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How do phonology and orthography feedback to influence syntactic encoding in language production? Evidence from structural priming in Mandarin

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## Abstract

Do speakers make use of a word's phonological and orthographic forms to determine the syntactic structure of a sentence? We reported two Mandarin structural priming experiments involving homophones to investigate word-form feedback on syntactic encoding. Participants tended to re-use syntactic structure across sentences; such a structural priming effect was enhanced when the prime and target sentences used homophone verbs (the homophone boost), regardless of whether homophones were heterographic (homophones written in different character; Experiments 1 and 2) or homographic (homophones written in the same character; Experiment 2). Critically, the homophone boost was comparable between homographic and heterographic homophone primes (Experiment 2). Hence unlike phonology, orthography appears to play a minimal role in mediating structural priming in production. We suggest that the homophone boost results from lemma associations between homophones that develop due to phonological identity between homophones early during language learning: such associations stabilise before literacy acquisition, thus limiting the influence of orthographic identity on lemma association between homophones and in turn on structural priming in language production.

**Keywords:** Syntactic encoding, structural priming, homophone, Chinese, phonology, orthography

People go through a series of stages when producing a spoken or written utterance. They have to determine the meaning that they wish to express (conceptualization), retrieve the appropriate words (lexicalization), arrange them in an appropriate order (syntactic encoding), and retrieve their phonological or orthographic forms (word-form retrieval). Syntactic encoding can be affected by conceptualisation and lexicalization as these processes occur before or alongside syntactic encoding (e.g., Ferreira, 1994; McDonald, Bock, & Kelly, 1993). But it is less clear whether syntactic encoding is affected by word-form retrieval. To the extent that it does, can we distinguish between effects of phonology and orthography?

There is mixed evidence about whether word-form (phonological and/or orthographic) information feeds back to affect syntactic encoding. Bock (1986a) had participants listen to prime words and then describe pictures depicting transitive events. Participants tended to produce descriptions in which a word semantically related to the prime came first, for instance, producing *Lightning strikes the church* after the prime *thunder*, but *The church is struck by lightning* after the prime *worship*. However, they did not tend to produce descriptions in which a word phonologically (or perhaps also orthographically) related to the prime came first. Thus, they were equally likely to produce *Lightning strikes the church* after the prime *frightening* or the prime *search*. But in contrast, Bock (1987) did find an effect of phonological or orthographic priming, with participants producing descriptions in which a phonologically related word came last. Lee and Gibbons (2007) also showed that speakers were more likely to produce the optional relativizer *that* when the subject (e.g., *Louis* vs. *Lucy*) of the complement clause following the main verb began with a strong rather than a weak syllable (e.g., *Henry knew (that) Lucy/Louis washed the dishes*), suggesting that the

metrical structure of phonology affects syntactic encoding.

More recent research has used structural priming to investigate whether and how phonological and orthographic information in homophones impact structural choices in language production. Structural priming is the tendency for people to re-use a syntactic structure that they have previously heard or produced (Pickering & Ferreira, 2008). For instance, people are more likely to use a double-object (DO) dative (e.g., *the girl gave the man a paintbrush*) instead of a prepositional-object (PO) dative (e.g., *the girl gave a paintbrush to the man*) after having heard a DO (e.g., *the undercover agent sold the rock star some cocaine*) than after having heard a PO (e.g., *the undercover agent sold some cocaine to the rock star*) (Bock, 1986b).

Patterns of structural priming effects have been explained with reference to mechanisms such as residual activation, implicit learning, and episodic memory traces (e.g., Chang, Dell, & Bock, 2006; Pickering & Branigan, 1998; Reitter, Keller, & Moore, 2011), with some models assuming multiple underlying mechanisms underpinning different aspects of these patterns (Branigan et al., 2006; Ferreira & Bock, 2006; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Reitter et al., 2011). Importantly, a number of studies have found that priming effects are modulated by relationships between lexical heads in the prime and target sentences, in ways that are most straightforwardly explained in terms of residual activation of syntactic representations that are linked to lexical entries. For example, Pickering and Branigan (1998) found that structural priming effects are enhanced when the prime and the target sentence have the same lexical head, such as the main verb. They argued that this lexical boost is due to the residual activation of the syntactic representation of the

verb (its *lemma*, e.g., *give*), the representation of the syntactic construction (e.g., PO), and the link between them.

In a study where participants decided whether a spoken (prime) phrase matched a picture and subsequently described a new picture, Cleland and Pickering (2003) investigated whether syntactic encoding in the picture description was affected by semantic and phonological information in the prime. Speakers tended to describe pictures using a syntactic structure they had previously heard (e.g., they were more likely to say *the sheep that's red* after hearing *the door that's red* than after hearing *the red door*). This tendency was enhanced when the prime and the target utterances had semantically related head nouns (the semantic boost; e.g., priming of *the sheep that's red* was stronger after *the goat that's red* than after *the door that's red*). These findings suggest that semantic information feeds forward to influence syntactic encoding (i.e., the choice of a syntactic structure) in language production.

For present purposes, it is more important to determine whether and how word-forms may feedback to affect syntactic encoding. That is, speakers select lemmas and the syntactic structures associated with the lemmas (especially the lexical head like the verb); then they retrieve word-forms for the lemmas. But does activation of these word-forms then feedback to the lemma to influence the selection of the syntactic structure? This possibility bears on a fundamental question about the architecture of the language production system: whether processing is serial so that activation flows top-down through the system from conceptualization through the various stages of formulation to articulation in a strictly feedforward manner (e.g., Levelt, 1989) or whether it is instead interactive, so that activation can flow both top-down and bottom-up (e.g., Dell, 1986).

Cleland and Pickering (2003) found that priming was not enhanced when prime and target had phonologically related head nouns (e.g., priming of *the sheep that's red* was no stronger after *the ship that's red* than after *the door that's red*) – that is, there was no phonological boost. In American Sign Language, signers also showed no phonological boost, though they did repeat syntactic structure (Hall, Ferreira, & Mayberry, 2014). Studies investigating structural priming between languages found that priming of dative structures did not change as a function of the phonological overlap between prime and target verbs (Cai et al., 2011; Huang et al., 2019; but cf. Bernolet, Hartsuiker, & Pickering, 2012, for a cross-linguistic boost based on phonological overlap of head nouns). In sum, there is limited evidence for a boost when the lexical heads in prime and target are (closely) related phonologically. These findings suggest that, for instance, activation from the word-form of *sheep* does not feedback to the lemma level to impact syntactic encoding as a result of the syntactic association of its word-form neighbour *ship*, and are therefore consistent with serial feedforward models of language production.

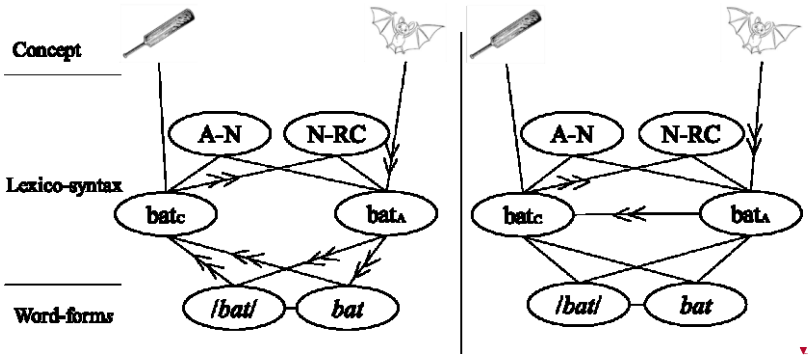
But priming is enhanced when prime and target contain *homophones* – that is, words that are phonologically identical. In a study similar to Cleland and Pickering (2003), Santesteban et al. (2010) found that people were more likely to say *the bat that's red* to refer to an animal bat after hearing *the pool that's red* than after hearing *the red pool*. More importantly, priming was enhanced when the prime contained a head noun (here, *the bat that's red* referring to a cricket bat) that was a homophone of the target head noun (*bat* referring to an animal). Interestingly, two experiments found that enhancement with homophone prime/target nouns was as large as in a condition with the same prime/target nouns (here, an animal bat) – that is,

the homophone boost (boost due to the prime and target containing homophonous words) was equivalent to the lexical boost (boost due to the prime and target containing the same word).

It is possible that the homophone boost reflects a tendency to activate the inappropriate meaning of the prime during comprehension, for example cricket bat when hearing *bat* in the context of an animal-bat picture (cf. Swinney, 1979). But this explanation suggests that priming would be unaffected by the inhibition of the inappropriate meaning. According to Santesteban et al. (2010), a more plausible explanation is that homophones (unlike phonologically related words) share a word-form representation, such as the phonological form /bat/, and it is this representation that relates to the syntactic construction and therefore mediates priming (see Figure 1, left panel). For instance, hearing *the bat that's red* referring to a cricket bat activates the phonological word-form /bat/, which in turn activates the cricket bat lemma and the noun-relative-clause representation. When the speaker subsequently has to describe an animal bat, the noun-relative-clause structure is more likely to be used due to structural priming. More importantly, Santesteban et al. showed that there is also a boost in structural priming because the animal *bat* and the cricket *bat* are homophones. They argue that the two bat lemmas are linked to the same word-form /bat/ (As they looked at structural priming in oral production, Santesteban only discussed feedback of shared phonological forms to syntactic encoding, though in theory the shared orthographic form of homophones can also have similar feedback; see Figure 1). The homophone boost is a result of feedback from the word-form to syntactic encoding (the word-form feedback account, Figure 1, left panel). That is, in describing an animal bat, the animal *bat* lemma activates the /bat/ word-form. This homophone word-form then activates the cricket *bat* lemma and in turn the



previously used noun-relative-clause structure, which then increases the likelihood of the speaker using the noun-relative-clause structure; this account would be consistent with interactive models of language production.<sup>1</sup>



**Figure 1.** Alternative accounts of the homophone boost in structural priming in the target description of an animal bat after comprehending the prime *the bat that was red* referring to a cricket bat. The lines refer to connections between linguistic representations (represented by ovals) and the symbol >> refers to directional activation between representations. Left: A word-form feedback account where the target lemma activates the homophone word-form, which in turn feeds back to activate the prime lemma and in turn the prime structure. Right:

<sup>1</sup> Santesteban et al. (2010) also pointed out that the effect may instead occur during the comprehension of the prime. Under this account, the homophone word-form /bat/ activates both the cricket bat and animal bat lemmas, thus strengthening the link between the N-RC structure and the animal bat lemma, leading to more N-RC descriptions of the animal bat. We note that this comprehension-based explanation of the effect is functionally equivalent to the production-based explanation of the effect as far as our study is concerned. For the sake of simplicity, we will not discuss it further.

A learned lemma association account where homophone lemmas directly activate each other via learned associations between them.

In contrast to the word-form feedback account, it is also likely that lemmas of homophones may develop inter-lemma associations (the learned lemma association account, Figure 1, right panel). In a recent paper, Huang et al. (2019) tested native Mandarin speakers who had learned Cantonese and English as second languages. They found that cross-language structural priming was larger from Cantonese to Mandarin than from English to Mandarin when the prime and target involved translation-equivalent verbs. More critically, Huang et al. showed that the magnitude of structural priming was unaffected by the amount of word-form overlap between the prime and target verbs. This latter finding suggests that the difference in priming between language pairs could not be attributed to translation equivalents having more word-form overlap between Cantonese and Mandarin (mostly cognates) than between English and Mandarin (mostly non-cognates). Instead, Huang et al. suggested that, during language learning, people develop inter-lemma associations for cognates due to their similarity in word-form (e.g., Jiang, 2000), via word-form-based cross-language activation (e.g., Thierry & Wu, 2007; cf. Costa, Pannunzi, Deco, Pickering, 2017). For instance, every time a Cantonese-Mandarin bilingual hears/reads the Cantonese word *dai<sub>6</sub>* (“pass”, subscript indicating the lexical tone), it not only activates the target Cantonese word but also its Mandarin cognate counterpart *di<sub>4</sub>* via phonological and/or orthographic similarity (*dai<sub>6</sub>* and *di<sub>4</sub>* are phonologically similar and have the same orthography). As a result of such repeated co-activation in language use (especially in childhood), cognates develop associations between

their lemmas. It is thus also likely that homophones develop associations between their lemmas.

Under this account (Figure 1, right panel), after hearing *the bat that's red* referring to a cricket bat, participants activate the target lemma and the noun-relative-clause representation, so that when they subsequently describe an animal bat, they will be more likely to select the noun-relative-clause structure due to residual activation. But more critically, when they select the animal-bat lemma, they also activate the cricket-bat lemma via the inter-lemma associations. This activation in turn raises the activation of the noun-relative-clause structure in which the cricket-bat lemma was used, leading to a boost in the use of the noun-relative-clause structure (the homophone boost).

The two accounts differ with regard to how word-forms (phonological and orthographic) feedback to syntactic encoding in language production. According to the word-form feedback account, the lexico-syntactic representation (the lemma) of a word can activate lexico-syntactic representations of its homophones via shared (phonological and/or orthographic) word-forms (see also Figure 2 using Mandarin examples). This means that phonological and orthographic information have independent feedback to syntactic encoding in language production. This in turn predicts that homophones that are identical in both phonology and orthography (homographic homophones, e.g., cricket *bat* and animal *bat*) will yield a stronger boost in structural priming than homophones that are identical in phonology but different in orthography (heterographic homophones, e.g., *pear* and *pair*).

The learned lemma association account, in contrast, does not assume online word-form feedback to syntactic encoding. Instead, it explains the homophone boost by assuming that

homophones develop inter-lemma associations in early language learning as a result of shared word-forms. For instance, a child will recognise that the cricket *bat* and animal *bat* have the same pronunciation, and so do *pear* and *pair*. Everything else being equal, the child will develop associations of similar strength for cricket and animal *bat* and for *pear/pair*. It is likely that these associations stabilise before literacy training kicks in, thus leaving little room for orthographic identity, if any, to play a role in association development. For instance, the orthography for most Chinese words (the focus of this paper) is acquired between primary and senior high school, between the ages of 6 to 18 (Wang et al., 2020). In other words, as homophone lemma associations are mainly developed via phonology, homographic homophones such as *bat/bat* may not have stronger associations than heterographic homophones such as *pear/pair*. The direct account thus predicts that homographic and heterographic homophones should yield similar boosts in structural priming, contrary to the word-form feedback account.

To discriminate between the two accounts, we use Mandarin Chinese, which has extensive homophony, with both homographic and heterographic homophones being extremely common. For instance, there are homographic homophone verbs (*da<sub>3</sub>* or 打,<sup>2</sup>

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<sup>2</sup>In the current paper, for the sake of exposition, we use a word's Pinyin (with a number representing tone; e.g., *da<sub>3</sub>*) to represent the word or its lemma (when needed, with an extra subscripted letter to distinguish lemmas of homophones, e.g., *da<sub>3K</sub>* and *da<sub>3F</sub>*), Pinyin inside two slashes (e.g., /*da<sub>3</sub>/*) to represent a word's phonological form, Chinese character form to represent a word's orthographic form, and upper-letter English translations to represent its meaning.

respectively meaning “fetch” and “knit”) between 厨师打给了男生一碗水. (lit., the chef fetched the boy a bowl of water) and 公主打给了医生一件毛衣 (lit., the princess knitted the doctor a sweater). In contrast, there are heterographic homophone verbs *ban<sub>1</sub>* or 搬 (meaning “carry”) and *ban<sub>1</sub>* or 颁 (meaning “award”) between 厨师搬了一桶水给男生. (lit., the chef carried the boy a bucket of water) and 公主颁给了医生一个奖牌 (lit., the princess awarded the doctor a medal).

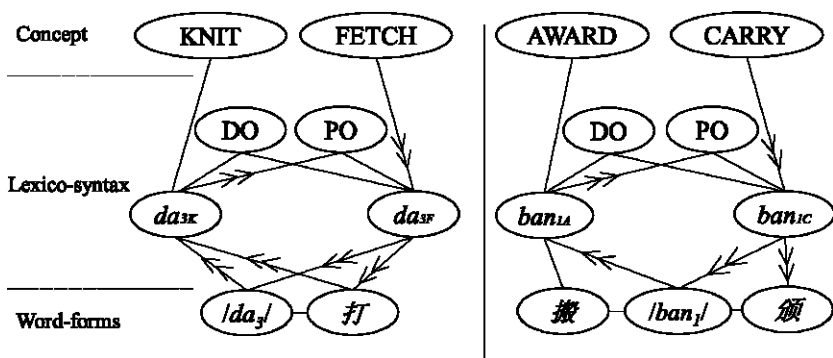


Figure 2. Spreading activation of information (indicated by double-arrows) when the prime and the target contain homographic (left) vs. heterographic (right) homophones under the word-form feedback account. The symbol >> refers to directional activation between representations; the subscripted upper-case letters (K, F, A, C) distinguish different lemmas of homophones. There are two sources of feedback (one via the shared spoken form and one via the shared written form) for homographic homophones but only one source of feedback (via the shared spoken form) for heterographic homophones.

Below, we report two structural priming experiments in Mandarin Chinese comparing homographic and heterographic homophone boosts in order to contrast the word-form

feedback account and the learned lemma association account. Studies of structural priming using Mandarin have found very similar patterns to studies in English and other European languages (e.g., Cai et al., 2011, 2012, 2015), and have assumed similar models of lexico-syntactic representation (e.g., Cai et al., 2011; Schoonbaert et al., 2007). If speakers produce Mandarin using the same mechanisms as English, there should be a homophone boost to structural priming just as in English. Moreover, this effect should occur for homophone verbs, just as for homophone nouns. In Experiment 1, we tested whether heterographic homophones also induce a homophone boost. Then in Experiment 2, we compared whether the boost in structural priming is similar for heterographic and homographic homophones. According to the word-form feedback account, the boost should be larger for homographic than heterographic homophones as homographic homophones have an additional source of feedback compared to heterographic homophones (see Figure 2). However, if word-forms do not provide feedback to syntactic encoding and the homophone boost is instead driven by lemma associations between homophones, as the learned lemma association account assumes, we should expect comparable structural priming between prime-target pairs involving homographic homophone verbs and prime-target pairs involving heterographic homophone verbs.

### **Experiment 1**

Experiment 1 investigated whether structural priming is greater between sentences involving heterographic homophone verbs (e.g., between [1a/b] and [2]) than between sentences involving phonologically/orthographically unrelated verbs (e.g., between [1c/d] and [2]) (Note that all pairs of verbs between the prime and target were semantically unrelated;

see pretest below). The strong evidence for priming (e.g., Bock, 1986b) implies that, when asked to describe the event expressed in [2], participants will be more likely to use a DO structure after hearing an unrelated verb DO prime [1c] than an unrelated verb PO prime [1d]. If heterographic homophones between the prime and the target lead to a homophone boost in structural priming, we should expect the tendency to repeat the syntactic structure in picture description to be enhanced after hearing a homographic homophone verb DO and PO primes [1a,b].

**Table 1.** Sample prime sentences and possible target descriptions in Experiment 1.

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***Heterographic homophone verb DO prime***

1a. 厨师搬了一桶水给男生. (lit. The chef carried the boy a bucket of water)

***Heterographic homophone verb PO prime***

1b. 厨师搬了一桶水给男生. (lit. The chef carried a bucket of water for the boy)

***Unrelated verb DO prime***

1c. 厨师打给了男生一碗水. (lit. The chef fetched the boy a bowl of water)

***Unrelated verb PO prime***

1d. 厨师打了一碗水给男生. (lit. The chef fetched a bowl of water for the boy)

***DO/PO description of target picture***

2. 公主颁给了医生一个奖牌/ 公主颁了一个奖牌给医生

(lit. The princess awarded the doctor a medal / the princess awarded a medal to the doctor)

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We adapted the priming paradigm used in Cai et al. (2011, 2012). Participants heard a prime sentence and decided if it matched a written match sentence; they then described a target picture that was presented with a written preamble ending with a verb (see also Figure 3). Note that the task encouraged the use of orthographic information in two important ways.

First, the (written) match sentence always used the same verb as in the spoken prime sentence, so participants would necessarily access the verb's orthographic form. Second, the fact that the preamble presented with the target picture included a printed dative verb meant that participants also had to access the target dative verb's orthographic form. Both these task characteristics maximized the possibility of a boost due to orthographic identity between homographic homophone verbs (if any).

## **Method**

### ***Participants***

Sixty native speakers of Mandarin Chinese from the South China Normal University community were paid 20 yuan to take part in the experiment. As Santesteban et al. (2010; Experiment 1) observed a homophone boost with 24 participants and 36 experimental items, we deemed the chosen number of participants (with 32 experimental items; see below) to have sufficient experimental power to detect a homophone boost (if any) in the current study.

### ***Design***

We used a 2 (prime: DO vs. PO) x 2 (prime/target verb relation: heterographic homophone vs. unrelated) within-participants and within-items design. For instance, for a target event such as a princess knitting a hat for a doctor expressed in [2] in Table 1 above, the prime would either be a DO [1a/c] or PO [1b/d] and it could either contain a heterographic homophone [1a/b] or an unrelated verb [1c/d].



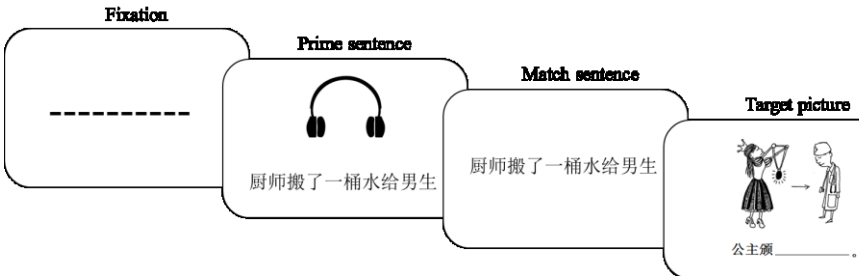
## Items

We constructed 32 experimental items and 96 filler items, each consisting of a spoken prime sentence, a written match sentence, and a target picture. All the materials (together with trial-level data and analytical scripts) for this and the following experiment are publicly available on Open Science Framework (<https://osf.io/sbvf/>).

For each experimental item, there were four versions of the spoken prime: heterographic homophone verb DO, heterographic homophone verb PO, unrelated verb DO, and unrelated verb PO (see [1] in Table 1 above). Each spoken prime sentence had a corresponding written match sentence, which was identical to the prime sentence for half of the items and differed in one of the nouns (the agent, the recipient, or the theme) for the other half. The target picture depicted a dative event (e.g., a princess knitting a hat for a doctor) that could be described with a DO or PO sentence (e.g., [2]). In half of the items, the target picture had the agent on the left, the theme in the middle, and the recipient on the right; in the other half, it had the agent on the right, the theme in the middle, and the recipient on the left. Below the target picture was a preamble that included the subject (the agent) and the verb (the action) (e.g., 公主颁\_\_\_\_\_ [princess award ...]); we included the preamble to ensure that participants accessed the orthography of the target verb, and to encourage the use of DO and PO descriptions and discourage the use of *ba*-constructions (see Cai et al., 2011, 2012, 2015).

The filler items consisted of 72 transitive (e.g., 警察踢了小丑 [the policeman kicked the clown]) and intransitive prime sentences (e.g., 消防员在打喷嚏 [the firefighter was sneezing]) and 24 DO prime sentences (which were used to increase the number of DO target descriptions; see Cai et al., 2012, 2015). The match sentence was either the same (for half of

the items) as the prime sentence or differed in one noun. The 96 target pictures depicted 64 transitive events and 32 intransitive events. As in the experimental target pictures, there was a sentence preamble containing the subject (the agent) and sometimes also a verb (for a transitive event but not for an intransitive event). The event type in the prime and the target picture could be the same (e.g., both transitive) or different (e.g., transitive event in prime and intransitive event in target picture); in addition, the verb was the same in the prime sentence and the target picture preamble half of the time.



**Figure 3.** Trial structure in Experiment 1. At the press of the spacebar, the fixation screen disappeared and the prime sentence (lit., *the cook fetched a bowl of water to the boy*, in the example sentence) was presented auditorily, immediately followed by a written match sentence. Participants decided whether the match sentence was the same or not as the spoken prime sentence. Then they described a target picture by repeating and completing a sentence preamble (lit., *the princess knitted \_\_\_\_\_*, in the example above).

### **Procedure**

Participants were individually tested in a quiet cubicle. After giving their informed consent and reading the instructions, they first familiarized themselves with the entities and

objects that they were to describe in the experiment (e.g. the boy, the cook, a bowl of water; presented on PowerPoint slides). The experiment was run on a desktop using DMDX.

Participants heard a spoken prime sentence, read a written match sentence, and decided if the match sentence was the same as the spoken sentence. They then saw a target picture, together with a written sentence preamble (see Figure 3), and described the pictured event by repeating and continuing the sentence preamble.

Participants went through a practice of three trials before starting the main experiment. As shown in Figure 3, a trial began with a line of dashes. At the press of the spacebar, participants heard a spoken prime sentence, followed by a match sentence presented at the centre of the screen. Participants judged whether the written sentence matched the spoken sentence (by pressing *F*) or not (by pressing *J*). They then saw the target picture and described it by repeating and continuing the written preamble. The description was digitally recorded. They pressed the spacebar at the end of their description to trigger the next trial. The experiment lasted for about 45 minutes.

### ***Semantic relatedness pre-test***

As semantic relatedness between prime and target verbs can boost priming (Cleland & Pickering, 2003), we conducted a pre-test in which 18 further participants from the same population assessed the degree to which the verb in the experimental target pictures was semantically related to the homophone verb and to the unrelated verb in the corresponding prime sentence. Participants read on the screen a sentence with an experimental target verb and a sentence with a corresponding homophone or unrelated verb (e.g., 厨师打了一碗水

[*The chef poured a bowl of water*] and 公主打了一件毛衣 [*The princess knitted a sweater*]). They rated the semantic relatedness between the two verbs on a 7-point scale (with 1 meaning highly unrelated and 7 meaning highly related). As expected, both the homographic homophone verbs and the unrelated verbs were both rated to have little semantic relatedness to their associated the target verb (1.7 vs. 1.7 out of 7), with no significant difference between the two ( $t(31) = 0.26, p = .799$ ).

### **Scoring**

We coded descriptions on the experimental trials (1920 in total) as DO responses (75 in total, 3.9% out of all the descriptions), PO responses (1787, 93.1%), or “other” responses (58, 3.0%). A description was coded as a DO when the preamble was grammatically continued with the recipient and followed by the theme (e.g., 公主颁给了医生一个奖牌 [lit. *the chef poured the doctor a medal*]) or as a PO when the preamble was grammatically continued with the theme and followed by the recipient in a prepositional phrase (e.g., 公主颁了一个奖牌给医生 [lit. *the chef awarded a medal to the doctor*]); all other responses were coded as “other” (including descriptions that did not use the provided verb in the preamble).

Following Cai et al. (2011, 2015), we further coded DOs and POs as primed or unprimed responses (excluding “other” responses). A response was a primed response if it had the same syntactic structure as the prime (e.g., a DO response following a DO prime or a PO response following a PO prime); otherwise it was an unprimed response. Trial-level (primed or unprimed) responses were subsequently used in the statistical analyses (see <https://osf.io/sbvfy/> for the trial-level coded data). Note that in this re-coding scheme, overall

structural priming manifests as an intercept effect (i.e., whether there are more primed than unprimed responses in general) rather than as a main effect of prime structure as in the traditional analysis where DO/PO responses are used as the dependent variable (e.g., whether there are more DOs following the DO than the PO prime). This re-coding helps to reduce the complexity of statistical analyses. For instance, we can determine whether a particular factor (e.g., verb relation) modulates structural priming by looking at the main effect of that factor (e.g., if homographic homophone verbs lead to more priming than unrelated verbs, we should expect a significant main effect of verb relation) rather than as an interaction between prime structure and verb relation, as in the traditional analysis.

To make the interpretation of the analyses most straightforward, we did not include prime structure (DO vs PO prime) as a predictor in the analyses. Any effect of prime structure may simply indicate a general preference to use the DO or PO structure in picture descriptions. For instance, if a significant main effect of prime structure suggests greater priming following the PO than DO prime, without a baseline prime, we would not be able to infer whether PO primes induced more priming or actually the effect only reflects a tendency for people to more often use POs to describe pictures. More importantly, our specific research questions do not depend on the priming effects of prime structures.

For exposition, we also calculated the magnitude of priming (proportion of primed out of primed and unprimed responses); for instance, a magnitude of 0.58 in priming for a particular condition means there were 58% primed responses (and 42% unprimed responses – a priming effect of 16%; see also Cai et al., 2011, 2015).

## Results and discussion

In both experiments, we removed participants whose picture descriptions in the experimental trials were coded as “other” responses more than 50% of the time, as these participants probably failed to fully understand the task instructions. In this experiment, one participant was removed from further analyses, leaving 59 participants for statistical analyses. Of the 1888 responses, 52% (990) were primed responses, 40% (775) unprimed responses, and 6% (123) “other” responses (excluded from analyses) (see also Table 2).

We used logit mixed effects (LME) modelling (Baayen, 2008) to evaluate whether structural priming (primed vs. unprimed responses) changed as a function of the verb relation between the prime and target (i.e. heterographic homophone vs. unrelated verb). Following recent proposals (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017), we used forward model comparisons to determine the maximal random effect structure justified by the data, using an alpha level of 0.2 rather than 0.05. Verb relation was contrast-coded (related verbs = 0.5; unrelated verbs = -0.5) and semantic relatedness was z-transformed. For the analytical scripts and data, see <https://osf.io/sbvfy/>.

Participants were sensitive to the prime structure in their picture descriptions, with more primed than unprimed responses ( $\beta = 0.24$ ,  $SE = 0.05$ ,  $z = 5.13$ ,  $p < .001$ ). There was a significant effect of verb relation ( $\beta = 0.27$ ,  $SE = 0.10$ ,  $z = 2.78$ ,  $p = .006$ ), with greater priming when the prime and the target had heterographic homophone than unrelated verbs (see Table 2). These results thus revealed a boost in structural priming when the prime and the target contained heterographic homophone verbs, in other words a homophone boost in structural priming when the prime and the target used verbs that were identical in phonology

but different in orthography.<sup>3</sup>

**Table 2.** Responses and priming as a function of verb relation and prime structure in Experiment 1.

	DO	PO	Other	Primed	Unprimed	Priming
Unrelated verbs						
DO prime	53	388	31	468	418	0.53
PO prime	30	415	27			
Heterographic homophone verbs						
DO prime	98	338	36	522	357	0.59
PO prime	19	424	29			

## Experiment 2

Experiment 1 showed that, compared to unrelated verbs, Chinese homophone verbs with

<sup>3</sup> Adding the semantic similarity between the prime and target verb as a predictor did not change the pattern of the results; also the priming effect was not modulated by semantic similarity. Furthermore, analyses using DO vs. PO (instead of primed vs. unprimed) responses as the dependent variable and including prime structure as a predictor did not change the results (e.g., overall priming, a homophone boost) in this and the following experiments. For instance, in such an analysis, we also observed a priming effect, with more DO responses following a DO than PO prime and more priming when the verbs are homophonous than unrelated, as indicated by the significant interaction between prime structure and verb relation. See <https://osf.io/sbvfy/> for the analytical scripts.

different orthography yield increased structural priming for dative sentences. These results are consistent with Santesteban et al.'s (2010) results for English homophone noun phrases with the same orthography in structural priming for noun phrase structure. But do homographic homophones lead to a larger boost than heterographic homophones as a result of also having orthographic identity? If the homophone boost is due to a homophone lemma activating shared word-form representations, which in turn activate the other homophone lemmas (as the word-form feedback account assumes), we should expect a greater boost for homographic homophones (identical in phonology and orthography) than heterographic homophones (identical in phonology but not in orthography). In contrast, under the assumption that people develop similar lemma associations for homographic homophones and heterographic homophones during childhood, the learned lemma association account predicts comparable boosts for the two types of homophones.

## Method

A further 72 participants from the same population as Experiment 1 (and who had not taken part in Experiment 1) were paid 20 RMB to take part. We used a 2 (target verb type: homographic vs heterographic homophone) x 2 (prime/target verb relation: related vs. unrelated) x 2 (prime structure: DO vs. PO) within-participants and within-items design. As shown in Table 3, a target event could be either described using a homographic homophone verb [4a] or a heterographic homophone verb [4b]. The corresponding prime had either a related verb or an unrelated verb. For instance, for the target event expressed in [4a], a prime such as [3a/b] contained a related (i.e. homographic homophone) verb and a prime such as



[3c/d] contained an unrelated verb. If homographic homophones lead to a boost in priming then when describing the target event expressed in [4a], participants should be more likely to re-use the primed syntactic structure if the prime contained a homographic homophone [3a/b] than an unrelated verb [3c/d]. In addition, when describing the dative event in [4b], participants should be more likely to re-use the primed syntactic structure if the prime contained a heterographic homophone [3c/d] than an unrelated verb [3a/b] (replicating the heterographic homophone boost in Experiment 1). More critically, this design enabled us to compare boosts caused by homographic homophones and heterographic homophone.

There were 32 experimental items and 96 fillers. These re-used the heterographic homophone verb primes and targets in Experiment 1 (e.g., 3c/d and 4b in Table 3). In addition, for each item, we also created homographic homophone verb primes and a homographic homophone verb target (picture plus sentence preamble) (e.g., 3a/b and 4a in Table 3). Critically, the two types of target allowed us to examine the homographic homophone boost and the heterographic homophone boost simultaneously. That is, we can determine the homographic homophone boost by comparing structural priming between 3a/b and 4a (with homographic homophone verbs) and between 3c/d and 4a (with unrelated verbs). Similarly, we can determine the heterographic homophone boost by comparing structural priming between 3c/d and 4b (with heterographic homophone verbs) and that between 3a/b and 4b (with unrelated verbs).

Finally, as Experiment 1 showed no difference in semantic relatedness between related and unrelated verbs (and indeed semantic relatedness did not modulate the priming effect; see <https://osf.io/sbvfy/>), we did not include a semantic relatedness test.

**Table 3.** Sample prime sentences and possible descriptions of target pictures in Experiment 2.

*Homographic homophone verb DO prime*

3a. 厨师打给了男生一碗水. (lit. The chef fetched the boy a bowl of water)

*Homographic homophone verb PO prime*

3b. 厨师打了一碗水给男生. (lit. The chef fetched a bowl of water for the boy)

*Heterographic homophone verb DO prime*

3c. 厨师搬了一桶水给男生. (lit. The chef carried the boy a bucket of water)

*Heterographic homophone verb PO prime*

3d. 厨师搬了一桶水给男生. (lit. The chef carried a bucket of water for the boy)

*Homographic homophone verb DO/PO description of target picture*

4a. 公主打给了医生一件毛衣/ 公主打了一件毛衣给医生

(lit. The princess knitted the doctor a sweater / the princess knitted a sweater for the doctor)

*Heterographic homophone verb DO/PO description of target picture*

4b. 公主颁给了医生一个奖牌/ 公主颁了一个奖牌给医生

(lit. The princess awarded the doctor a medal / the princess awarded a medal to the doctor)

## Results and discussion

One participant was excluded from further analyses for having more than 50% “other” responses in the target picture descriptions. Table 4 presents the results from the remaining 71 participants. Of the 2272 responses, 55% (1243) were primed responses, 42% (951) unprimed responses, and 3% (78) “other” responses (excluded from analyses). As in Experiment 1, we contrast-coded target verb type (homographic homophone verb = 0.5; heterographic homophone verb = -0.5) and verb relation (related verb = 0.5; unrelated verb = -0.5) in the LME analysis. (Note that we did not include prime structure as a predictor as it was subsumed in the dependent variable coding already.)

LME modelling on primed vs. unprimed responses revealed an overall priming effect, with more primed than unprimed responses ( $\beta = 0.27$ ,  $SE = 0.05$ ,  $z = 5.78$ ,  $p < .001$ ). There was no difference in priming between homographic and heterographic homophone verb type ( $\beta = -0.09$ ,  $SE = 0.09$ ,  $z = -1.09$ ,  $p = .274$ ). There was a significant main effect of verb relation ( $\beta = 0.33$ ,  $SE = 0.09$ ,  $z = 3.86$ ,  $p < .001$ ), with more primed responses when the prime and target had related (homophone) verbs than unrelated verbs. Critically, the interaction between target verb type and verb relation was not significant ( $\beta = -0.05$ ,  $SE = 0.17$ ,  $z = -0.29$ ,  $p = .772$ ), indicating that there was no reliable difference in priming boost between homographic and heterographic homophone verbs.

To test whether there are boosts in structural priming for homographic and heterographic homophones, we conducted separate analyses on the two verb types in the target picture (i.e., homographic homophone verb targets and heterographic homophone verb targets). When the verb in the target picture was a homographic homophone, there was an overall structural priming effect, with more primed than unprimed responses ( $\beta = 0.22$ ,  $SE = 0.06$ ,  $z = 3.62$ ,  $p < .001$ ). Such a priming effect was larger when the prime verb was a homographic homophone of the target verb than when it was an unrelated verb ( $\beta = 0.31$ ,  $SE = 0.12$ ,  $z = 2.52$ ,  $p = .011$ ). This latter finding suggests a homographic homophone boost in structural priming (consistent with Santesteban et al., 2010).<sup>4</sup>

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<sup>4</sup> This finding is further supported here by an initial experiment, not reported here, that tested the homographic homophone boost using the relevant conditions in Experiment 1 (i.e., DO/PO primes with a homographic homophone or unrelated verb with the target description). This experiment also yielded

When the verb in the target picture was a heterographic homophone, there was an overall structural priming effect, with more primed than unprimed responses ( $\beta = 0.32$ ,  $SE = 0.06$ ,  $z = 5.15$ ,  $p < .001$ ). Such a priming effect was larger when the prime verb was a heterographic homophone of the target verb than when it was an unrelated verb ( $\beta = 0.36$ ,  $SE = 0.12$ ,  $z = 2.93$ ,  $p = .003$ ). This latter finding suggests a heterographic homophone boost in structural priming, replicating the finding in Experiment 1.

However, we note that the null finding regarding the difference in boost between the two homophone types does not necessarily mean that there is no difference. We therefore turned to Bayes Factor (BF) analysis, which quantifies the likelihood of the alternative hypothesis versus the null hypothesis on the basis of the observed data (Jeffreys, 1998; Kass & Raftery, 1995; Wagenmakers, 2007). Following Wagenmakers (2007), we obtained the Bayesian Information Criterion (BIC) for the alternative-hypothesis model (i.e., the boosts was different between homographic and heterographic homophone verbs) and BIC for the null-hypothesis

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a homographic homophone boost, with more priming when the prime contained a homographic homophone verb than an unrelated verb. Note however that, due to the syntactic preference of the homographic homophone verbs, participants rarely produced DO responses (with DO responses constituting only 4% of DO and PO responses; data for this unreported experiment is also available on <https://osf.io/sbvfy/>). For this reason, we conducted Experiment 2, directly contrasting homographic and heterographic homophone target verbs in the same experiment, where the more DO-favouring heterographic homophone verbs would yield more DO productions for the homographic homophone verbs.

model (i.e., the boosts were comparable between the two types of homophone verbs). Using the formula  $BF = e^{ABIC/2}$ , we observed that the BF was 0.022 (i.e. the alternative hypothesis is 0.022 times as likely as the null hypothesis; in other words, the null hypothesis is 45 times more likely than the alternative hypothesis), suggesting that the null hypothesis was very likely given the data. Thus, the BF analysis strongly supports the conclusion that the orthographic identity in homographic homophones does not contribute to the homophone boost in structural priming.

**Table 4.** Responses and priming as a function of verb relation and prime structure in Experiment 2.

		DO	PO	Other	Primed	Unprimed	Priming
Homographic homophone target verbs							
Related	DO prime	51	223	10	326	224	0.59
	PO prime	1	275	8			
Unrelated	DO prime	12	256	16	279	261	0.52
	PO prime	5	267	12			
Heterographic homophone target verbs							
Related	DO prime	76	200	8	346	211	0.62
	PO prime	11	270	3			
Unrelated	DO prime	35	239	10	292	255	0.53
	PO prime	16	257	11			

### General Discussion

In two experiments, we showed that the tendency for people to repeat a previous structure (i.e., structural priming) was enhanced when the prime and the target used verbs that had the same phonology, regardless whether they additionally shared the same orthographic

(heterographic homophones, Experiments 1 and 2) or not (homographic homophones, Experiment 2). These results thus replicated the homophone boost in structural priming (Santesteban et al., 2010) and extended it from noun phrase structures to sentence structures (dative structures). In addition, they also suggested that the homophone boost occurs independently of orthography. More importantly, Experiment 2 showed that the magnitude of the homophone boost did not differ for homographic and heterographic homophones; this finding suggests that there is no extra boost in structural priming due to orthographic identity between verbs in the prime and target. These results are thus more consistent with the learned lemma association account than with the word-form feedback account we outlined in the introduction.

Homophone and other (e.g., lexical and semantic) boosts have been interpreted in terms of an extension of Pickering and Branigan's (1998) account of the lemma stratum, which in turn is based on Levelt, Roelofs, and Meyer (1999). On this account, verb or noun lemmas (e.g., give) are associated with syntactic nodes corresponding to the constructions (e.g., DO and PO). Priming results from residual activation of the syntactic nodes, and the lexical boost results from residual activation of the link between verb lemmas and syntactic nodes.

Homophones involve different lemmas and so do not result in a lexical boost. According to the word-form feedback account (Santesteban et al., 2010), the homophone boost (like the semantic boost; Cleland & Pickering, 2003) is due to co-activation of the two homophones. For example, if a participant has heard a DO sentence about a carrying event involving the verb *ban<sub>1</sub>* ("carry") and subsequently goes on to describe an awarding event using the verb *ban<sub>1</sub>* ("award"), the residually activated DO syntactic representation will increase the

likelihood of the DO structure (i.e., a lexical-independent general structural priming effect); in addition, the phonological encoding of the word-form /*ban*/ will also feedback to the lemma of the prime verb *ban* (“carry”) and in turn further activate the associated DO structure, additionally increasing the likelihood of DO use (the homophone boost).

The word-form feedback account, however, faces two problems. First, it would require two steps of spreading activation to yield the homophone boost – first from the retrieved shared word-form to the primed lemma, and then from the primed lemma to the primed structure. This two-step spreading activation is likely to reduce any boost – but the homophone boost is strong (here and in Santesteban et al., 2010). Second and more importantly, such an account would suggest a stronger boost from homographic than heterographic homophones, contrary to the results of Experiment 2. This is because homographic homophones share two (phonological and orthographic) word-forms, and so activation would spread back to the target lemma via both routes; whereas the heterographic homophones share only one (phonological) word-form, and so activation would spread back to the target lemma via the phonological route alone.

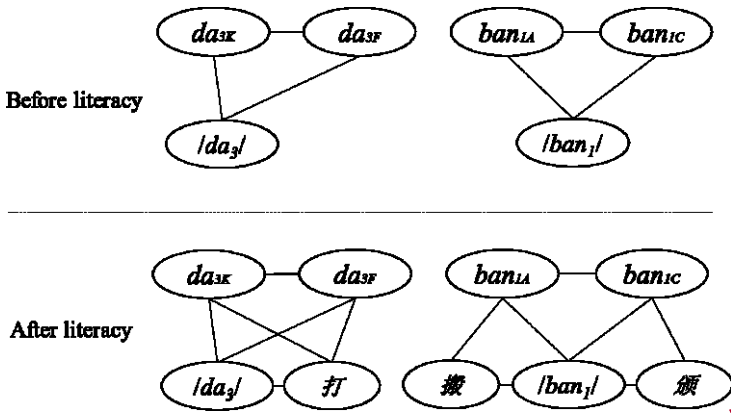
But is it possible that the lack of a boost for homographic homophones is due to a reason other than a lack of word-form feedback to syntactic encoding? It is possible that phonology but not orthography feeds back to the syntactic encoding of the picture descriptions. For example, even though written information was provided in the experiments, structural priming might be mediated by phonological but not orthographic working memory traces (hence the lack of a orthography-based boost for homographic homophones). However, there is no clear reason why phonological feedback but not orthographic feedback should occur.

More importantly, it has been shown that structural priming and the lexical boost (in both speaking and in writing) are equally strong after people have verbally produced a prime and after they have written a prime (Cleland & Pickering, 2006). These findings are thus inconsistent with the assumption that structural priming is mediated only by phonological working memory traces; otherwise, one should expect a larger boost in structural priming, say, from a spoken than written prime to a spoken target.

Our findings are instead more consistent with the learned lemma association account.

That is, phonological identity may affect the lemma representations that develop during early childhood. Thus during development, Mandarin-speaking children come to represent *da<sub>3</sub>* (“fetch”) and *da<sub>3</sub>* (“knit”) (and similarly *ban<sub>1</sub>* meaning “carry” and *ban<sub>1</sub>* meaning “award”) as very closely related lemmas as a consequence of their phonological identity. Such phonological-identity-based associations (i.e., inter-lemma associations between homophones) stabilise early in development, and therefore persist into adulthood. But these links are not further enhanced by orthographic identity (i.e., in the case of homographic homophones) because orthographic identity becomes apparent only later in development following the acquisition of literacy, at a point at which lemma associations have already become stable and entrenched. For example, the orthographic forms of the homophones used in our experiments are normally acquired through formal education, around the ages of 6-12 years (Shu, Chen, Anderson, Wu, & Xuan, 2003; Wang, Huang, Zhou, & Cai, 2020).





**Figure 4.** Learned lemma associations based on phonological (but not orthographic) identity between homophones. These associations give rise to the homophone boost in structural priming. In addition, we assume that the associations fossilize before literacy acquisition and are thus unaffected by later-learned orthographic relations between homophones; as a result, the associative strength is comparable between homographic and heterographic homophones, which explains the lack of difference in the homophone boost between the two types of homophones.

Thus, our findings can be straightforwardly explained in terms of associations between lemmas that are established early in childhood on the basis of spoken input, and are not influenced by later orthographic experience. As illustrated in Figure 4, lemmas are associated with syntactic nodes (DO and PO here) and more critically also with other lemma nodes if they are homophones. In addition, although lemmas are linked to phonology and orthography (e.g., hearing /da<sub>3</sub>/ or reading 打 would activate both da<sub>3</sub> lemmas during word recognition), these word-form representations do not directly feedback to influence syntactic encoding during production. To again use the carrying/awarding examples above, the retrieval of the

word-form /*ban1*/ for the lemma of *ban<sub>1</sub>* (“award”) does not feedback to the primed lemma (*ban<sub>1</sub>* “carry”) and in turn activate the DO structure. Instead, the homophone boost is a result of learned associations between homophone lemmas. That is, the selection of the *ban<sub>1</sub>* (“award”) lemma also activates the primed *ban<sub>1</sub>* (“carry”) lemma, which in turn further activates the DO representation, leading to a further increase in structural priming (the homophone boost). Importantly, as the lemma associations are established before literacy training, there is no distinction between homographic and heterographic homophones in terms of association strength and there is no difference in the magnitude of boost between the two homophone types.

As we have noted, learned lemma associations based on form similarity are also evoked by Huang et al. (2019) to explain stronger cross-language structural priming from Cantonese to Mandarin than from English to Mandarin, when the prime and target involved translation-equivalent verbs. Huang et al. argued that cognate translation-equivalents (as exist between Cantonese and Mandarin) have inter-lemma associations whereas non-cognate translation-equivalents (as exist between English and Mandarin) do not, and that these associations underlay the enhanced priming between Cantonese and Mandarin. Consistent with this account, Bernolet, Hartsuiker, and Pickering (2012) showed that structural priming from Dutch to English was larger when the Dutch prime and the English target contained cognate translation-equivalents than non-cognate ones. Indeed, at least for second language learners (probably in contrast to early bilinguals), words in the second language are often initially learned as associations of their corresponding words in the first language before they are developed as independent lexical entries (Jiang, 2000).

But it remains an open question to how much overlap in word-form is required for two words to develop inter-lemma associations and whether more overlap leads to a stronger association. There is evidence that the magnitude of structural priming boost does not vary as a function of measured degree of similarity in phonology between Cantonese-Mandarin cognates (Cai et al., 2011; Huang et al., 2019); in other words, it is not the case that phonologically more overlapping cognates enjoy closer associations and hence show a larger boost. However, Bernolet et al. (2012) observed a larger boost for more similar Dutch-English cognates.

In sum, both homographic and heterographic homophone verbs led to a boost in structural priming and the two boosts were comparable in magnitude. These findings thus show that phonology affects structural priming in language production, whereas orthography appears to play a minimal role. We proposed that language learners develop lemma associations between homophones on the basis of phonological (but not orthographic) identity in childhood; therefore, homographic and heterographic homophones have similar inter-lemma associations and lead to comparable boost in structural priming.

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