity. In five structural priming experiments, we manipulated the phonological overlap between the prime verb and target verb while avoiding orthographic overlap between the two, so that we were able to examine whether phonological overlap alone boosts the priming effect.

Segmental and metrical effect on grammatical encoding

Retrieval of phonological form in language production involves the retrieval of segmental and metrical representations of the words (Dell, 1986; Goldrick, 2014; Levelt et al., 1999). If phonological processing influences grammatical encoding, an interesting question is to what extent the retrieval of the segments and the metrical frame contributes to the phonological effect. Most earlier studies on the phonological boost used word pairs that match in both segments and metrical frames (e.g., homophones). Further investigation is needed to tease apart the role of segmental and metrical processing in the phonological effect on grammatical encoding.

Some previous findings suggest that both segmental and metrical processing affect sentence structure encoding. Bernolet and colleagues (2012) found that the magnitude of cross-language priming is a function of the number of phonemes overlapping between prime and target heads. Such a continuous effect of phoneme overlap seems to suggest that the extent to which segments are shared modulates the phonological boost effect. However, studies on cross-language structural priming using Mandarin as the target language found no such continuous effect (Cai, Pickering, Yan, & Branigan, 2011; Huang et al., 2019).

As for the metrical frame, Lee and Gibbons (2007) found in a sentence recall experiment that the stress pattern of the upcoming word influenced the use of complementiser *that* in the recall task: Speakers were more likely to omit *that* when it preceded the subject of a complement clause that started with a strong syllable (e.g., *Lucy*) rather than a weak syllable (e.g., *Louise*). This indicates that the metrical properties of words affect the encoding of sentence structures. Taken together, it seems that segmental processing and metrical processing both contribute to phonological effects on grammatical encoding.

However, the evidence is not conclusive yet. In Bernolet et al. (2012), all of the phonologically similar words also overlapped in the number of syllables and the stress pattern (e.g., *appel [ʻapəl] – apple[ʻæpəl]*). Any segmental overlap between these words could also entail a metrical overlap. Therefore, we do not yet know whether segmental overlap alone boosts structural priming. In terms of the effects of metrical frame, despite a clear metrical effect on the syntactic choice in target production, Lee and Gibbons (2007) did not find any evidence that the metrical properties affected the recall of complement structures, which suggests that syntactic persistence is independent of the mapping between syntactic structure and metrical frame. In addition, previous studies showed that abstract prosodic structures (e.g., intonational structure, pitch accent) do not persist from prime to target (Tooley, Konopka, & Watson, 2014, 2018). These findings cast doubt on whether there is a metrical effect on the persistence of syntactic structures. To address this issue, we need to disentangle segmental and metrical processing in sentence production, which is difficult in alphabetic languages. The current study examines the effect of overlap at the segmental and metrical levels on structural priming in Mandarin.

Mandarin is a typical tonal language. It features metrical properties that are distinct from non-tonal languages such as English and Dutch. Different from the metrical property in alphabetic languages, the tonal property in Mandarin is lexical-specific: Words that share segments but are distinct in tone are, with exceptions, represented differently at other levels of lexical representation. For instance, the orthographic and semantic representations of *ma* are different when it features the second tone (*ma2[麻, linen])* and the third tone (*ma3[马, horse]).* The separation of segmental and tonal representation in Mandarin enables us to untangle the effects of segmental processing and the metrical processing in grammatical encoding.

How are segmental and metrical information represented and processed in Mandarin? Studies on phonological encoding in Mandarin word production generally supported the view that an atonal syllable is the most prominent phonological planning unit (T.-M. Chen & Chen, 2013; O'Seaghdha, Chen, & Chen, 2010; Roelofs, 2015; Wang, Wong, & Chen, 2018; Wong & Chen, 2008). That is to say, the first phonological unit selected after lemma retrieval is a syllabic representation that incorporates the bundled segmental information but the syllable tone has not yet been specified. This is in contrast with the phonological encoding in Germanic languages in which subsyllabic segments are considered as the functional planning unit (Levelt et al., 1999; Meyer, 1990, 1991). On the other hand, the tonal frame in Mandarin is generally regarded as a lexically-specific metrical component in phonological encoding that is analogous to the stress frame in Germanic languages.

Roelofs (2015) extended a lexicalist model of language production (Levelt et al., 1999) to incorporate the processing of both syllabic and tonal features in Mandarin (see Fig. 1). The syntactic form of the word (i.e., the lemma node) links to a lexeme node in which word-form information is indexed but not realized. Immediately after lemma selection, the atonal syllable(s) and the tonal frame(s) that are indexed by the lexeme node are accessed in parallel. The selected syllable then combines with the tonal frame to formulate a syllable motor program. Importantly, although syllabic and tonal information are processed in parallel, the syllabic encoding always takes priority in word-form processing. The syllable selection comes about prior to tone selection (Zhang, Damian, & Yang, 2007) and the tonal information can only be accessed after the syllable has been selected. The information at word-form level cannot flow to the other nodes before syllable selection.

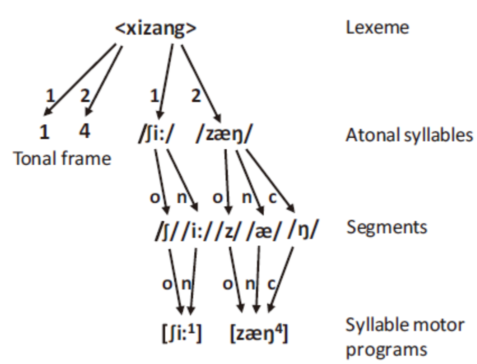

Fig. 1. Illustration of the representation of the Mandarin Chinese word *xizang* (*西藏*, meaning Tibet) in the extended lexicalist model from Roelofs (2015). The numbers in the tonal frame denote tone numbers. Syllable motor programs are specified for tone. 1 = high; 4 = high-falling; c = coda; n =

The model depicted above is well buttressed by empirical evidence. In a series of implicit priming tasks, J-Y Chen and colleagues (2002) demonstrated that word forms of disyllabic words in Mandarin could be prepared in advance when both the first syllable and the associated tone were consistent between the response words. This effect occurred despite orthographical inconsistency. Importantly, when only the syllables were homogeneous between the response words, speakers also showed a significant implicit priming effect, indicating that the atonal syllable alone can be prepared in advance. In contrast, when only the tones were homogeneous, no implicit priming effect was found. This suggested that tonal frame was not a stand-alone planning unit in word-form encoding. Finally, the homogeneous onsets also failed to exert any implicit priming effect, confirming that any segmental unit smaller than a syllable cannot be functionally prepared by Mandarin speakers. The findings of the facilitation effect caused by atonal syllabic consistency and the lack of a tonal consistency effect were later replicated in a series of picture-word interference tasks in Cantonese (Wong & Chen, 2008) and in a computational model simulation (Roelofs, 2015).

Based on the postulated model of Mandarin word production (Roelofs, 2015), we can outline several possibilities with regard to the effects of the atonal syllable and tonal feedback on grammatical encoding. First, as Mandarin speakers can plan the atonal syllable as a free-standing unit, it is conceivable that the information of an atonal syllable can flow back to the lemma node and further modulate the processing of the combinatorial information that is linked to the lemma. On the other hand, since a syllable-unspecific tone cannot be retrieved in advance, it is possible that the tonal processing alone cannot effectively induce a feedback effect. However, if alignment universally occurs at all linguistic levels and the alignment at one level leads to greater alignment at the other levels (Pickering & Garrod, 2004), it is still possible that prosodic alignment such as tonal alignment exerts to some extent a facilitation effect on syntactic alignment. In four structural priming experiments reported below, we manipulated the segmental overlap (henceforth syllabic overlap) and metrical overlap (henceforth tonal overlap) between Mandarin prime verbs and target verbs. In doing so, we were able to examine whether processing at these levels feeds back to grammatical encoding.

Transitive alternation in Mandarin Chinese

As the target structures we used Mandarin Subject Verb Object (SVO) transitives (e.g., *Nanren tuo-LE yifu. [The man take off-LE the clothes.]*) and Ba transitives (e.g., *Nanren ba yifu tuo le. [The man ba the clothes take off-LE.]*). It is well established that the SVO transitive and

Ba transitive are interchangeable sentence structures with a similar conceptual representation (James, Li, & Li, 2009; Li & Thompson, 1974; Sybesma, 2013; Thompson, 1973). Historically, *ba* used to be a verb meaning “to hold up” but it is now grammaticalized as a light verb with no concrete meaning[1]. The SVO transitive features a subject-verb-object order. In the Ba transitive structure, the marker *ba* is placed between the subject and object, which renders an order of subject-ba-object-verb. Ba transitive and SVO transitive feature the same functional assignment (subject-agent; object-patient) and the same thematic order (agent then patient). The two structures also do not differ in the emphasis given to the theme (Cai, Pickering, & Branigan, 2012). So the only conceptually and syntactically related difference between the two is the constituent order of the sentence (SbaOV vs. SVO).

The SVO structure arguably predominates transitive production in adults (around 90%, Sun & Givón, 1985). Nevertheless, Hsu (2014a, 2014b) found that children at the age of three and five were able to produce Ba transitive sentences when they were prompted by Ba transitive prime sentences, even when the prime sentences were headed by artificial verbs. Hsu’s finding testified that native speakers have already acquired abstract knowledge of SOV Ba structure early on. More important to our purpose, she demonstrated a structural priming effect with the SVO-Ba alternation, indicating that both structures are compatible with a transitive event, and the syntactic choice between the two alternatives is affected by the preceding prime. However, while addressing important issues such as abstract syntactic representations of Mandarin SVO transitive and Ba transitive, Hsu (2014a, 2014b) did not investigate whether the persistence of these representations is modulated by lexically specific effects such as the lexical boost and the semantic boost. In fact, as far as we know, most studies on structural priming of word order alternations have not asked whether lexical (semantic or phonological) repetition between prime and target increases the accessibility of the prime word order. In Experiment 1 of the current study, we also examined whether Ba transitive structure can be lexically or semantically boosted. To do so, we manipulated the lexical and semantic overlap between the prime verb and the target verb.

In sum, it is still not clear whether phonological boost is purely phonological or also orthographic, and elucidation is still needed regarding what role of syllabic and tonal processing plays in the phonological boost effect. These research questions will be tested in four experiments

[1] There is still a debate with regard to the function of *ba* in the Ba construction (see James, Li, & Li, 2009 for a discussion). But a general consensus is that *ba* does not function as a lexical verb and contains no important syntactic and semantic properties.

using Ba/SVO alternation. But first, Experiment 1 tests for overlap effects on the strength of this type of priming at multiple levels including lexical and semantic level.

Experiment 1: Effects of lexical, semantic, and phonological overlap on structural priming

In the current study, we used a structural priming paradigm to examine the effect of shared lexical representations on grammatical encoding in sentence production. We first tested whether there was an effect of phonological overlap that was independent of orthographic overlap (Experiment 1). We then took a closer look at the phonological effect by investigating the effects of syllabic and tonal overlap on structural priming (Experiment 2a-b, Experiment 3a-b).

Experiment 1 investigated whether the lexical, the semantic, and the phonological overlap between the verbs of the prime and the target contribute to structural priming. In particular, we asked whether the effect of phonological overlap survives in the absence of orthographic overlap. To do this, we controlled the overlap of grapheme and phoneme between the prime verb and target verb, so that the verb pairs in the phonological overlap conditions were minimal pairs that shared nothing but phonemic features. We manipulated the transitive verbs in the prime and the target either as a lexically overlapping pair (e.g., *脱[tuo1, to take off]-脱 [tuo1]*), a semantically overlapping pair (e.g., *卸[xie4, to remove]-脱[tuo1]*), a phonologically overlapping pair (e.g., *拖[tuo1, to mop]-脱[tuo1]*), or a non-overlapping pair (e.g., *洗[xi3, to wash]脱[tuo1]*). All the pairs except lexically overlapping pairs contain minimal orthographic overlap.

In Experiment 1, semantic relatedness was manipulated in order to have an additional examination of the effect of semantic relatedness on verb phrase priming. Among others, one way to explore the effect of feedforward activation from conceptual formulation on grammatical encoding is to examine the effect of semantic relatedness of the heads on structural priming. It has been found that the likelihood that a primed noun phrase is reused in the subsequent production is increased if the prime head and the target head are semantically related pairs (e.g., *goat-sheep*) (e.g., Cleland & Pickering, 2003; Santesteban et al., 2010). Important to our purpose, the semantic boost effect and the lexical boost effect in Mandarin provide a context for the postulated phonological boost. As we have already mentioned, lexical and semantic boost effects to structural priming have not been investigated for the syntactic contrast under study. In fact, it is unclear whether a semantic boost can be obtained in Mandarin. In a series of structural priming experiments, Huang and colleagues (2016) found that dative priming in Mandarin occurred irrespective of animacy overlap. This led the authors to suggest that a semantically independent syntactic representation can be computed during sentence processing in Mandarin. Taken at face value, the findings of Huang and colleagues (2016) seem to conflict with the well documented semantic boost effects on structural priming. However, as was noted by the authors, the animacy overlap could only account for a small portion of the semantic overlap between the prime and the target sentence, thus it still remains a question whether a semantic boost in Mandarin structural priming manifests itself when there is a stronger manipulation of semantic overlap. In the current study, we paired the target verb with a semantically related prime verb (e.g., *卸[xie4, to remove]-脱[tuo1, to take off]*) while controlling the phonological and orthographic overlap. This way, we were able to examine whether a stronger semantic relatedness between the prime verb and the target verb could result in a larger structural priming effect in Mandarin.

Experiment 1 (as well as Experiment 2a and 3a) employed a picture description task with a scripted confederate (Branigan, Pickering, & Cleland, 2000). During the experiment, two participants jointly accomplished a picture judgment task in which they made decisions about whether the picture illustrated on their computer screen matched with the one for their partner. Between the two participants, one member was a confederate of the experimenter who pretended to be a naïve participant. The confederate made her descriptions based on a written script and these productions functioned as the prime sentences for the naïve participants.

Method

Participants

Forty students from Xi’an Jiaotong University, all native Mandarin speakers, were paid to participate in Experiment 1 (24 females and 16 males, average age 19.98 years). All participants reported to be non-color-blind and had normal or corrected-to-normal vision. A 21-year-old female native Mandarin speaker acted as confederate.

Fig. 2. Example of a target picture. The target verb is shown above the picture (*脱* [tuo], *to take off*) and the preamble is below the picture (*秘书* [*The secretary*]_____。).

Materials

We created a verification set of 128 pictures and a description set of 128 pictures. All pictures showed colored cartoon images. The participant's description set contained 64 critical description pictures and 64 filler description pictures. The critical description pictures depicted transitive events (e.g., a secretary is taking off the coat; see Fig. 2). A target verb (e.g., *脱[tuo1]*) was placed above the picture and a preamble beneath the picture (e.g., *Mi4shu1* _____. *[The secretary* _____。*]*).

We selected eight target verbs (*搬[ban1, to move], 补[bu3, to patch], 采[cai3, to pick up], 截[jie2, to cut off], 记[ji4, to note], 踢[ti1, to kick], 脱[tuo1, to take off], 折[zhe2, to fold]*). Each target verb corresponded to eight target pictures. The filler description pictures depicted intransitive expressions (e.g., a baby is crying). The configuration of the filler description pictures was the same as that of the critical description pictures.

The participant's verification set contained 64 critical pictures and 64 filler pictures. Among the critical pictures in the verification set, 32 pictures matched with the confederate's description and 32 pictures differed from the description in one component of the event (agent or recipient). The verification pictures contained no verb or preamble. The configuration was the same for the filler verification pictures (32 matched and 32 unmatched). This way, we made sure that the prime sentence and pictures matched in 50% of the overall trials in Experiment 1 (and the same applied to all the experiments thereafter).

A description set of 192 sentences for the confederate was created. There were more sentences for the confederate than the total number of participant's verification pictures because for each of the 64 critical description pictures, two structurally counterbalanced critical prime sentences were constructed. Specifically, for each critical description picture, there were a Ba sentence (e.g., 1a, 2a, 3a, and 4a) and an SVO transitive sentence (e.g., 1b, 2b, 3b, and 4b). The overlap conditions were counterbalanced within each experimental list. The critical prime sentence in the Lexical Overlap condition (e.g., 1a and 1b) contained a prime verb that was the same as the target verb (e.g., *脱[tuo1, to take off]*).*]-脱[tuo1]*, all the example prime sentences correspond to the example target picture of Fig. 2). In the Semantic Overlap condition (e.g., 2a and 2b), the prime verb was semantically related to the target verb (e.g., *卸[xie4, to remove]-脱 [tuo1].* In the Phonological Overlap condition (e.g., 3a and 3b), half of the prime verbs shared both the syllable and tone with four of the target verbs (e.g., *拖[tuo1, to mop]-脱[tuo1]*), and half of the prime verbs only shared the syllable with the other four of the target verbs (e.g., *裁[cai2, to cut out]* in *Caifeng ba zhuobu cai-LE/ cai-LE zhuobu [The tailor Ba the table cloth cut-out-LE/ cut-out-LE the table cloth]-采[cai3, to pick up]* in a picture depicting a female farmer picking up grapes). In the No Overlap condition (e.g., 4a and 4b), no phoneme was shared between the prime verb and the target verb, and the semantic overlap was kept to a minimum (e.g., *洗[xi3, to wash]-脱[tuo1]*). Since there were only a limited number of pictures applicable for each verb, the critical prime sentences were recycled for different target pictures in the other lists. The remaining 64 sentences in the confederate's description set were filler sentences that could be used to describe the filler items in the participant's verification set. All verbs used in the current experiments were monosyllabic verbs. Half of the sentences matched with the participants' pictures from the verification set. The confederate's verification set contained 128 further pictures that were the same as the pictures in the participant's description set. All materials are listed in Appendix B.

(1a) Mama BA yurongfu tuo1-LE. *Ba transitive, Lexical Overlap*
Mum BA the down jacket take-off-LE.
[Mum took off the down jacket.]

(1b) Mama tuo1-LE yurongfu. *SVO transitive, Lexical Overlap*
Mum take-off-LE the down jacket.
[Mum took off the down jacket.]

(2a) Shibing BA toukui xie4-LE. *Ba transitive, Semantic Overlap*
The soldier BA the helmet remove-LE.
[The soldier removed the helmet.]

(2b) Shibing xie4-LE toukui. *SVO transitive, Semantic Overlap*
The soldier remove-LE the helmet.
[The soldier removed the helmet.]

(3a) Qingjiegong BA yangtai tuo1-LE. *Ba transitive, Phonological Overlap*
The cleaner BA the balcony mop-LE.
[The cleaner mopped the balcony.]
(3b) Qingjiegong tuo1-LE yangtai. *SVO transitive, Phonological Overlap*
The cleaner mop-LE the balcony.
[The cleaner mopped the balcony.]
(4a) Siji BA che xi3-LE. *Ba transitive, No Overlap*
The driver BA the car wash-LE.
[The driver washed the car.]
(4b) Siji xi3-LE che. *SVO transitive, No Overlap*
The driver wash-LE the car
[The driver washed the car.]

A pretest was conducted in order to examine whether only the verbs in the Semantic Overlap condition were semantically closely related to the target verbs. We asked native Mandarin speakers to rate the semantic relatedness of the verb pairs (i.e., a semantic relatedness judgment task). An online test was created. The test contained 24 pairs of SVO transitive sentences and 24 pairs of Ba transitive sentences. The verbs in the sentence pairs were highlighted. The sentence pairs corresponded to the critical prime-target pairs in Experiment 1 with the exclusion of the pairs in the Lexical Overlap condition. Specifically, we created 48 SVO transitive or Ba transitive sentences corresponding to the target pictures. Sixteen of these sentences were paired with the sentences in the Semantic Overlap condition (Semantic Overlap pairs), 16 were paired with the sentences in the Phonological Overlap condition (Phonological Overlap pairs), and 16 were paired with the sentences in the No Overlap condition (No Overlap pairs). The structure of the sentences was the same within each sentence pair. The structure of the sentence pair and the order of the two sentences in each pair were counterbalanced within subjects. The test was implemented and administered online via LimeSurvey. Eighty-two further native Mandarin speakers were recruited for the pretest (50 female and 32 male, average age 24.71 years). They were instructed to rate the relatedness of the meaning of the highlighted verb pairs on a 5-point likert scale (1 = not related at all, 3=neutral, 5 = very much related).

The judgment task showed that the Semantic Overlap pairs (M=4.097, 95% CI [3.941, 4.253]) were much more related than the Phonological Overlap pairs (M= 1.841, 95% CI [1.655, 2.027]) and the No Overlap pairs (M= 1.474, 95% CI [1.279, 1.669]). The 95% confidence intervals indicated that only the relatedness of the Semantic Overlap pairs was rated significantly above the neutral value, whereas the scores in other conditions were significantly below this value. This suggested that only the verbs used in the Semantic Overlap condition share a high degree of semantic similarity with the target verbs.

We implemented several further manipulations in order to ensure that no extra level was overlapping in each prime-target pair. First, the verb pairs in the Semantic Overlap and in the No Overlap conditions shared no phonemes or tones. Second, the verb pairs in all conditions except the Lexical Overlap condition shared no meaningful graphic component (e.g., radicals). This way, verbs in the Semantic and Phonological Overlap conditions only shared semantic and phonological features, respectively, and verbs in the No Overlap condition shared no critical features. Third, in each trial, the agent and the object of the prime sentence were different from those in the target picture. This way, we avoided the repetition of the argument nouns between prime and target, which arguably influences the magnitude of structural priming (Scheepers et al., 2017; but see Carminati, van Gompel, & Wakeford, 2019).

A critical trial was defined as a pairing of the confederate's critical prime sentence and the participant's critical description picture. Thus, 64 critical trials and 64 filler trials were created for each participant. We had a 2 (prime condition) x 4 (overlap condition) design; all factors were manipulated within-items and -participants. We constructed eight counterbalanced pseudo-random lists so that each target verb was preceded by the same verb in two lists (Lexical Overlap condition), by a semantically related verb in two lists (Semantic Overlap condition), by a phonologically related verb in two lists (Phonological Overlap condition), and by a non-related verb in two lists (No Overlap condition) . In each overlap condition, the target picture was preceded by an SVO transitive sentence in four lists and by a Ba transitive in the other four lists. For each of the eight lists, the trials were presented in the same pseudo-random order. There were four fillers at the beginning of each list; critical trials were separated by 0 to 4 filler trials. Each participant was presented with one of these eight lists.

Procedure

Both the participant and the confederate sat in front of one of the two screens that were placed opposite to each other. Each screen was connected to a computer that independently ran the program. The participant and confederate could not see each other's screens. They were told that they would cooperate with their partners in a series of tasks and try to perform as fast and accurately as possible. One would describe pictures and the other would judge whether the picture on his/her screen matched with the description made by the partner. At the beginning of the experiment, the participants and the confederate read the instruction to learn the series of tasks they would perform and the possible pictures they would see during the experiment. They then familiarised themselves with the procedure in a practice session. The practice session included five filler trials.

The program was set up so that the confederate always took the first turn. At the beginning of each trial, the confederate started by "describing the picture" while she actually read sentences directly from her computer screen. The participant pressed "1" if the description matched with the verification picture on the participant's screen and "2" otherwise. After the keypress, the verification picture immediately disappeared from the participant's screen and a description picture appeared after an interval of 500 ms. Simultaneous with the keypress, a beep sound was generated by the participant's computer and was amplified through a speaker. Upon hearing the beep sound, the confederate pressed "3". The prime sentence disappeared and a verification picture appeared on the confederate's screen after an interval of 500 ms. The participant then described the picture to the confederate. The confederate judged whether the description matched with the picture. As the confederate's verification picture was always the same as the participants' description picture, the confederate would constantly press "1" in the judgment task. The duration of the experiment was about 30 minutes. A Sony ICD-PX440 recorder was used to record the utterances made by the participant and the confederate.

Scoring

All the participants' descriptions of target pictures were coded as SVO transitive, Ba transitive, or Other responses. A description was an SVO transitive if the utterance was grammatical and the sentence preamble was completed in such a way that the agent was followed by the target verb (with or without the perfective marker -le) and then the patient (e.g., *Mishu tuo-LE waitao [The secretary took off-LE the jacket]*). It was taken as a Ba transitive if the utterance was grammatical and the sentence preamble was completed in such a way that the agent was immediately followed by the marker *ba*, then the patient, and finally the target verb (e.g., *Mishu BA waitao tuo-LE [The secretary BA the jacket took off-LE]*). All the other utterances were categorized as Other responses, including ungrammatical utterances, utterances that used the wrong verb, and utterances that used light verbs other than *ba* (e.g., *jiang*). It should be noted that there were cases in which speakers produced a disyllabic verb that combined the target verb with another monosyllabic word (e.g., *tuo1 – tuo1xia4*). The meaning and the syntactic function of the compound verbs are highly related to the monosyllabic verb (Chung, 2006). We did not categorize these cases as Other responses, because the production of a disyllabic word did not interfere with any of the manipulations in the current study.

Results

Data and analysis scripts for all experiments reported in this paper are available online (on the Open Science Framework at https://osf.io/ur567/). Critical trials in which participants produced no response or an Other response were excluded from the analyses (0.4% of the data). The final data set contained 2549 target responses, among which were 321 Ba transitive responses (12.6%) and 2228 SVO transitive responses (87.4%).

The descriptive data of the Ba transitive production for each prime condition x overlap condition are illustrated in Fig. 3 and Table 1. The proportion of Ba transitive responses was 20.8% after Ba transitive primes and 4.4% after SVO primes, resulting in a 16.4% general structural priming effect. In the No Overlap condition, the proportion of Ba transitive responses after Ba transitive primes was 13.0% higher than that after SVO transitive primes. This difference was 27.8% in the Lexical Overlap condition, 15.5% in the Semantic Overlap condition, and 9.1% in the Phonological Overlap condition.

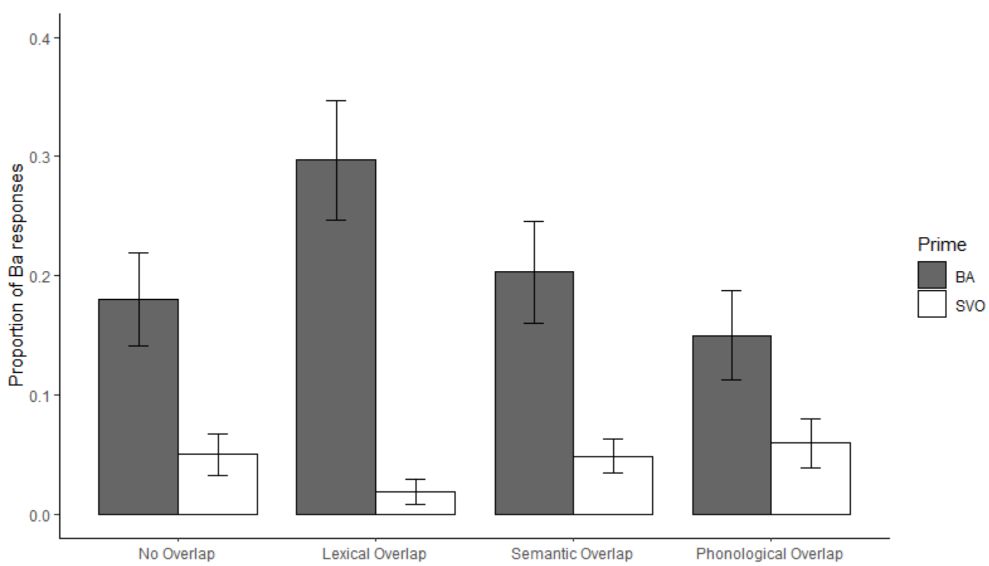

Fig. 3. The proportion of Ba responses as a function of prime condition and overlap condition in Experiment 1. Error bars reflect standard errors calculated for a by-participants analysis.

Table 1

Proportions Ba responses for each prime condition*overlap condition combination in each experiment, “Ba” and “SVO” in the header row indicate the prime condition. The “Structural priming” in the header row indicate the priming effect (the proportion of Ba responses in Ba prime condition minus that in SVO prime condition).

		Prime condition		
Experiment	Overlap condition	Ba	SVO	Structural priming
1	No Overlap	.180	.050	.130
	Phonological Overlap	.150	.059	.091
	Semantic Overlap	.203	.048	.155
	Lexical Overlap	.297	.019	.278
2a	No Overlap	.270	.114	.156
	Syllabic Overlap	.292	.103	.189
	Full Phonological Overlap	.322	.108	.214
2b	No Overlap	.393	.101	.292
	Syllabic Overlap	.434	.077	.357
	Full Phonological Overlap	.451	.079	.372
3a	No Overlap	.312	.130	.182
	Tonal Overlap	.341	.137	.204
	Full Phonological Overlap	.354	.113	.241
3b	No Overlap	.382	.091	.291
	Tonal Overlap	.395	.083	.312
	Full Phonological Overlap	.430	.068	.362

The participants’ responses were fit by a Generalized Linear Mixed Model (GLM model), using the lme4 package in R. The model predicted the logit-transformed likelihood of a Ba transitive response. Prime condition and overlap condition were included in the model as fixed factors. The predictor of prime condition was entered into the model in mean-centered form (deviation coded). The predictor of overlap condition was entered into the model via simple effect coding in which we treated the No Overlap condition as a reference level and the three levels of the predictor represented contrasts between that baseline level and each of the three remaining levels. For the analysis (and all the analyses thereafter), we employed the maximal random effects structure justified by the design (Barr, Levy, Scheepers, & Tily, 2013). Specifically, we included in the model the by-subject and by-item random intercepts as well as random slopes for all main effects and interactions in the fixed model. If the maximal model could not converge or showed singularity, we first dropped the random correlation terms in one go for all predictors. If the model without random correlation could not converge either, we began to drop one random factor at a time, starting from the most complex terms in the random model. When there were multiple terms with the same level of complexity, we compared the variances of the random effects in the last model and dropped the term that accounted for the least amount of variance. We repeated this step until the model converged and no warning of singular fit was reported.

The final model included a random intercept and a random slope of prime condition for both subjects and items. The random correlations were dropped. The summary of the fixed effects of the model is listed in Appendix A. We found a significant main effect of prime condition ($\chi2$ = 40.345, df = 1, $p < .001$), showing an overall structural priming effect. There was a significant interaction between prime condition and overlap condition ($\chi2$ = 29.539, df = 3, $p < .001$). The three interaction effects in the model illustrate the comparison of structural priming effects between the No Overlap condition and the other three conditions. The priming effect was significantly stronger in the Lexical Overlap than in the No Overlap condition (β = 2.222, SE = 0.563, $p < .001$). However, no significant difference was found between the Semantic Overlap condition and the No Overlap condition or between the Phonological Overlap condition and the No Overlap condition (p_zs > .1).

Descriptively, there seemed to be priming in each condition individually. To test whether these effects were significant, four further LME models were fitted. Each model predicted the likelihood of Ba transitive production in a subset of the data divided by overlap condition (i.e., Full Overlap subset, Semantic Overlap subset, Phonological Overlap subset, and No Overlap subset). The prime condition (deviation coded) was included as the only fixed factor. The final model in the Full Overlap subset and the Semantic Overlap subset included a random intercept and a random slope of prime condition for both subjects and items. The final model in the Phonological Overlap subset included a random intercept and a random slope of prime condition for subjects as well as a random intercept for items. The final model in the No Overlap subset included a random intercept for both subjects and items. All random correlations were dropped. Significant main effects of prime condition were found in all four analyses (p_zs < .001), indicating that there were significant structural priming effects in all overlap conditions.

Exploratory analyses

In order to further examine the role of semantic overlap and phonological overlap in structural priming, we conducted two exploratory analyses. A first analysis examined whether semantic relatedness modulates structural priming. Using the subset of data that excluded the

Lexical Overlap condition, we tested whether the semantic ratings from the pretest predicted the magnitude of structural priming. We fitted a GLM model that predicts the logit-transformed likelihood of a Ba transitive response. The model included prime structure (deviation coded) and the semantic rating (mean-centered) as the predictors. There was no significant interaction between semantic rating and prime structure ($\chi2 = 0.505$, df = 1, $p = .477$). Thus, we found no evidence that semantic relatedness affects structural priming.

The second analysis explored the phonological effect on structural priming further, by dividing the Phonological Overlap subset into subsets with or without shared tones. As noted above, half of the target verbs in the Phonological Overlap condition shared the full phonological representation (syllable and tone) with the prime verb, while the other four only shared the syllables. We used Cohen's d to calculate the effect size of structural priming in each sub-condition. We found that the priming effect was larger when the target verb shared full phonological features with the prime verb (mean difference = 11.5%, Cohen's d = 0.544) in comparison with when the verb pairs only shared syllables (mean difference = 6.0%, Cohen's d = 0.234). It thus seems that phonological overlap induced a larger structural priming effect when more phonological features were shared between the prime and target verbs.

Discussion Experiment 1

In Experiment 1, we found a significant structural priming effect on the production of Ba transitive sentences. This replicated the previous finding of a similar priming effect in children (Hsu, 2014a, 2014b). As the SVO transitive prime and the Ba transitive prime differ only in the word order and the presence of Ba, the priming effect demonstrated that the presence of a prime sentence increased the likelihood for the speaker to choose the primed word order over its alternatives. Furthermore, there was a significant lexical boost effect on the priming of Ba transitive sentences. This suggests that there might be a lexical factor modulating the retrieval of the word order of the prime sentence (Chang, Dell, & Bock, 2006; Hartsuiker et al., 2008). We will further discuss the lexical overlap effect on word order processing in the General Discussion.

There was no significant effect of semantic overlap on structural priming. Despite a numerical difference, the priming effect exerted in the Semantic Overlap conditions did not differ from that in the baseline condition. We found no significant correlation between the semantic relatedness ratings and the priming effect. The priming effect in the Phonological Overlap condition was also not different from that in the baseline condition. However, the priming effect seems to be modulated by the extent to which the phonological features were shared between the prime verb and the target verb: the priming effect appeared to be larger when tone and syllables were shared than when only syllables were shared. If this is indeed the case, it might be necessary to further examine the effect of syllabic overlap and tonal overlap on Mandarin structural priming and to verify whether the overlap of both syllables and tone indeed leads to a larger structural priming effect.

In four follow-up experiments, we zoomed in on the phonological effect on syntactic encoding in structural priming. In both Experiments 2a-b and 3a-b, we scrutinized whether the full overlap of phonological features (syllable and tone) facilitates structural priming. In Experiment 2a-b, we further examined the effect of syllabic overlap on structural priming; and in Experiment 3a-b, we investigated the tonal overlap effect on structural priming. To guarantee substantial statistical power, each experiment was carried out in 1) a laboratory environment with more than seventy participants and 2) in an online environment with more than two hundred participants.

Experiment 2a The effect of phonological and syllabic overlap on structural priming (Lab experiment)

In Experiments 2a and 2b, we further tested for a phonological boost that is independent of orthographic overlap. Crucially, we also investigated the effects of syllabic overlap on structural priming. We therefore manipulated the transitive verbs in the prime and the target: they either had full-phonological overlap (e.g., *拖[tuo1]-脱[tuo1]*), syllabic overlap only (e.g., *驮[tuo2, to carry]-脱[tuo1]*), or no overlap (e.g. *打[da3, to beat]-脱[tuo1]*). All the pairs contained minimal orthographic and semantic overlap.

Experiment 2a was conducted in the laboratory; the procedure was the same as that in Experiment 1. In Experiment 2b, we tried to replicate the results of Experiment 2b in an online Experiment with much higher statistical power. Given that it is not an option for online experiments to use an on-site confederate that performed face-to-face interaction with the participants, we employed audio prime stimuli in the picture verification task. This way, we kept the procedure of Experiment 2a and 2b as similar as possible.

Method

Participants

Seventy-two further students from Xi'an Jiaotong University, all native Mandarin speakers, participated in Experiment 2a for payment (49 females and 23 males, average age 20.86 years). All participants reported to be non-color-blind and had normal or corrected-to-normal vision. A 21-year-old female native Mandarin speaker acted as confederate.

Materials

We created a verification set of 180 pictures and a description set of 180 pictures. Both sets were composed of 72 critical pictures and 108 filler pictures. The configuration of the pictures is the same as in Experiment 1. Six transitive verbs were used as target verbs (*倒[dao4, to pour], 剪[jian3. To cut out], 截[jie2, to cut off], 绊[ban4, to trip], 脱[tuo1, to take off], 遮 [zhe1, to cover]*). Each target verb corresponded to 12 target pictures.

A description set of 252 sentences for the confederate were created. The confederate's description set contained 144 critical prime sentences that corresponded to 72 critical description pictures for participants. Half of these critical sentences were Ba transitive sentences (e.g., 5a, 6a, and 7a) and the other half were SVO transitive sentences (e.g., 5b, 6b, and 7b). The prime sentence in the Full Phonological Overlap condition (e.g., 5a and 5b) contained a prime verb that shared both the syllable and the tone with the corresponding target verb (e.g., *拖[tuo1, to mop]-脱 [tuo1, to take off],* all the example prime sentences correspond to the example target picture of Fig. 2). The prime verbs in the Syllabic Overlap condition (e.g., 6a and 6b) only shared the syllable with the target verbs (e.g., *驮[tuo2, to carry]-脱[tuo1]*). In the No Overlap condition (e.g., 8a and 8b), no phoneme or tone was shared between the prime verb and the target verb (e.g., *打[da3, to beat]-脱[tuo1]*). No meaningful graphic feature was shared within each verb pair. The other 108 sentences in the description set were the filler prime sentences. Thus, seventy-two critical trials and one hundred and eight filler trials were created for each participant. We had a 2 (prime condition) x 3 (overlap condition) design. Twelve counterbalanced pseudo-random lists were constructed for Experiment 2a.

(5a) Chushi BA zoulang tuo1-LE. *Ba transitive, Full phonological Overlap*
The chef BA the corridor mop-LE.
[The chef mopped the corridor.]

(5b) Chushi tuo1-LE zoulang. *SVO transitive, Full phonological Overlap*
The chef mop-LE the corridor.
[The chef mopped the corridor.]

(6a) Xiaoniao BA shuiguo tuo2-LE. *Ba transitive, Syllabic Overlap*

The bird BA the fruit carry-LE.

[The bird carried the fruit.]

(6b) Xiaoniao tuo2-LE shuiguo. *SVO transitive, Syllabic Overlap*

The bird carry-LE the fruit.

[The bird carried the fruit.]

(7a) Fuwuyuan BA e'gun da3-LE. *Ba transitive, No Overlap*

The waiter BA the bully beat-LE.

[The waiter beat the bully.]

(7b) Fuwuyuan da3-LE e'gun. *SVO transitive, No Overlap*

The waiter beat-LE the bully.

[The waiter beat the bully.]

A pretest was conducted to examine the semantic relatedness between prime verbs and target verbs in Experiment 2a-b and 3a-b. We employed a semantic relatedness judgment task of which the design was similar to the one used in Experiment 1. In the task, we adopted 48 prime-target sentence pairs from Experiment 2a-b and 3a-b. The critical sentence pairs included 12 Full Phonological Overlap pairs, 12 Syllabic Overlap pairs, 12 Tonal Overlap pairs, and 12 No Overlap pairs. We also included the Semantic Overlap pairs used in the pretest of Experiment 1. The Semantic Overlap pairs were taken as a reference level. Seventy-two further native Mandarin speakers (40 female and 32 male, average age 24.29 years) were recruited to participate in the judgment task. This confirmed that the semantic relatedness of the Semantic Overlap pairs (M= 3.988, 95% CI [3.854, 4.122]) was much higher than that of the Full Phonological Overlap pairs (M=1.398, 95% CI [1.220, 1.576]), that of the Syllabic Overlap pairs (M=1.568, 95% CI [1.382, 1.755]), that of the Tonal Overlap pairs (M=1.512, 95% CI [1.316, 1.707]), and that of the No Overlap pairs (M=1.556, 95% CI [1.381, 1.731]). The 95% confidence intervals indicated that all verb pairs (except for the Semantic Overlap pairs) were rated significantly below the neutral value. This suggested that the semantic relatedness was negligible between the prime verbs and target verbs in Experiment 2a-b and 3a-b.

Procedure and Scoring

The procedure and the scoring of Experiment 2a were the same as Experiment 1.

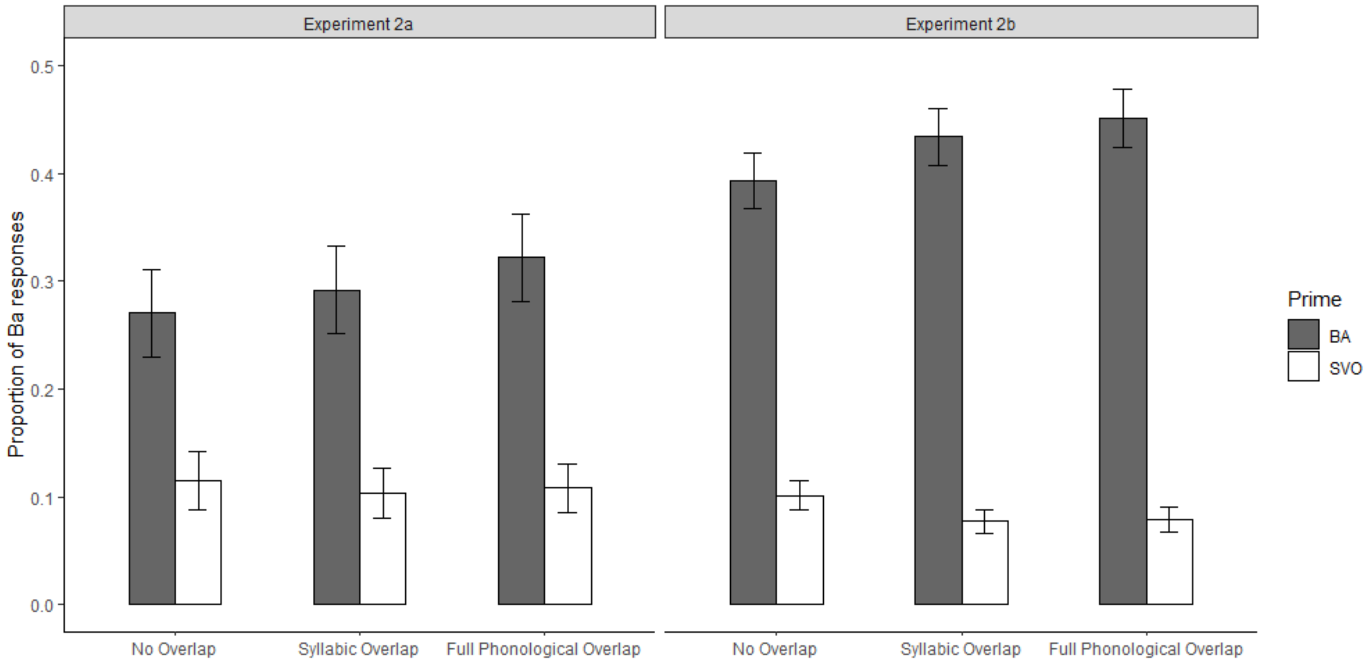

Fig. 4. The proportion of Ba responses as a function of prime condition and overlap condition in Experiment 2a and 2b. Error bars reflect standard errors calculated for a by-participants analysis.

Results

Critical trials in which participants produced no response or an Other response were excluded from the analyses (2.8% of the data). The final data set contained 5038 target responses, among which were 1017 Ba transitive responses (20.2%) and 4021 SVO transitive responses (79.8%).

The descriptive data of the Ba transitive production for each prime condition x overlap condition are illustrated in Fig. 4 and Table 1. The proportion of Ba transitive responses was 29.5% after Ba transitive primes and 10.9% after SVO primes, resulting in an 18.6% general structural priming effect. In the No Overlap condition, the proportion of Ba transitive responses after Ba transitive primes was 15.6% higher than that after SVO transitive primes. This difference was 21.4% in the Full Phonological Overlap condition and 18.9% in the Syllabic Overlap condition.

A GLM model was fitted that predicted the logit-transformed likelihood of a Ba transitive response. Prime condition (deviation coded) and overlap condition (simple difference coded, No Overlap as reference level) were included in the model as fixed factors. The final model included a random intercept and a random slope of prime condition for both subjects and items. The summary of the fixed effects of the model is listed in Appendix A. There was a significant main effect of prime condition ($\chi2 = 60.036$, df = 1, $p < .001$) and a marginally significant interaction between prime condition and overlap condition ($\chi2 = 5.963$, df = 2, $p = .058$). We then compared the magnitude of structural priming between each level of overlap condition (using false discovery rate [FDR] correction). We found that, in comparison with the No Overlap condition, there was a significantly stronger priming effect in the Full Phonological Overlap condition ($\beta = 0.599$, SE = 0.245, $p = .015$), but the contrasts between the priming effect in the Syllabic Overlap and No Overlap conditions as well as between Syllabic and Full Phonological Overlap conditions were not significant (p_zs > .1).

Again, three further LME models were fitted for each subset divided by overlap condition (i.e., Full Phonological Overlap, Syllabic Overlap, and No Overlap). Full models converged in the Full Phonological Overlap and No Overlap subsets. The final model in the Syllabic Overlap subset included a random intercept and a random slope of prime condition for subjects (with no random correlation) and a random intercept for items. Significant main effects of prime condition were found in all three subsets (p_zs < .001).

Experiment 2b The effect of phonological and syllabic overlap on structural priming (Online replication)

Method

Participants

Two hundred and twenty-three further participants, all native Mandarin speakers, were recruited online (mostly from social media groups including Tencent Wechat group and Tencent QQ group) and participated in Experiment 2b for payment (141 females, 55 males, 18 other, 6 unreported; average age 22.09 years). All participants reported to be non-color-blind and had normal or corrected-to-normal vision. Two participants were excluded from the final dataset because their accuracy in the picture verification task was below 60%. Five further participants were excluded because of technical issues.

Materials

The material employed in Experiment 2b was the same as that in Experiment 2a. The only change in Experiment 2b was that instead of a live confederate reading prime sentences from the confederate's description set, the prime sentences were presented to the participants in the form of audio clips. All the clips of prime sentences were pre-recorded by the same native speaker who acted as a confederate in Experiment 2a. The intensity of the clips was normalized to 75 dB.

Procedure

The study was administered online via JATOS (Lange, Kühn, & Filevich, 2015) using jsPsych (De Leeuw, 2015). To simulate an interactive task, the participants were instructed that they would hear another participant's description of a picture, that they had to verify the match between the description and the picture, and then describe another picture by themselves. An audio input check and a microphone check were placed at the beginning of the experiment. The overall procedure of the main test was the same as that in Experiment 1 with a few changes: first, to stimulate participants to focus on the tasks, the picture description tasks in Experiment 2b (and 3b) were computer-paced (duration = 5000 ms); second, since the participants did not have to wait for the confederate to proceed with the task, there was no longer a beep signal in the experiment.

Scoring

The scoring of Experiment 2b was the same as in Experiment 1.

Results

Critical trials in which participants produced no response or an Other response were excluded from the analyses (4.8% of the data). The final data set contained 14509 target responses, among which were 3804 Ba transitive responses (26.2%) and 10705 SVO transitive responses (73.8%).

The descriptive data of the Ba transitive production for each prime condition x overlap condition are illustrated in Fig. 4 and Table 1. The proportion of Ba transitive responses was 42.6% after Ba transitive primes and 8.6% after SVO primes, resulting in a 34.0% general structural priming effect. In the No Overlap condition, the proportion of Ba transitive responses after Ba transitive primes was 29.2% higher than that after SVO transitive primes. This difference was 37.2% in the Full Phonological Overlap condition and 35.7% in the Syllabic Overlap condition.

A GLM model was fitted that predicted the logit-transformed likelihood of a Ba transitive response. Prime condition (deviation coded) and overlap condition (simple difference coded, No

Overlap as reference level) were included in the model as fixed factors. The final model included a random intercept and a random slope of prime condition for both subjects and items. The summary of the fixed effects of the model is listed in Appendix A. There was a significant main effect of prime condition ($\chi2 = 212.37$, df = 1, $p < .001$) and a significant interaction between prime condition and overlap condition ($\chi2 = 42.178$, df = 2, $p < .001$). In comparison with the No Overlap condition, there was a significantly stronger priming effect in the Full Phonological Overlap condition ($\beta = 0.881$, SE = 0.147, $p < .001$) and, importantly, there was also a stronger priming effect in the Syllabic Overlap condition ($\beta = 0.838$, SE = 0.148, $p < .001$). The contrast between the priming effects in the Syllabic and Full Phonological Overlap conditions was not significant ($\beta = 0.042$, SE = 0.151, $p = .781$).

Again, three further LME models were fitted for each subset divided by overlap condition (i.e., Full Phonological Overlap, Syllabic Overlap, and No Overlap). Full models converged in all subsets. Significant main effects of prime condition were found in all three subsets (p_zs < .001).

Discussion Experiments 2a and 2b

In Experiments 2a and 2b, we first replicated the structural priming effect of the Ba transitive vs. the SVO transitive. This once again indicates that the structure of a previously experienced sentence influences native Mandarin speakers' choice of word order. More importantly, in both experiments the priming effect was significantly stronger in the Full Phonological Overlap condition, indicating that the persistence of syntactic structure can benefit from phonological overlap that is independent of orthographic consistency. In Experiment 2a, we did not find a significant effect of syllabic overlap, although there was a numerical trend. This is possibly because even with more than seventy participants, the statistical power of the experiment was not high enough to detect a syllabic effect. In Experiment 2b, we tried to replicate the results of Experiment 2a in a large-scale online experiment (with three times as many participants as in Experiment 2a). We found a significant syllabic overlap effect on structural priming, the magnitude of which was not different from that of the full phonological boost. Taken together, the findings supported the hypothesis that the information of a full phonological form and an atonal syllable in Mandarin flow back to the lemma level and modulate the encoding of the combinatorial information in sentence production.

In Experiments 3a and 3b, we tried to replicate the full phonological boost effect in two further experiments (a laboratory experiment and a large-scale online experiment). Crucially, we also investigated the effects of tonal overlap on structural priming. We therefore manipulated the transitive verbs in the prime and the target: they either had full-phonological overlap (e.g., *拖[tuo1]*-*脱[tuo1]*), tonal overlap only (e.g., *称[cheng1, to weigh]-脱[tuo1]*), or no overlap (e.g. *打[da3, to beat]*-*脱[tuo1]*). All the pairs contained minimal orthographic and semantic overlap.

Experiment 3a The effect of phonological and tonal overlap on structural priming (Lab experiment)

Method

Participants

Seventy-two further students from Xi'an Jiaotong University, all native Mandarin speakers, participated in Experiment 3a (50 females and 22 males, average age 20.86 years). All participants reported to be non-color-blind and had normal or corrected-to-normal vision. The same native Mandarin speaker as in Experiment 2a acted as a confederate.

Materials, procedure, and scoring

The materials used in Experiment 3a were almost identical to those of Experiment 2a. The only difference was that instead of prime sentences containing syllabically overlapping verbs, Experiment 3a used prime sentences with tonally overlapping verbs (e.g., 8a and 8b). The prime sentences in the Tonal Overlap condition contained prime verbs that only shared the tones with the target verb (e.g., *称[cheng1, to weigh]-脱[tuo1, to take off]*).

(8a) Hushi BA ying'er cheng1-LE. *Ba transitive, Tonal Overlap*
The nurse BA the baby weight-LE.
[The nurse weighted the baby.]

(8b) Hushi cheng1-LE ying'er. *SVO transitive, Tonal Overlap*
The nurse weigh-LE the baby.
[The nurse weighed the baby.]

The procedure and the scoring of Experiment 3a were the same as in Experiment 1.

Results

Critical trials in which participants produced no response or an Other response were excluded from the analyses (2.7% of the data). The final data set contained 5043 target responses, among which were 1174 Ba transitive responses (23.3%) and 3869 SVO transitive responses (76.7%).

The descriptive data of the Ba transitive production for each prime condition x overlap condition are illustrated in Fig. 4 and Table 1. The proportion of Ba transitive responses was 33.6% after Ba transitive primes and 12.7% after SVO primes, resulting in a 20.9% general structural priming effect. In the No Overlap condition, the proportion of Ba transitive responses after Ba transitive primes was 18.2% higher than that after SVO transitive primes. This difference was 24.1% in the Full Phonological Overlap condition, and 20.4% in the Tonal Overlap condition.

A GLM model was fitted that predicted the logit-transformed likelihood of a Ba transitive response. Prime condition (deviation coded) and overlap condition (simple difference coded) were included in the model as fixed factors. The final model included a random intercept and a random slope of prime condition for both subjects and items. The summary of the fixed effects of the model is listed in Appendix A. We found a significant main effect of prime condition ($\chi 2$ = 56.997, df = 1, $p < .001$) and a significant interaction between prime condition and overlap condition ($\chi 2$ = 6.550, df = 2, $p = .038$). Priming was significantly stronger in the Full Phonological Overlap than in the No Overlap conditions ($\beta = 0.583$, SE = 0.224, $p = .009$), but no difference was found between the Tonal Overlap and the No Overlap condition as well as between the Tonal Overlap and the Full Phonological Overlap condition (p_zs > .1).

Again, three further LME models were fitted for each subset divided by overlap condition (i.e., Full Phonological Overlap subset, Tonal Overlap subset, and No Overlap subset). Full models converged in the Full Phonological Overlap subset and the No Overlap subset. The by-item random slope of prime condition was dropped in the Tonal Overlap subset. Significant main effects of prime were found in all three subsets (p_zs < .001).

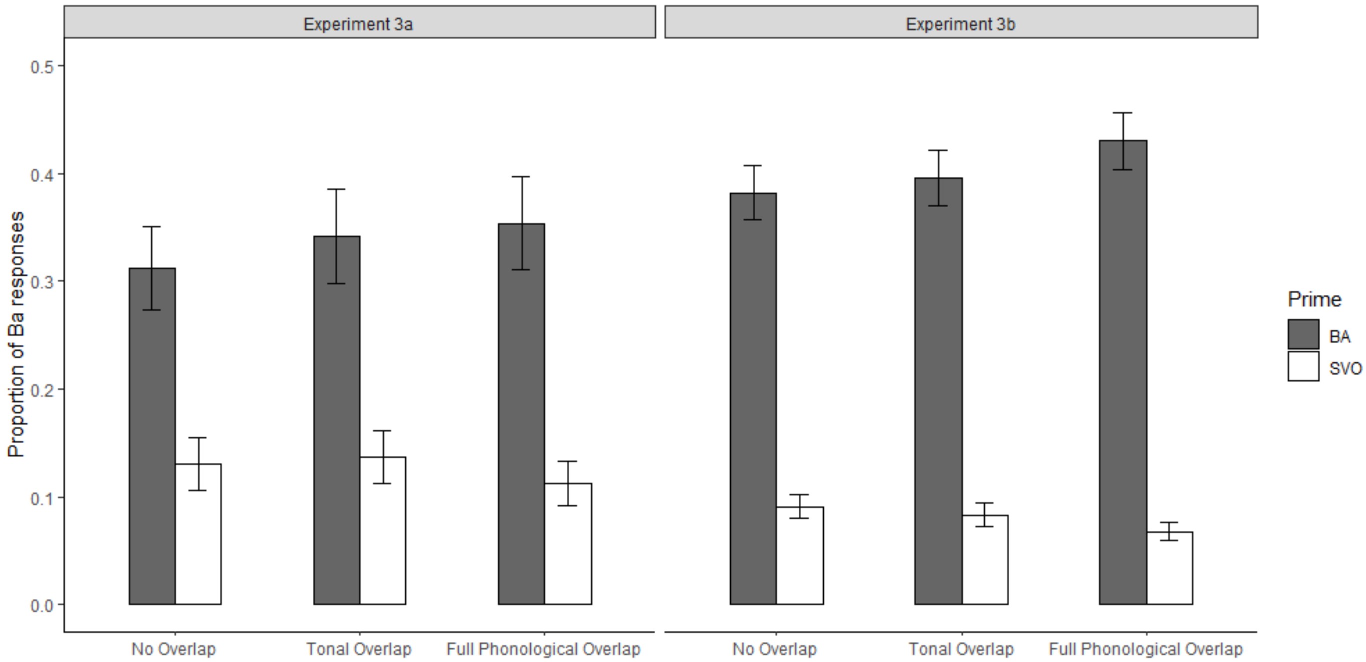

Fig. 5. The proportion of Ba responses as a function of prime condition and overlap condition in Experiment 3a and 3b. Error bars reflect standard errors calculated for a by-participants analysis.

Experiment 3b The effect of phonological and tonal overlap on structural priming (Online replication)

Method

Participants

Two hundred and twenty-eight further participants, all native Mandarin speakers, were recruited online and participated in Experiment 3b for payment (153 females, 54 males, 20 other, 1 unreported; average age 21.55 years). All participants reported to be non-color-blind and had normal or corrected-to-normal vision. Six participants were excluded because their accuracy in the picture verification task was below 60%. Six further participants were excluded because of technical problems.

Materials, procedure, and scoring

The materials used in Experiment 3b were the same as Experiment 3a except that the prime sentences were pre-recorded audio clips. The procedure and scoring were the same as Experiment 2b.

Results

Critical trials in which participants produced no response or an Other response were excluded from the analyses (4.6% of the data). The final data set contained 14584 target responses, among which were 3550 Ba transitive responses (24.3%) and 11034 SVO transitive responses (75.7%).

The descriptive data of the Ba transitive production for each prime condition x overlap condition are illustrated in Fig. 5 and Table 1. The proportion of Ba transitive responses was 40.2% after Ba transitive primes and 8.1% after SVO primes, resulting in a 32.2% general structural priming effect. In the No Overlap condition, the proportion of Ba transitive responses after Ba transitive primes was 29.1% higher than that after SVO transitive primes. This difference was 36.2% in the Full Phonological Overlap condition and 31.2% in the Tonal Overlap condition.

A GLM model was fitted that predicted the logit-transformed likelihood of a Ba transitive response. Prime condition (deviation coded) and overlap condition (simple difference coded, No Overlap as reference level) were included in the model as fixed factors. The final model included a random intercept and a random slope of prime condition for subjects as well as a random intercept, a random slope of prime condition, and a random slope of overlap condition for items. The summary of the fixed effects of the model is listed in Appendix A. There was a significant main effect of prime condition ($\chi2 = 213.67$, df = 1, $p < .001$) and a significant interaction between prime condition and overlap condition ($\chi2 = 32.133$, df = 2, $p < .001$). In comparison with the No Overlap condition, there was a significantly stronger priming effect in the Full Phonological Overlap condition ($\beta = 0.825$, SE = 0.148, $p < .001$). However, tonal overlap did not influence the priming effect ($\beta = 0.174$, SE = 0.143, $p = .223$). The priming effect was significantly stronger in the Full Phonological Overlap condition than that in the Tonal Overlap condition ($\beta = 0.652$, SE = 0.148, $p < .001$).

Again, three further LME models were fitted for each subset divided by overlap condition (i.e., Full Phonological Overlap, Tonal Overlap, and No Overlap). Full models converged in all subsets. Significant main effects of prime condition were found in all three subsets (p_zs < .001).

Discussion Experiments 3a and 3b

In Experiment 3a and 3b, we once again replicated the structural priming effect for the Mandarin transitive. The full phonological boost effect on structural priming was also replicated in both experiments. In both experiments, the tonal overlap only showed a numerical advantage in structural priming. In the more well-powered Experiment 3b, the structural priming effect was in fact significantly weaker in the Tonal Overlap condition than in the Full Phonological Overlap condition and comparable to the No Overlap condition. The results suggest that the effect of tonal overlap on structural priming was negligible.

General Discussion

In five structural priming experiments in Mandarin, we investigated the effects of phonological feedback on structural priming. In Experiment 1, we tested the effects of three types of overlap between prime and target verbs on priming, namely lexical overlap, semantic overlap, and phonological overlap (full phonological overlap or syllabic overlap only). This experiment demonstrated a clear structural priming effect of the Mandarin Ba transitive vs. SVO transitive. The structural priming effects, relative to baseline priming, were stronger when the full lexical representations were shared between the prime verb and the target verb (i.e., lexical boost). As far as we know, the current study is the first to demonstrate Mandarin Ba transitive structural priming in adult speakers and the first to show the lexical boost effect on Ba transitive structural priming. However, neither semantic overlap nor phonological overlap increased the magnitude of structural priming. In Experiments 2a and 2b, the prime verb and the target verb either had full phonological overlap, overlap only in the atonal syllable, or no overlap. In both experiments, priming was boosted by full phonological overlap, demonstrating that there is a phonological boost of structural priming in the absence of overlap in orthographic representations. A significant syllabic boost effect was also found in the well-powered online experiment (Experiment 2b). Experiments 3a-b replicated Experiments 2a-b but replaced the syllabic-only condition with a tonal-only condition. The facilitation effect of full phonological overlap was replicated in both experiments, demonstrating once more that there is a phonological boost on priming even in the absence of orthographic overlap. However, no evidence of a tonal overlap effect could be found in Experiments 3a-b.

Free-standing Phonological boost of Mandarin structural priming

In two lab-based experiments (Experiments 2a and 3a) and two large-scale online experiments (Experiments 2b and 3b), we demonstrated phonological boost effects on structural priming that were independent of orthographic overlap. The priming effect was significantly stronger when there was a full phonological overlap between the prime and the target verbs than when no representation was shared. We did not find a similar phonological boost of structural priming in Experiment 1. The most probable explanation would be that in Experiment 1 there was a lack of statistical power to detect a phonological boost effect. The sample size of Experiment 1 (40 participants, 64 items) should guarantee an 80% power to detect a structural priming effect as well as a lexical boost effect (Mahowald et al., 2016), but given that the effect size of a phonological boost is usually considerably smaller than that of the lexical boost, it is reasonable to suspect that Experiment 1 is underpowered for the interaction between prime condition and phonological overlap. This explanation is supported by the fact that significant phonological boost effects consistently manifested themselves in four statistically more powerful experiments, especially in the two large-scale online experiments.

The findings are consistent with the phonological boost effect found in noun phrase structural priming (Bernolet et al., 2012; Santesteban et al., 2010). Our finding demonstrates that a phonological boost effect can also arise in verb phrase structural priming, and importantly, that it occurs even when representations at the other linguistic levels (e.g., orthography) are not shared between prime and target. Our findings seem to be at odds with studies that found a null effect of phonological overlap (Cleland & Pickering, 2003). However, as we have noted, the lack of a significant phonological effect in Cleland and Pickering (2003) might be attributed to the limited phonological overlap between the prime and the target head nouns, rendering feedback from the overlapping phonemes too weak to induce a facilitation effect on grammatical encoding.

As the orthographic overlap between the prime and target verb was controlled, we further demonstrated that speakers were able to exploit repeated phonological representations to facilitate sentence encoding despite the orthographic inconsistency. This finding contrasts with a broad assumption that an orthographic representation is mandatorily activated during spoken production (Damian & Bowers, 2003). As argued by Damian and Bowers (2003) and Roelofs (2006), one possible cross-linguistic factor that mediates the orthographic consistency effect in spoken word processing is the phonology-to-spelling transparency. They predicted that the contribution of orthographic forms should weigh more in a language in which the phonology-to-spelling correspondence is less transparent, as is the case with Mandarin. In contrast, the independent phonological boost effect in the current study indicates that the activation of a related orthographic representation is not an obligatory precondition for phonological overlap to be functional in grammatical encoding in Mandarin sentence production.

We did not rule out the possibility of an effect of orthographic overlap on structural priming, since we did not manipulate the orthographic overlap between the prime verb and the target verb. Nevertheless, the current findings do suggest that phonemes and graphemes can be at least processed separately when formulating utterances in Mandarin. This is consistent with the assumption that phonological and orthographic overlap effects occur at independent processing levels in Mandarin spoken word production (J.-Y. Chen et al., 2002; Zhang, Chen, Stuart Weekes, & Yang, 2009; Zhang et al., 2007; Zhang & Weekes, 2009; but see Zhao, La Heij, & Schiller, 2012). Taken together, the current study offered ample evidence for a stand-alone phonological boost effect on structural priming. This suggests that the processing of phonological information feeds back to the lemma node and modulates grammatical encoding.

Effects of syllabic and tonal processing on grammatical encoding

Our study is the first to examine the effect of segmental and tonal overlap on structural priming. In four experiments, we studied how syllabic and tonal processing in Mandarin feed back to the syntactic choices in sentence production. We first turn our focus to the syllabic effect on structural priming. In Experiment 2a, there was a numerical trend that syllabic overlap facilitated structural priming. This might once again suggest that the experiments were underpowered to detect a phonological effect that was induced by a subcomponent of the full phonological overlap. In a further online experiment with substantial sample size (Experiment 2b), we found a significant boost effect caused by syllabic overlap. The magnitude of the syllabic boost effect, although numerically smaller, was not different from that of the full phonological boost effect. We thus showed convincing evidence that the processing of an atonal syllable modulates the syntactic choices in structural priming.

The facilitation effect exerted by the atonal syllable meshes nicely with the findings in word production in Mandarin (J.-Y. Chen et al., 2002). As we have mentioned, Mandarin speakers' voice onset time for a cued word was shortened when the targets in the same block overlapped in the atonal syllable (e.g., the target production of *科技[ke1ji4, technology* speeded up the production of a subsequent target *咳嗽[ke2sou4, cough]*). This indicates that the atonal syllable is a selectable unit in word-form preparation and that the advance knowledge about an atonal syllable is sufficient to benefit the subsequent phonological planning (J.-Y. Chen et al., 2002; O'Seaghdha et al., 2010). Similarly, the syllabic boost effect found in the current study suggested that the atonal syllable was selectable during the encoding of the target verb. Once the target syllable was activated, the activation of the syllable node effectively spread backwards to lemma selection, thus reinforcing the activation of the associated combinatorial information. Our findings thus converge with the evidence in Mandarin word production in that both supported the hypothesis that syllables in Mandarin can be prepared as a free-standing phonological unit (O'Seaghdha et al., 2010). We further argue that the preparation of an atonal syllable in Mandarin not only modulates the forward flow to syllabic motor program but also influences the backward flow to lemma encoding.

Our finding of an atonal syllable boost effect seems to contrast with the results of cross-language structural priming studies using Mandarin as the target language, in which no significant effect of phonemic overlap on structural priming was found (Cai et al., 2011; Huang et al., 2019). One possible reason for the discrepancy in the phonological overlap effect is whether or not the full syllables were manipulated in the experiments. As we have mentioned, phonological processing in Mandarin might not be sensitive to the activation of subsyllabic components (O'Seaghdha et al., 2010). In Cai et al. (2011) and Huang et al. (2019), phonemic overlap cumulated mostly within a syllable. The consistency at the subsyllabic level does not necessarily lead to the selection of a syllable, such that the activation of subsyllabic segments cannot effectively spread to other levels. In contrast, the current experiments included a condition in which the verb pairs fully overlapped in syllabic representation. Consistent with the assumption that the proximate phonological planning unit in Mandarin is an atonal syllable (T.-M. Chen & Chen, 2013; O'Seaghdha et al., 2010; Roelofs, 2015), the activation of the atonal syllable is sufficient to flow to the lemma node, leading to a syllabic feedback effect at the lemma stratum. To fully illustrate whether there is a qualitative distinction between the feedback of syllabic information and the feedback of subsyllabic information in Mandarin, future studies might systematically examine the overlap effect at both the syllabic level (e.g., the first and second syllable of a disyllabic word) and subsyllabic level (e.g., the onset, body, and coda of a syllable).

On the other hand, we did not find any evidence of a tonal effect on structural priming. In Experiment 3a and 3b, tonal overlap did not effectively promote the persistence of the syntactic structure. We showed that the tonal boost effect was extremely weak at best. The lack of tonal effect squares with the findings in word production in Mandarin (J.-Y. Chen et al., 2002; Wong & Chen, 2008) in that the tonal overlap alone did not lead to a faster preparation of the lexical item. This supports the view that the tonal frame cannot be taken as a functional phonological planning unit (J.-Y. Chen et al., 2002; T.-M. Chen & Chen, 2013; O'Seaghdha et al., 2010; Wang et al., 2018). It is conceivable why speakers cannot retrieve the tonal frame alone: Given that syllabic encoding and tonal encoding proceed in parallel (J.-Y. Chen et al., 2002; O'Seaghdha et al., 2010; Roelofs, 2015), it is possible that speakers orient the phonological encoding to the process that is more essential to the retrieval of the lexeme. Since only the advance information of atonal syllables is beneficial to the subsequent encoding of segments, speakers might prioritize syllabic encoding over tonal encoding. If this is the case, tonal information cannot be effectively prepared unless the syllabic information has been specified. Consequently, the lexically unspecific tonal frame is not selectable and cannot influence the encoding at other levels. Thus, no tone-only feedback effect can be found in structural priming. This once again supports the proximate unit hypothesis in language production in Mandarin (O'Seaghdha et al., 2010).

Alternatively, it is also possible that there is no qualitative but only a quantitative distinction between the feedback effects of syllabic overlap and tonal overlap. If this is the case, the lack of tone-only feedback effect can be attributed to a fan effect that modulates the interactivity between levels of language processing (Anderson & Reder, 1999; Cohen & Grossberg, 1987; Radvansky & Zacks, 1991, see Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009 and Wong & Chen, 2008 for a related discussion of fan effects in language processing). One of the basic assumptions of the fan effect is that the strength of the association between node A and B is modulated by the number of nodes A is associated with. The more nodes link to A, the weaker the association strength between A and B, and less activation is spread from A to B. Specific to the current study, the number of words that share the same tone in Mandarin is much larger than the number of words that share the same atonal syllable. It follows that there are considerably more lemma nodes associated with a tone than those associated with a syllable. It is reasonable that the large number of candidates at the lemma stratum weakened the link between the tonal frame and the prime verb and further diluted the activation feedback from the tonal frame.

The phonological effects we observed in this study are consistent with at least two theoretical accounts of structural priming. The first account is an adaptation of Pickering and Branigan (1998)'s model of sentence production for Mandarin (Fig. 6). Based on the lexicalist account of production (Levelt et al., 1999), Pickering and Branigan (1998) proposed that syntactic information is encompassed in the lemma level, wherein a lemma node is linked to combinatorial nodes that represent the syntactic structures licensed by the word. Priming effects occur when the activation of the combinatorial node attached to the lemma node of the prime sentence persists to the target production. If, in addition, the lemma node is activated again, more activation of the lemma node streams to the combinatorial node. This reinforced activation further boosts the preference for the primed structure, causing a lexical boost effect to syntactic priming.

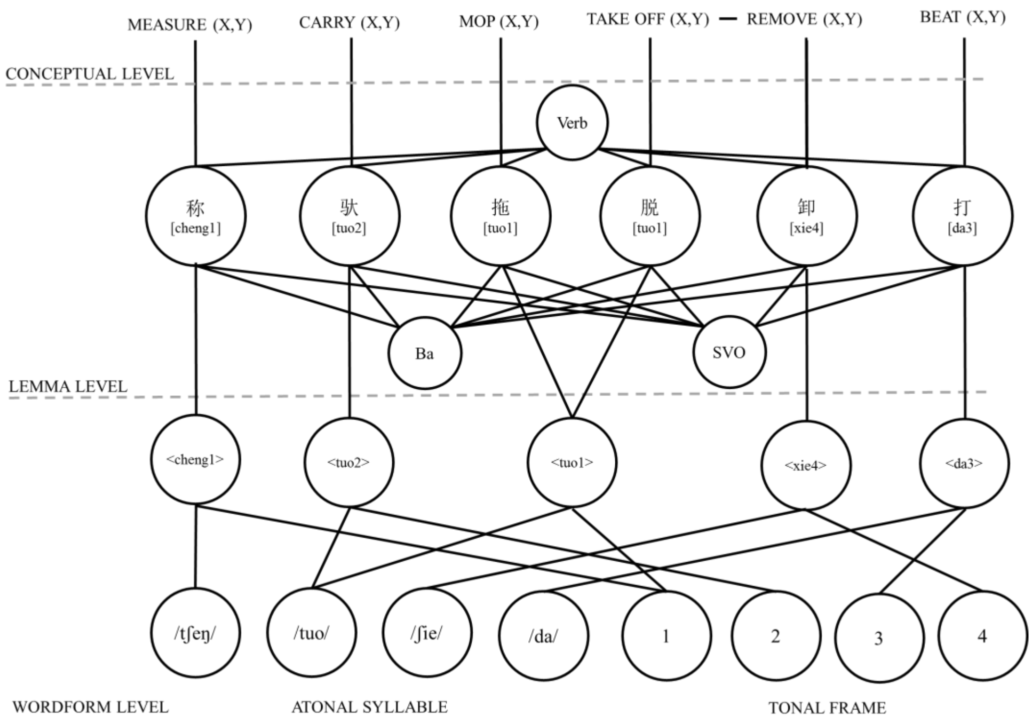

Fig. 6. A model of sentence production in Mandarin adapted from Pickering and Branigan (1998) with the relevant nodes. Each lemma node is connected to a conceptual node (e.g., TAKE OFF (X,Y)), a categorical node (Verb), the combinatorial nodes that represent the syntactic structure (Ba transitive and SVO transitive), and a lexeme node. A tonal frame and an atonal syllable in the word-form level are attached to the lexeme node in the word-form level. In tonal frame, 1 = high, 2 = mid-rising, 3 = low-dipping, 4 = high-falling.

In line with this account, upon hearing the prime sentence *Chushi BA zoulang tuo-LE (The chef mop-LE the corridor)*, the lemma node of the verb (*拖[tuo1]*), the combinatorial node for the syntactic structure (Ba transitive [NPbaNPVP]), and the link between the lemma node and the combinatorial node are activated. This activation persists until the target task, when the lemma node of the target verb (*脱[tuo1]*) is activated. The activation of the target verb streams downwards and reinforces the activation of the syllable (*/tuo/*) and the tonal frame (first tone) that are shared between the prime verb and the target verb. In the Full Phonological Overlap condition, the reinforced activation at the syllable and tonal representations feeds back to the prime verb and further to the connected combinatorial node that is activated during the prime task (Ba transitive). This results in a higher likelihood for the speakers to choose Ba transitive over SVO transitive in the target picture description when both the syllable and the tone are repeated between the prime and the target verb, relative to the No Overlap condition. When the prime and the target overlap only in syllable, the activation of the syllable of the target verb is also sufficient to flow back to the lemma node, resulting in a higher activation level of the primed combinatorial node (Ba transitive). However, when only the tonal frames are repeated, the activation at the tonal node cannot effectively spread to other nodes, yielding little to no tonal effect on structural priming.

An alternative way to interpret the phonological boost effect is given by the multifactorial account of structural priming (Chang et al., 2006; Hartsuiker et al., 2008). This account posits that structural priming is driven by multiple memory systems (Chang et al., 2006; Chang, Janciauskas, & Fitz, 2012; Hartsuiker et al., 2008). Specifically, an implicit learning process drives long-term, abstract priming, whereas the short-term priming effect is underpinned by an explicit memory-related process. When a lexical item is repeated between prime and target, the repeated item can be taken as a lexical cue that facilitates the memory retrieval of sentence structure in explicit memory. This way, the lexical boost is intrinsically a lexical cueing effect on structure retrieval. Generalizing this assumption, speakers might also take the overlapping phonological features with the prime sentence as a retrieval cue, resulting in a phonological boost effect on the explicit memory-related process in structural priming.

This surmised phonological cueing effect seems to be supported by some early work on levels of processing in cue-dependent memory retrieval (Craik & Tulving, 1975; Fisher & Craik, 1977). In these studies, participants were instructed to read certain words and pay attention to certain features of the words (e.g., they were asked to judge whether the word rhymes with *weight* before encoding the word *crate*), and after encoding they were given an incidental recall task. Craik and colleagues found that speakers recalled the encoded words better when the phonological features (rhyme) of the words were cued in both encoding and retrieval phase, indicating that speakers were able to capitalize on the phonological features of the words to facilitate memory retrieval. They argued that memory traces of the associated phonological form are encoded during comprehension. Such traces can be retained in short-term memory so as to increase the likelihood of memory retrieval when the phonological form is cued. Pertaining to the case in the current study, the lexico-syntactic information of the prime sentence structure could be better retrieved when the phonological representations were repeated between sentence structure encoding and retrieval, yielding a boost effect on structural priming. In this account, the cohort size of the words sharing the same feature can be one of the factors that determine the associative strength between the cue (i.e., the shared phonological information) and the to-be-retrieved memory traces (i.e., the lexico-syntactic information of the prime). Specific to the current study, the fan effect was the most detrimental to the association between the tonal feature and the prime because of the large cohort of tone-related words, whereas it was the least detrimental to the association between the full phonological feature and the prime. This accounts for the cueing effects of the full phonological and syllabic overlap, and the absence of such cueing with tonal overlap.

In spite of the multiple possible interpretations, our finding of the phonological boost effect on structural priming clearly suggests that the activation in phonological processing influences the accessibility of syntactic structures in sentence production. This is consistent with the notion that the information at the phonological level can be exploited to guide the speakers' sentence formulation (Bock, 1982; Vigliocco & Hartsuiker, 2002).

Semantic boost effects on structural priming

In Experiment 1, we examined whether there is a semantic boost of structural priming with the Mandarin Ba-SVO alternation. There was a small numerical trend of such a semantic boost but it was not statistically significant. There are several possible reasons why we did not find a significant semantic boost. Transitive verbs have an overlap in general in the *event structures* that map onto the transitive verbs, possibly along the lines of "X acting on Y:" (Goldberg, 2006; Pinker, 1989). Recent studies suggested that there is a contribution of semantic consistency in structural priming (Bernolet, Colleman, & Hartsuiker, 2014; Bunger, Papafragou, & Trueswell, 2013; Cleland & Pickering, 2003; Santesteban et al., 2010; J. Ziegler et al., 2018). In particular, some authors demonstrated that the shared event structure enhanced or even gave rise to some structural priming effects (Bernolet et al., 2014; Bunger et al., 2013; J. Ziegler et al., 2018). Although we tried to eliminate the semantic relatedness between transitive verbs, this shared event structure might have exerted an across-the-board effect on structural priming and possibly overrode the effects arising from the similarity of the semantic representation of the verbs.

On the other hand, it is also possible that syntactic encoding in Mandarin is independent of the semantics-to-structure mapping. This view seems to be supported by the findings of Huang et al. (2016). In a series of structural priming experiments with Mandarin datives, Huang and colleagues found no evidence that animacy overlap in the recipient enhanced structural priming. X. Chen, Branigan, Wang, Huang, and Pickering (2020) provided further evidence for this conclusion by showing that syntactic persistence is independent of the persistence of animacy order between prime and target. To generalize this conclusion, we might assume that, at least in Mandarin, the consistency of any semantic relation between the prime and target would not interact with syntactic persistence. This assumption is compatible with the lack of semantic boost effect in the current study. Nevertheless, the null effect of semantic relatedness in these studies including ours might be caused by the fact that the manipulation of semantic overlap was not strong enough to induce a boost effect. One possibility is that the semantic boost effect on structural priming will only manifest itself when the prime verb and the target verb are (near-) synonyms.

Lexical overlap effect on word order priming

In Experiment 1, we also found a lexical boost effect with considerable magnitude on structural priming of Mandarin Ba transitive construction. As we have argued, the locus of the structural priming effect with SVO-Ba transitive alternation is the persistence of the word order. Thus, the lexical boost effect in Experiment 1 is intrinsically a facilitation effect of lexical repetition on word-order priming. To the best of our knowledge, no study has demonstrated a similar lexical overlap effect on word-order priming. Most of the studies on lexical boost used structure alternations where grammatical role assignment and linear order co-vary (e.g., DO vs. PO, Pickering & Branigan, 1998; Of-genitive vs. S-genitive, Bernolet, Hartsuiker, & Pickering, 2013). In contrast, the current study reveals that the activation of the prime verb in the subsequent production enhanced the accessibility of the primed word order.

It should be noted that this proposed locus of the lexical effect only holds if the two structures only differ in the linear word order. Some linguists would suggest that the presence of *Ba* changes the hierarchical structure and signals a patient that is more affected by the agent (James et al., 2009), which renders the Ba transitive a construction distinct from the SVO transitive. However, generalized from the view of DO vs. Ba-DO in Cai et al. (2012), it is unlikely that this lexical effect reinforced the persistence of mapping between the thematic role and the grammatical function since both structures have the same mapping (agent-subject, patient-object). It is also implausible that this lexical effect functioned during the mapping between thematic role and linear position because the thematic role orders are always the same (agent then patient) and the insertion of *ba* does not assign more emphasis on any of the thematic roles. This would leave us with the persistence of word order as the most feasible locus of the Ba transitive priming. Thus, the lexical boost effect on Mandarin Ba transitive priming suggests that overlap of lexical representations can increase the accessibility of the associated word order.

This finding is compatible with grammatical encoding models in which lexical items and constituent structure can be retrieved in parallel (Cai et al., 2012; Pickering, Branigan, & McLean, 2002). In contrast with Bock (1987), we suggest that an effect of lexical representation overlap, in particular the phonological overlap effect on grammatical encoding, might not primarily come about at the conceptual level in the form of a conceptual accessibility effect. Bock argued that the competition between phonological neighbors might reduce the conceptual accessibility of the target and further result in a delayed production of the target word. If this would be the case, we would expect more verb-final (i.e., Ba transitive) production in the conditions where the phonological representation of the verb was repeated. This is unlikely since we did not find significant main effects of phonological overlap on the proportions of Ba transitive responses in any of the experiments (see Appendix A). Thus, our findings suggest that the lexical boost effect on structural priming mainly comes about later than during conceptualization, and one possible locus of such effect is the computation of the linear order of the sentence.

Online studies of sentence production

Large-scale online experiments were employed in Experiment 2b and 3b. This joins the small group of studies using online platforms to test sentence production (J. Ziegler, Bencini, Goldberg, & Snedeker, 2019; J. Ziegler & Snedeker, 2018). Importantly, we observed that the structural priming effects were numerically larger in the online experiments (34.0% general structural priming effect in Experiment 2b, 32.2% in Experiment 3b) than in the lab experiments (18.6% in Experiment 2a, 20.9% in Experiment 3a). There is no principled reason why the structural priming effects are stronger in the online experiments. One possible factor is that in the online experiments we additionally set a five seconds deadline in the picture description task. Under such time pressure, speakers might be less influenced by strategic processes (e.g., monitoring), such that the priming effects might be less hindered by them. However, as there is no previous evidence showing a deadline effect on structural priming, this explanation is speculative. Regardless of what underlays the apparant "boost" of the effect in the online experiments, it is noteworthy that a well-attested effect in sentence production (i.e., structural priming, Mahowald et al., 2016) can be very robust in online settings, suggesting that online platforms can be exploited as an eligible alternative to lab-based experiments in the study of sentence production.

Conclusion

The current study addressed two main questions with respect to the phonological boost of structural priming: 1) whether the phonological effect on structural priming arises without orthographic overlap; and 2) whether segmental or tonal overlap alone is enough to induce boost effects. In five experiments in Mandarin, we found that phonological overlap facilitated structural priming when no orthographic representation was shared between prime and target verbs. We further demonstrated that syllabic overlap but not tonal overlap effectively facilitated structural priming. The pattern of the boost effects suggests that the lexical effect on grammatical encoding entails interactivity with the word-form level, as well as a syllable-oriented parallel processing within the phonological level, and that such interaction might be likely to occur during the formulation of the word order.

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Declaration of interest

None.

Informed consent was obtained for experimentation with human subjects.

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Appendix A

Summary of fixed effects in logit mixed effect models in Experiment 1, 2a-b, and 3a-b

	Estimate	SE	z	p-value
Experiment 1				
Intercept	-3.586	0.342	-10.471	<.001
Structure (Ba vs. SVO)	2.541	0.311	8.162	<.001
Overlap (Full vs. No)	-0.059	0.280	-0.211	.833
Overlap (Semantic vs. No)	0.181	0.235	0.767	.443
Overlap (Phonological vs. No)	-0.045	0.234	-0.192	.848
Structure (Ba vs. SVO) : Overlap (Full vs. No)	2.222	0.563	3.947	.000
Structure (Ba vs. SVO) : Overlap (Semantic vs. No)	0.045	0.471	0.096	.923
Structure (Ba vs. SVO) : Overlap (Phonological vs. No)	-0.622	0.469	-1.326	.185
Experiment 2a (Lab Experiment)				
Intercept	-2.861	0.303	-9.437	<.001
Structure (Ba vs. SVO)	2.251	0.245	9.170	<.001
Overlap (Syllabic vs. No)	0.029	0.123	0.233	.816
Overlap (Full phonological vs. No)	0.213	0.122	1.742	.082
Structure (Ba vs. SVO) : Overlap (Syllabic vs. No)	0.411	0.247	1.665	.096
Structure (Ba vs. SVO) : Overlap (Full phonological vs. No)	0.599	0.245	2.445	.015
Experiment 2b (Online Replication)				
Intercept	-2.595	0.187	-13.910	<.001
Structure (Ba vs. SVO)	3.712	0.216	17.212	<.001
Overlap (Syllabic vs. No)	-0.059	0.074	-0.800	.424
Overlap (Full phonological vs. No)	0.033	0.073	0.455	.649
Structure (Ba vs. SVO) : Overlap (Syllabic vs. No)	0.838	0.148	5.670	<.001
Structure (Ba vs. SVO) : Overlap (Full phonological vs. No)	0.881	0.147	5.998	<.001

(Continue)

	Estimate	SE	z	p-value
Experiment 3a (Lab Experiment)				
Intercept	-2.355	0.276	-8.539	<.001
Structure (Ba vs. SVO)	2.003	0.218	9.174	<.001
Overlap (Tonal vs. No)	0.175	0.110	1.597	.110
Overlap (Full phonological vs. No)	0.053	0.112	0.473	.636
Structure (Ba vs. SVO) : Overlap (Tonal vs. No)	0.198	0.219	0.902	.367
Structure (Ba vs. SVO) : Overlap (Full phonological vs. No)	0.583	0.224	2.602	.009
Experiment 3b (Online Replication)				
Intercept	-2.496	0.173	-14.408	<.001
Structure (Ba vs. SVO)	3.326	0.189	17.590	<.001
Overlap (Tonal vs. No)	0.002	0.072	0.030	.976
Overlap (Full phonological vs. No)	-0.014	0.076	-0.182	.856
Structure (Ba vs. SVO) : Overlap (Tonal vs. No)	0.174	0.143	1.217	.223
Structure (Ba vs. SVO) : Overlap (Full phonological vs. No)	0.825	0.148	5.593	<.001

Appendix B

Primes and exemplar targets used in Experiments 1, 2a-b, and 3a-b

Note. The description of the target picture given in line a depicts the content of the exemplar target picture (in SVO transitive structure). Prime sentences in Ba transitive and SVO transitive are given in Mandarin (with the literal translation in English in the parenthesis). Line b-e in Experiment 1 corresponds to prime sentences in Full Overlap, Semantic Overlap, Phonological Overlap, and No Overlap conditions. In Experiments 2a-b and 3a-b, they correspond to prime sentences in Full Phonological Overlap, Syllabic Overlap, Tonal Overlap, and No Overlap conditions. In each prime sentence, the Ba transitive sentence is mentioned in the braces before the slash and the SVO transitive sentence is mentioned in the braces after the slash. The pinyin and tone of the prime and target verbs is given in the square brackets after the verb.

Experiment 1

1a) 士兵搬[ban1]了沙发. The soldier move-LE the sofa.

1b) 妈妈(把烤箱搬[ban1]了)/(搬[ban1]了烤箱). The mother {BA the oven move-LE}/{move-LE the oven}.

1c) 邮递员(把包裹送[song4]了)/(送[song4]了包裹). The postman {BA the parcel deliver-LE}/{deliver-LE the parcel}.

1d) 小狗(把小猫绊[ban4]了)/(绊[ban4]了小猫). The dog {BA the cat trip-LE}/{trip-LE the cat}.

1e) 猎人(把绳子解[jie3]了)/(解[jie3]了绳子). The hunter {BA the rope untie-LE}/{untie-LE the rope}.

2a) 爸爸搬[ban1]了箱子. The father move-LE the box.

2b) 老师(把玻璃搬[ban1]了)/(搬[ban1]了玻璃). The teacher {BA the glass move-LE}/{move-LE the glass}.

2c) 员工(把盒饭送[song4]了)/(送[song4]了盒饭). The employee {BA the food deliver-LE}/{deliver-LE the food}.

2d) 骑士(把对手绊[ban4]了)/(绊[ban4]了对手). The cavalier {BA the rival trip-LE}/{trip-LE the rival}.

2e) 老人(把彩带解[jie3]了)/(解[jie3]了彩带). The old man {BA the ribbon untie-LE}/{untie-LE the ribbon}.

3a) 工人补[bu3]了屋顶. The worker patch-LE the roof.

3b) 牧民(把帐篷补[bu3]了)/(补[bu3]了帐篷). The shepherd {BA the tent patch-LE}/{patch-LE the tent}.

3c) 水手(把海盗旗缝[feng2]了)/(缝[feng2]了海盗旗). The sailor {BA the pirate flag sew-LE}/{sew-LE the pirate flag}.

3d) 警察(把运动员捕[bu3]了)/(捕[bu3]了运动员). The policeman {BA the athlete arrest-LE}/{arrest-LE the athlete}.

3e) 女孩(把树苗浇[jiao1]了)/(浇[jiao1]了树苗). The girl {BA the sapling water-LE}/{water-LE the sapling}.

4a) 裁缝补[bu3]了毛衣. The tailor patch-LE the sweater.

4b) 男人(把布片补[bu3]了)/(补[bu3]了布片). The man {BA the cloth patch-LE}/{patch-LE the cloth}.

4c) 爷爷(把桌布缝[feng2]了)/(缝[feng2]了桌布). The grandfather {BA the table cloth sew-LE}/{sew-LE the table cloth}.

4d) 女警(把盗贼捕[bu3]了)/(捕[bu3]了盗贼). The policewoman {BA the thief arrest-LE}/{arrest-LE the thief}.

4e) 农夫(把草坪浇[jiao1]了)/(浇[jiao1]了草坪). The farmer {BA the lawn water-LE}/{water-LE the lawn}.

5a) 机器人采[cai3]了苹果. The robot pick-up LE the apple.

5b) 小猫(把水蜜桃采[cai3]了)/(采[cai3]了水蜜桃). The cat {BA the peach pick-up-LE}/{pick-up-LE the peach}.

5c) 女孩(把稻谷收[shou1]了)/(收[shou1]了稻谷). The girl {BA the crop harvest-LE}/{harvest-LE the crop}.

5d) 士兵(把布匹裁[cai2]了)/(裁[cai2]了布匹). The soldier {BA the cloth cut-out-LE}/{cut-out-LE the cloth}.

5e) 女孩(把糖浆服[fu2]了)/(服[fu2]了糖浆). The girl {BA the syrup take-in-LE}/{take-in-LE the syrup}.

6a) 农妇采[cai3]了葡萄. The female farmer pick-up-LE the grapes.

6b) 绅士(把蘑菇采[cai3]了)/(采[cai3]了蘑菇). The gentleman {BA the mushroom pick-up-LE}/{pick-up-LE the mushroom}.

6c) 农夫(把向日葵收[shou1]了)/(收[shou1]了向日葵). The farmer {BA the sunflower harvest-LE}/{harvest-LE the sunflower}.

6d) 裁缝(把桌布裁[cai2]了)/(裁[cai2]了桌布). The tailor {BA the table cloth cut-out-LE}/{cut-out-LE the table cloth}.

6e) 警察(把药片服[fu2]了)/(服[fu2]了药片). The policeman {BA the pill take-in-LE}/{take-in-LE the pill}.

7a) 学生记[ji4]了数字. The student note-LE the number.

7b) 教授(把代码记[ji4]了)/(记[ji4]了代码). The professor {BA the code note-LE}/{note-LE the code}.

7c) 教徒(把经书抄[chao1]了)/(抄[chao1]了经书). The disciple {BA the script copy-LE}/{copy-LE the script}.

7d) 秘书(把包裹寄[ji4]了)/(寄[ji4]了包裹). The secretary {BA the parcel mail-LE}/{mail-LE the parcel}.

7e) 工人(把墙刷[shua1]了)/(刷[shua1]了墙). The worker {BA the wall brush-LE}/{brush-LE the wall}.

8a) 思想家记[ji4]了字母. The thinker note-LE the letter.

8b) 老师(把数字记[ji4]了)/(记[ji4]了数字). The teacher {BA the number note-LE}/{note-LE the number}.

8c) 运动员(把答案抄[chao1]了)/(抄[chao1]了答案). The athlete {BA the answer copy-LE}/{copy-LE the answer}.

8d) 妻子(把信寄[ji4]了)/(寄[ji4]了信). The wife {BA the letter mail-LE}/{mail-LE the letter}.

8e) 农夫(把房子刷[shua1]了)/(刷[shua1]了房子). The farmer {BA the house brush-LE}/{brush-LE the house}.

9a) 爷爷截[jie2]了木棍. The grandfather cut-off-LE the stick.

9b) 女人(把钢板截[jie2]了)/(截[jie2]了钢板). The woman {BA the steel plate cut-off-LE}/{cut-off-LE the steel plate}.

9c) 工人(把树桩砍[kan3]了)/(砍[kan3]了树桩). The worker {BA the tree stump chop-off-LE}/{chop-off-LE the tree stump}.

9d) 精灵(把老师劫[jie2]了)/(劫[jie2]了老师). The elf {BA the teacher rob-LE}/{rob-LE the teacher}.

9e)丈夫(把灯泡换[huan4]了)/(换[huan4]了灯泡). The husband {BA the bulb change-LE}/{change-LE the bulb}.

10a) 经理截[jie2]了树枝. The manager cut-off-LE the twig.

10b) 工程师(把钢管截[jie2]了)/(截[jie2]了钢管). The engineer {BA the steel tube cut-off-LE}/{cut-off-LE the steel tube}.

10c) 勇士(把石柱砍[kan3]了)/(砍[kan3]了石柱). The warrior {BA the stone pillar chop-off-LE}/{chop-off-LE the stone pillar}.

10d) 圣诞老人(把厨师劫[jie2]了)/(劫[jie2]了厨师). Santa Claus {BA the chef rob-LE}/{rob-LE the chef}.

10e) 哥哥(把轮胎换[huan4]了)/(换[huan4]了轮胎). The brother {BA the tire change-LE}/{change-LE the tire}.

11a) 老师踢[ti1]了课本. The teacher kick-LE the textbook.

11b) 厨师(把冰柜踢[ti1]了)/(踢[ti1]了冰柜). The chef {BA the freezer kick-LE}/{kick-LE the freezer}.

11c) 拳击手(把对手打[da3]了)/(打[da3]了对手). The boxer {BA the rival beat-LE}/{beat-LE the rival}.

11d) 医生(把羊毛剃[ti4]了)/(剃[ti4]了羊毛). The doctor {BA the wool shave-LE}/{shave-LE the wool}.

11e) 经理(把茶倒[dao4]了)/(倒[dao4]了茶). The manager {BA the tea pour-LE}/{pour-LE the tea}.

12a) 男孩踢[ti1]了罐子. The boy kick-LE the can.

12b) 设计师(把电脑踢[ti1]了)/(踢[ti1]了电脑). The designer {BA the computer kick-LE}/{kick-LE the computer}.

12c) 骑士(把乞丐打[da3]了)/(打[da3]了乞丐). The cavalier {BA the beggar beat-LE}/{beat-LE the beggar}.

12d) 男人(把头剃[ti4]了)/(剃[ti4]了头). The man {BA the head shave-LE}/{shave-LE the head}.

12e) 教授(把水倒[dao4]了)/(倒[dao4]了水). The professor {BA the water pour-LE}/{pour-LE the water}.

13a) 青年脱[tuo1]了背心. The youngster take-off-LE the vest.

13b) 妈妈(把羽绒服脱[tuo1]了)/(脱[tuo1]了羽绒服). The mother {BA the down jacket take-off-LE}/{take-off-LE the down jacket}.

13c) 士兵(把头盔卸[xie4]了)/(卸[xie4]了头盔). The soldier {BA the helmet remove-LE}/{remove-LE the helmet}.

13d) 清洁工(把阳台拖[tuo1]了)/(拖[tuo1]了阳台). The cleaner {BA the balcony mop-LE}/{mop-LE the balcony}.

13e) 司机(把车洗[xi3]了)/(洗[xi3]了车). The driver {BA the car wash-LE}/{wash-LE the car}.

14a) 秘书脱[tuo1]了风衣. The secretary take-off-LE the coat.

14b) 男孩(把夹克脱[tuo1]了)/(脱[tuo1]了夹克). The boy {BA the jacket take-off-LE}/{take-off-LE the jacket}.

14c) 骑士(把马鞍卸[xie4]了)/(卸[xie4]了马鞍). The cavalier {BA the saddle remove-LE}/{remove-LE the saddle}.

14d) 女人(把地板拖[tuo1]了)/(拖[tuo1]了地板). The woman {BA the floor mop-LE}/{mop-LE the floor}.

14e) 老人(把盘子洗[xi3]了)/(洗[xi3]了盘子). The old man {BA the plate wash-LE}/{wash-LE the plate}.

15a) 经理折[zhe2]了纸. The manager fold-LE the paper.

15b) 学生(把尺子折[zhe2]了)/(折[zhe2]了尺子). The student {BA the ruler fold-LE}/{fold-LE the ruler}.

15c) 妻子(把手绢卷[juan3]了)/(卷[juan3]了手绢). The wife {BA the handkerchief roll-LE}/{roll-LE the handkerchief}.

15d) 蝎子(把熊蜇[zhe1]了)/(蜇[zhe1]了熊). The scorpion {BA the bear sting-LE}/{sting-LE the bear}.

15e) 厨师(把橘子称[cheng1]了)/(称[cheng1]了橘子). The chef {BA the orange weigh-LE}/{weigh-LE the orange}.

16a) 运动员折[zhe2]了球棒. The athlete fold-LE the bat.

16b) 男孩(把棋盘折[zhe2]了)/(折[zhe2]了棋盘). The boy {BA the checkerboard fold-LE}/{fold-LE the checkerboard}.

16c) 警察(把毛毯卷[juan3]了)/(卷[juan3]了毛毯). The policeman {BA the carpet roll-LE}/{roll-LE the carpet}.

16d) 蜜蜂(把老师蜇[zhe1]了)/(蜇[zhe1]了老师). The bee {BA the teacher sting-LE}/{sting-LE the teacher}.

16e) 农夫(把胡萝卜称[cheng1]了)/(称[cheng1]了胡萝卜). The farmer {BA the carrot weigh-LE}/{weigh-LE the carrot}.

Experiment 2a and 2b

17a) 秘书倒[dao4]了废纸. The secretary pour-LE the waste paper.

17b) 白兔{盗[dao4]了胡萝卜)/(把胡萝卜盗[dao4]了). The rabbit {BA the carrot steal-LE}/{steal-LE the carrot}.

17c) 护士{捣[dao3]了中药)/(把中药捣[dao3]了). The nurse {BA the herbal medicine mash-LE}/{mash-LE the herbal medicine}.

17d) 牛仔{剃[ti4]了羊毛)/(把羊毛剃[ti4]了). The cowboy {BA the wool shave-LE}/{shave-LE the wool}.

17e) 少女{缝[feng2]了靴子)/(把靴子缝[feng2]了). The lady {BA the boot sew-LE}/{sew-LE the boot}.

18a) 宝宝倒[dao4]了牛奶. The baby pour-LE the milk.

18b) 小鸟{盗[dao4]了鸭梨)/(把鸭梨盗[dao4]了). The bird {BA the pear steal-LE}/{steal-LE the pear}.

18c)男孩{捣[dao3]了年糕)/(把年糕捣[dao3]了). The boy {BA the year cake mash-LE}/{mash-LE the year cake}.

18d) 女人{剃[ti4]了腿毛)/(把腿毛剃[ti4]了). The woman {BA the leg hair shave-LE}/{shave-LE the leg hair}.

18e) 女孩{缝[feng2]了衬衣)/(把衬衣缝[feng2]了). The girl {BA the shirt sew-LE}/{sew-LE the shirt}.

19a) 服务员倒[dao4]了咖啡. The waitress pour-LE the coffee.

19b) 小猫{盗[dao4]了香肠)/(把香肠盗[dao4]了). The cat {BA the sausage steal-LE}/{steal-LE the sausage}.

19c) 女孩{捣[dao3]了大米)/(把大米捣[dao3]了). The girl {BA the rice mash-LE}/{mash-LE the rice}.

19d) 老人{剃[ti4]了胡子)/(把胡子剃[ti4]了). The old man {BA the beard shave-LE}/{shave-LE the beard}.

19e) 女巫{缝[feng2]了袍子)/(把袍子缝[feng2]了). The witch {BA the robe sew-LE}/{sew-LE the robe}.

20a) 牛仔倒[dao4]了啤酒. The cowboy pour-LE the beer.

20b) 恐龙{盗[dao4]了木桩)/(把木桩盗[dao4]了). The dinosaur {BA the tree stump steal-LE}/{steal-LE the tree stump}.

20c) 妹妹{捣[dao3]了大蒜)/(把大蒜捣[dao3]了). The younger sister {BA the garlic mash-LE}/{mash-LE the garlic}.

20d) 男人{剃[ti4]了头发)/(把头发剃[ti4]了). The man {BA the hair shave-LE}/{shave-LE the hair}.

20e) 警察{缝[feng2]了牛仔裤)/(把牛仔裤缝[feng2]了). The policeman {BA the jean sew-LE}/{sew-LE the jean}.

21a) 女人剪[jian3]了头发. The woman cut-out-LE the hair.

21b) 大象{捡[jian3]了猎枪)/(把猎枪捡[jian3]了). The elephant {BA the shotgun pick-up-LE}/{pick-up-LE the shotgun}.

21c) 工程师{建[jian4]了公路)/(把公路建[jian4]了). The engineer {BA the road construct-LE}/{construct-LE the road}.

21d) 男人{锁[suo3]了门)/(把门锁[suo3]了). The man {BA the door lock-LE}/{lock-LE the door}.

21e) 圣诞老人{读[du2]了书)/(把书读[du2]了). The Santa Claus {BA the book read-LE}/{read-LE the book}.

22a) 姐姐剪[jian3]了杂草. The sister cut-out-LE the weed.

22b) 青年{捡[jian3]了纸币)/(把纸币捡[jian3]了). The youngster {BA the cash pick-up-LE}/{pick-up-LE the cash}.

22c) 巫师{建[jian4]了房子)/(把房子建[jian4]了). The wizard {BA the house construct-LE}/{construct-LE the house}.

22d) 程序员{锁[suo3]了电脑)/(把电脑锁[suo3]了). The programmer {BA the computer lock-LE}/{lock-LE the computer}.

22e) 小猴子{读[du2]了报纸)/(把报纸读[du2]了). The monkey {BA the newspaper read-LE}/{read-LE the newspaper}.

23a) 裁缝剪[jian3]了布匹. The tailor cut-out-LE the cloth.

23b) 男孩{捡[jian3]了球)/(把球捡[jian3]了). The boy {BA the ball pick-up-LE}/{pick-up-LE the ball}.

23c) 士兵{建[jian4]了木桥)/(把木桥建[jian4]了). The soldier {BA the wooden bridge construct-LE}/{construct-LE the wooden bridge}.

23d) 商人{锁[suo3]了汽车)/(把汽车锁[suo3]了). The businessman {BA the carrot lock-LE}/{lock-LE the carrot}.

24e) 女人{读[du2]了报纸)/(把报纸读[du2]了). The woman {BA the newspaper read-LE}/{read-LE the newspaper}.

24a) 爷爷剪[jian3]了树叶. The grandfather cut-out-LE the leaf.

24b) 歌手{捡[jian3]了垃圾)/(把垃圾捡[jian3]了). The singer {BA the garbage pick-up-LE}/{pick-up-LE the garbage}.

24c) 工人{建[jian4]了大厦)/(把大厦建[jian4]了). The worker {BA the skyscraper construct-LE}/{construct-LE the skyscraper}.

24d) 柜员{锁[suo3]了金币)/(把金币锁[suo3]了). The clerk {BA the coin lock-LE}/{lock-LE the coin}.

24e) 僧人{读[du2]了电表)/(把电表读[du2]了). The monk {BA the electric meter read-LE}/{read-LE the electric meter}.

25a) 老人截[jie2]了木棍. The old man cut-off-LE the stick.

25b) 牛仔{劫[jie2]了经理)/(把经理劫[jie2]了). The cowboy {BA the manage rob-LE}/{rob-LE the manage}.

25c) 男孩{解[jie3]了彩带)/(把彩带解[jie3]了). The boy {BA the ribbon untie-LE}/{untie-LE the ribbon}.

25d) 病人{服[fu2]了胶囊)/(把胶囊服[fu2]了). The patient {BA the capsule take-in-LE}/{take-in-LE the capsule}.

25e) 男孩{烧[shao1]了木桥)/(把木桥烧[shao1]了). The boy {BA the wooden bridge burn-LE}/{burn-LE the wooden bridge}.

26a) 男人截[jie2]了树枝. The man cut-off-LE the twig.

26b) 厨师{劫[jie2]了圣诞老人)/(把圣诞老人劫[jie2]了). The chef {BA the Santa Claus rob-LE}/{rob-LE the Santa Claus}.

26c) 儿童{解[jie3]了领带)/(把领带解[jie3]了). The kid {BA the tie untie-LE}/{untie-LE the tie}.

26d) 男人{服[fu2]了药片)/(把药片服[fu2]了). The man {BA the pill take-in-LE}/{take-in-LE the pill}.

26e) 姐姐{烧[shao1]了帽子)/(把帽子烧[shao1]了). The sister {BA the hat burn-LE}/{burn-LE the hat}.

27a) 妻子截[jie2]了木头. The wife cut-off-LE the wood.

27b) 强盗{劫[jie2]了奶奶)/(把奶奶劫[jie2]了). The burglar {BA the grandmother rob-LE}/{rob-LE the grandmother}.

27c) 男人{解[jie3]了鞋带)/(把鞋带解[jie3]了). The man {BA the shoelace untie-LE}/{untie-LE the shoelace}.

27d) 男孩{服[fu2]了鱼油)/(把鱼油服[fu2]了). The boy {BA the fish oil take-in-LE}/{take-in-LE the fish oil}.

27e) 厨师{烧[shao1]了烤箱)/(把烤箱烧[shao1]了). The chef {BA the oven burn-LE}/{burn-LE the oven}.

28a) 木工截[jie2]了钥匙. The carpenter cut-off-LE the key.

28b) 间谍{劫[jie2]了奶奶)/(把奶奶劫[jie2]了). The spy {BA the grandmother rob-LE}/{rob-LE the grandmother}.

28c) 狐狸{解[jie3]了包裹)/(把包裹解[jie3]了). The fox {BA the parcel untie-LE}/{untie-LE the parcel}.

28d) 武术家{服[fu2]了药水)/(把药水服[fu2]了). The martial artist {BA the potion take-in-LE}/{take-in-LE the potion}.

28e) 经理{烧[shao1]了电脑)/(把电脑烧[shao1]了). The manager {BA the computer burn-LE}/{burn-LE the computer}.

29a) 企鹅绊[ban4]了男孩. The penguin trip-LE the boy.

29b) 男人{办[ban4]了信用卡)/(把信用卡办[ban4]了). The man {BA the credit card prepare-LE}/{prepare-LE the credit card}.

29c) 护士{搬[ban1]了烤箱)/(把烤箱搬[ban1]了). The nurse {BA the oven move-LE}/{move-LE the oven}.

29d) 青年{喂[wei4]了骏马)/(把骏马喂[wei4]了). The youngster {BA the horse feed-LE}/{feed-LE the horse}.

29e) 浣熊{洗[xi3]了苹果)/(把苹果洗[xi3]了). The raccoon {BA the apple wash-LE}/{wash-LE the apple}.

30a) 鳄鱼绊[ban4]了商人. The crocodile trip-LE the businessman.

30b) 厨师{办[ban4]了护照)/(把护照办[ban4]了). The chef {BA the passport prepare-LE}/{prepare-LE the passport}.

30c) 军人{搬[ban1]了汽车)/(把汽车搬[ban1]了). The soldier {BA the carrot move-LE}/{move-LE the carrot}.

30d) 饲养员{喂[wei4]了大象)/(把大象喂[wei4]了). The breeder {BA the elephant feed-LE}/{feed-LE the elephant}.

30e) 男孩{洗[xi3]了汽车)/(把汽车洗[xi3]了). The boy {BA the carrot wash-LE}/{wash-LE the carrot}.

31a) 女孩绊[ban4]了滑雪者. The girl trip-LE the skier.

31b) 老人{办[ban4]了护照)/(把护照办[ban4]了). The old man {BA the passport prepare-LE}/{prepare-LE the passport}.

31c) 猩猩{搬[ban1]了木箱)/(把木箱搬[ban1]了). The chimpanzee {BA the wooden box move-LE}/{move-LE the wooden box}.

31d) 男孩{喂[wei4]了幼狼)/(把幼狼喂[wei4]了). The boy {BA the young wolf feed-LE}/{feed-LE the young wolf}.

31e) 警察{洗[xi3]了制服)/(把制服洗[xi3]了). The policeman {BA the costume wash-LE}/{wash-LE the costume}.

32a) 鸵鸟绊[ban4]了学生. The ostrich trip-LE the student.

32b) 女经理{办[ban4]了结婚证)/(把结婚证办[ban4]了). The female manager {BA the marriage certificate prepare-LE}/{prepare-LE the marriage certificate}.

32c) 邮递员{搬[ban1]了纸箱)/(把纸箱搬[ban1]了). The postman {BA the paper box move-LE}/{move-LE the paper box}.

32d) 女孩{喂[wei4]了小鸡)/(把小鸡喂[wei4]了). The girl {BA the chicken feed-LE}/{feed-LE the chicken}.

32e) 小猴子{洗[xi3]了衣服)/(把衣服洗[xi3]了). The monkey {BA the clothes wash-LE}/{wash-LE the clothes}.

33a) 娃娃脱[tuo1]了袜子. The baby take-off-LE the sock.

33b) 士兵{拖[tuo1]了街道)/(把街道拖[tuo1]了). The soldier {BA the street mop-LE}/{mop-LE the street}.

33c) 大象{驮[tuo2]了钢笔)/(把钢笔驮[tuo2]了). The elephant {BA the pen carry-LE}/{carry-LE the pen}.

33d) 农夫{称[cheng1]了南瓜)/(把南瓜称[cheng1]了). The farmer {BA the pumpkin weigh-LE}/{weigh-LE the pumpkin}.

33e) 拳击手{打[da3]了沙袋)/(把沙袋打[da3]了). The boxer {BA the sandbag beat-LE}/{beat-LE the sandbag}.

34a) 精灵脱[tuo1]了外套. The elf take-off-LE the coat.

34b) 少女{拖[tuo1]了阳台)/(把阳台拖[tuo1]了). The lady {BA the balcony mop-LE}/{mop-LE the balcony}.

34c) 小鸟{驮[tuo2]了水果)/(把水果驮[tuo2]了). The bird {BA the fruit carry-LE}/{carry-LE the fruit}.

34d) 科学家{称[cheng1]了蜥蜴)/(把蜥蜴称[cheng1]了). The scientist {BA the lizard weigh-LE}/{weigh-LE the lizard}.

34e) 妻子{打[da3]了小偷)/(把小偷打[da3]了). The wife {BA the theif beat-LE}/{beat-LE the thief}.

35a) 男人脱[tuo1]了风衣. The man take-off-LE the coat.

35b) 男人{拖[tuo1]了阳台)/(把阳台拖[tuo1]了). The man {BA the balcony mop-LE}/{mop-LE the balcony}.

35c) 驴子{驮[tuo2]了石头)/(把石头驮[tuo2]了). The donkey {BA the stone carry-LE}/{carry-LE the stone}.

35d) 厨师{称[cheng1]了西红柿)/(把西红柿称[cheng1]了). The chef {BA the tomato weigh-LE}/{weigh-LE the tomato}.

35e) 男孩{打[da3]了足球)/(把足球打[da3]了). The man {BA the football beat-LE}/{beat-LE the football}.

36a) 女兵脱[tuo1]了外衣. The soldier take-off-LE the coat.

36b) 厨师{拖[tuo1]了走廊)/(把走廊拖[tuo1]了). The chef {BA the corridor mop-LE}/{mop-LE the corridor}.

36c) 河马{驮[tuo2]了女人)/(把女人驮[tuo2]了). The hippo {BA the woman carry-LE}/{carry-LE the woman}.

36d) 护士{称[cheng1]了婴儿)/(把婴儿称[cheng1]了). The nurse {BA the baby weigh-LE}/{weigh-LE the baby}.

36e) 服务员{打[da3]了恶棍)/(把恶棍打[da3]了). The waitress {BA the bully beat-LE}/{beat-LE the bully}.

37a)官员遮[zhe1]了相机. The officer cover-LE the camera.

37b) 马蜂{蜇[zhe1]了男孩)/(把男孩蜇[zhe1]了). The wasp {BA the boy sting-LE}/{sting-LE the boy}.

37c) 秘书{折[zhe2]了手帕)/(把手帕折[zhe2]了). The secretary {BA the handkerchief fold-LE}/{fold-LE the handkerchief}.

37d) 大象{浇[jiao1]了鲜花)/(把鲜花浇[jiao1]了). The elephant {BA the flower water-LE}/{water-LE the flower}.

37e) 爸爸{放[fang4]了烟花)/(把烟花放[fang4]了). The father {BA the firework release-LE}/{release-LE the firework}.

38a) 房东遮[zhe1]了泳池. The landlord cover-LE the swimming pool.

38b) 蝎子{蜇[zhe1]了水牛)/(把水牛蜇[zhe1]了). The scorpion {BA the buffalo sting-LE}/{sting-LE the buffalo}.

38c) 小偷{折[zhe2]了高尔夫棒)/(把高尔夫棒折[zhe2]了). The thief {BA the golf stick fold-LE}/{fold-LE the golf stick}.

38d) 囚犯{浇[jiao1]了仙人掌)/(把仙人掌浇[jiao1]了). The prisoner {BA the cactus water-LE}/{water-LE the cactus}.

38e) 女孩{放[fang4]了鞭炮)/(把鞭炮放[fang4]了). The girl {BA the firecracker release-LE}/{release-LE the firecracker}.

39a) 游客遮[zhe1]了阳光. The tourist cover-LE the sunshine.

39b) 蜜蜂{蜇[zhe1]了棕熊)/(把棕熊蜇[zhe1]了). The bee {BA the bear sting-LE}/{sting-LE the bear}.

39d) 音乐家{折[zhe2]了指挥棒)/(把指挥棒折[zhe2]了). The musician {BA the baton fold-LE}/{fold-LE the baton}.

39d) 农夫{浇[jiao1]了植物)/(把植物浇[jiao1]了). The farmer {BA the plant water-LE}/{water-LE the plant}.

39e) 妻子{放[fang4]了烟)/(把烟放[fang4]了). The wife {BA the smoke release-LE}/{release-LE the smoke}.

40a) 间谍遮[zhe1]了手枪. The spy cover-LE the gun.

40b) 蜜蜂{蜇[zhe1]了狐狸)/(把狐狸蜇[zhe1]了). The bee {BA the fox sting-LE}/{sting-LE the fox}.

40c) 法官{折[zhe2]了铅笔)/(把铅笔折[zhe2]了). The judge {BA the pencil fold-LE}/{fold-LE the pencil}.

40d) 女孩{浇[jiao1]了树苗)/(把树苗浇[jiao1]了). The woman {BA the sapling water-LE}/{water-LE the sapling}.

40e) 猎人{放[fang4]了犀牛)/(把犀牛放[fang4]了). The hunter {BA the rino release-LE}/{release-LE the rino}.

Picture Captions

Fig. 1. Illustration of the representation of the Mandarin Chinese word *xizang* (*西藏*, meaning Tibet) in extended lexicalist model from Roelofs (2015). The numbers in the tonal frame denote tone numbers. Syllable motor programs are specified for tone. 1 = high; 4 = high-falling; c = coda; n = nucleus; o = onset.

Fig. 2. Example of a target picture. The target verb is shown above the picture (*脱* [tuo], *to take off*) and the preamble is below the picture (*秘书* [*The secretary*]_____。).

Fig. 3. The proportion of Ba responses as a function of prime condition and overlap condition in Experiment 1. Error bars reflect standard errors calculated for a by-participants analysis.

Fig. 4. The proportion of Ba responses as a function of prime condition and overlap condition in Experiments 2a and 2b. Error bars reflect standard errors calculated for a by-participants analysis.

Fig. 5. The proportion of Ba responses as a function of prime condition and overlap condition in Experiments 3a and 3b. Error bars reflect standard errors calculated for a by-participants analysis.

Fig. 6. A model of sentence production in Mandarin adapted from Pickering and Branigan (1998) with the relevant nodes. Each lemma node is connected to a conceptual node (e.g., TAKE OFF (X,Y)), a categorical node (Verb), the combinatorial nodes that represent the syntactic structure (Ba transitive and SVO transitive), and a lexeme node. A tonal frame and an atonal syllable in the word-form level are attached to the lexeme node in the word-form level. In tonal frame, 1 = high, 2 = mid-rising, 3 = low-dipping, 4 = high-falling.