Lexical and syntactic influences on syntactic encoding in written language production by deaf speakers

Zhenguang G. Cai^{1,2}, Nan Zhao³, Hao Lin⁴,

¹Department of Linguistics and Modern Languages, The Chinese University of Hong Kong, Hong Kong SAR

²Brain and Mind Institute, The Chinese University of Hong Kong, Hong Kong SAR

³Department of Translation, Interpreting and Intercultural Studies, Hong Kong Baptist University, Hong Kong SAR

⁴Institute of Linguistics, Shanghai International Studies University, China

Author notes

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Abstract

It remains unclear whether deaf and hearing speakers differ in the processes and representations underlying written language production. Using the structural priming paradigm, this study investigated syntactic and lexical influences on syntactic encoding in writing by deaf speakers of Chinese in comparison with hearing controls. Experiment 1 showed that deaf speakers tended to reuse a prior syntactic structure in written sentence production (i.e., structural priming) to the same extent as hearing speakers did; in addition, such a tendency was enhanced when the target sentence repeated the verb from the prime sentence (i.e., lexical boost) in both deaf and hearing speakers to the same extent. These results suggest that deaf and hearing speakers are similarly affected by syntactic and lexical factors in syntactic encoding in writing. Experiment 2 revealed comparable boosts in structural priming between prime-target pairs with homographic homophone verbs and prime-target pairs with heterographic homophone verbs in hearing speakers, but a boost for prime-target pairs with homographic homophone verbs but not those with heterographic homophone verbs in deaf speakers. These results suggest that while syntactic encoding in writing is influenced by lemma associations developed for homophones as a result of phonological identity in hearing speakers, it is influenced by lemma associations developed for homographs as a result of orthographic identity in deaf speakers. In all, syntactic encoding in writing seems to employ the same syntactic and lexical representations in hearing and deaf speakers, though lexical representations are shaped more by orthography than phonology in deaf speakers.

Keywords: deaf, written language production, structural priming, Chinese, syntactic encoding

To produce a sentence in either speaking or writing, speakers¹ need to retrieve words corresponding; then, in what is known as syntactic encoding, they will need to arrange the received words into a particular syntactic structure. Much research has shown that, in speaking, syntactic encoding is, among other things, driven by prior syntactic experience (e.g., Bock & Levelt, 1994) and lexical characteristics (e.g., structural preferences of the verb; e.g., Ferreira, 1994). In hearing speakers, there is much theoretical ground to assume that, writing employs largely the same syntactic encoding processes used for speaking (e.g., Hayes & Flower, 1986; Pickering & Branigan, 1998). What is much less clear is how deaf speakers syntactically encode words into a structure in writing, given that they have no access to a spoken language. In this paper, we investigated whether and how deaf speakers differ from hearing speakers in syntactic encoding in writing.

Written language production by deaf speakers

Deaf speakers can communicate in signing and/or in writing. However, there is good evidence that, in written language production, deaf speakers lag behind age-matched hearing controls in both syntactic formulation and lexical expressions (Marschark, Mouradian, & Halas, 1994; Yoshinaga-Itano, 1996); it is observed that deaf speakers at the age of 17-18 often write at a level of hearing speakers at the age of 8-10 (Marschark, Lang, & Albertini, 2001; Paul, 2009). For instance, deaf speakers are lexically less diversified in writing (Albertini & Schley, 2003; Heefner & Shaw, 1996), produce shorter written texts (Bochner & Albertini, 1988), and use fewer cohesive devices in text organisation (Bochner & Albertini, 1988). More importantly for the current research, they also show deficits in syntactic encoding. Compared to hearing controls, deaf speakers often produce more syntactic anomalies, use fewer function words such as auxiliaries, conjunctions and articles, and make more mistakes in morphological marking in their writing (Marschark et al., 1994; Thierfelder &

¹ We use the term “speakers” to broadly refer to users of a verbal language in both speaking and writing; therefore, we use the term “deaf speakers” to refer to deaf people who read or write in a verbal language. We also use the term “verbal language” in contrast to sign language, to mean a spoken language and its written system.

Stapleton, 2016); they also have difficulties at producing syntactically complex texts (Wolbers, Dostal, & Bowers, 2012).

But what leads to these lexical and syntactic disadvantages in deaf compared to hearing speakers in written sentence production? Deaf speakers normally acquire a sign language before they learn to read and write a verbal language; thus, it is likely that some writing problems can be due to negative transfer from the sign language. It is well-known that different linguistic systems interfere with each other at a variety of linguistic levels (Costa, Colomé, Gómez, & Sebastián-Gallés, 2003; Flege & Port, 1981; Odlin, 1989; Thierry & Wu, 2007), notably in syntactic encoding (Cai, Pickering, Yan, & Branigan, 2011; Hartsuiker, Pickering, & Veltkamp, 2004; Nicoladis, 2006; Yip & Matthews, 2000). Thus, when a deaf speaker read or write, they are likely to also activate corresponding representations in their sign language (as a first/dominant language; e.g., Meade, Midgley, Sehyr, Holcomb, & Emmorey, 2017; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011; Thierfelder, Wigglesworth, & Tang, 2020a). Indeed, by examining written productions of English by deaf users Hong Kong Sign Language, Thierfelder and Stapleton (2016) showed that these writings contain linguistic errors (e.g., misuse of articles and count/mass nouns) that can be attributed to cross-linguistic influence from their first language, Hong Kong Sign Language.

But more importantly, it is well known that the lack of (or severe limit in) exposure to a language in the critical period leads to failure to attain native-like proficiency in the language (e.g., Snow, Hoefnagel-Höhle, 1978; Johnson & Newport, 1989). Thus, it is highly likely that deaf speakers' lack of (or severe limit in) spoken language exposure in the critical childhood years lead to impoverished representations and processes underlying written language comprehension and production (e.g., Marschark et al., 1994; Miller et al., 2012). Therefore, it remains an empirical question whether deaf speakers make use of similar syntactic and lexical representations in syntactic encoding in writing.

In addition, there is also ample evidence that hearing speakers make use of spoken representations in reading (Ferrand & Grainger, 1992; Frost, 1998; Perfetti & Zhang, 1995; Stone, Vanhoy, & Van Orden, 1997) and more importantly also in writing (Huang, Lin, Xu, Wang, & Cai, in press; Qu & Damian, 2020; Qu, Damian, Zhang, & Zhu, 2011; M. Wang, Cai, Wang, Branigan, &

Pickering, in press; R. Wang, Huang, Zhou, & Cai, 2020). For instance, R. Wang et al., (2020) showed that, Chinese speakers are quicker at handwriting a Chinese character if the character has more regularity between its pronunciation and orthography (see more evidence below). For deaf speakers, there is evidence that they may have some (though limited) access to spoken language representations and these representations are activated in reading (Gutierrez-Sigut, Vergara-Martínez, & Perea, 2017; Hanson, 1989; Thierfelder, Wigglesworth, & Tang, 2020b; Wang, Trezek, Luckner, & Paul, 2008; see Mayberry, Del Giudice, & Lieberman, 2011, for a meta-analysis). For instance, in a lexical decision task, Gutierrez-Sigut et al. (2017) showed that deaf readers (as hearing readers) were quicker at responding to a target (e.g., *CORAL*) preceded by a masked pseudo-homophone prime (e.g., *koral*) than by a masked orthographic control (e.g., *toral*). However, it is much less clear whether deaf speakers also make use of phonological information in writing, especially in syntactic encoding, as hearing speakers do. Thus, in this paper, we used structural priming to investigate whether and how deaf speakers differ from hearing speakers in syntactic encoding in writing.

Structural priming and syntactic encoding in language production

Language production begins with a conceptualisation of a preverbal message consisting of event participants (e.g., who does what to whom; Levelt, 1989). The message then leads to activation of lemmas (lexico-syntactic representations of words; Levelt, Roelofs, Meyer, 1999) corresponding to the event participants and the selection of a syntactic structure for organising the lemmas (syntactic encoding; Bock & Levelt, 1994). It is also likely that argument structure encoded in lemmas may help to select a particular syntactic structure (e.g., Melinger & Dobel, 2005; Ferreira, 1994, 2000). The next step is then to retrieve the lexeme or (phonological/orthographic) wordform for each lemma and then articulate or write the words as output. There is much evidence, especially from structural priming, that syntactic encoding of lemmas is influenced by, among other things, syntactic experience and lexical preferences.

Bock (1986) showed that speakers tend to re-use a previously used structure when there are alternative ways to express the same message (a tendency known as structural priming). For instance, speakers tend to use a double-object (DO) dative structure in describing a picture (e.g., *the girl is*

handing the man a paintbrush) after being asked to repeat a DO sentence (e.g., *the undercover agent sold the rock star some cocaine*) than a prepositional-objective (PO) dative sentence (e.g., *the undercover agent sold some cocaine to the rock star*). Bock and Loebell (1990) further showed that structural priming is not driven by superficial word order or prosodic similarity. They found that a sentence that was superficially similar to a PO sentence (e.g., *Susan brought a book to study*) did not increase people's tendency to subsequently use a PO sentence for picture description. Structural priming has been widely observed in many other languages and constructions (see Pickering & Ferreira, 2008, for a review; see Mahowald, James, Futrell, & Gibson, 2016, for a meta-analysis). For instance, in Chinese, people have the tendency to repeat a dative structure (DO or PO) that they have previously produced/comprehended (Cai et al., 2011, 2012, 2015). The abundance of structural priming suggests that syntactic encoding in language production is sensitive to a speaker's prior syntactic experience (e.g., Bock & Loebell, 1990).

Further structural priming studies also show that syntactic encoding is also sensitive to a speaker's recent experience with lexical heads (e.g., verbs or head nouns). Pickering and Branigan (1998) showed that, the tendency for a target sentence to repeat a prime structure is enhanced if the target sentence uses the same verb from the prime sentence than it used a different verb, an enhancement that they referred to as the lexical boost. The lexical boost is the same regardless whether the prime and the target have the same morphological markings (e.g., *gives – gives*) or not (e.g., *gives – gave*), suggesting that it is the lemma instead of the wordform that gives rise to the lexical boost. Pickering and Branigan (1998) suggest that syntactic structures (e.g., DO and PO structures) are linked to the lemma of individual verbs. The tendency to re-use a structure in language production (i.e., structural priming) is a result of a structural representation being residually activated from prior use; similarly, the lexical boost occurs a result of residually activated link between the verb and the earlier structure, in addition to the residually activated structure. The lexical boost also suggests that syntactic encoding is at least partly lexically-driven (e.g., Melinger & Dobel, 2005; Ferreira, 1994, 2000). That is, a lexical head (e.g., a verb) dictates how its dependent lexical expressions (e.g., objects of the verb) should be syntactically encoded in a sentence.

Finally, there is also structural priming evidence that syntactic encoding can be also affected by wordform (phonological and/or orthographic) in lexical heads between a target sentence and a prime sentence. Santesteban, Pickering, and McLean (2010) showed that the choice between a relativized noun phrase (NP) structure (e.g., *the bat that's red*) and an adjective NP structure (e.g., *the red bat*) in picture descriptions can be structurally primed, with more relativized-NP productions following a relativized-NP prime than an adjective-NP prime (see also Cleland & Pickering, 2003). More importantly, they showed a boost in structural priming when the prime and target had a full overlap in the head noun (i.e., homophone words); for example, speakers were more likely to say *the bat's that's red* to describe an animal bat after hearing *the bat that's red* as a description of a cricket bat than after hearing *the pool that's red*. Note that such wordform effects on syntactic encoding are not observed when the lexical heads between the prime and the target have only partial instead of full overlap; for example, there is no more productions of *the sheep that's red* following *the ship that's red* than *the pool that's red*, despite *sheep* and *ship* had partial overlap in wordform (e.g., Cai et al., 2011; Cleland & Pickering, 2003; Hall, Ferreira, & Mayberry, 2015).

Santesteban et al. (2010) argued that the homophone boost in structural priming reflects a lemma-mediated binding between wordforms and syntactic representations. More specifically, the shared wordform of homophones is linked to their respective lemmas. When speakers are to describe an animal bat, say, after hearing *the bat that's red* (compared to after hearing *the red bat*) as a description of a cricket bat, the relativized NP structure is increased in use due to the structure's residual activation; in addition, the wordform /bat/ also activate, which further activates the relativized NP that the cricket bat lemma has been used with, thus leading to the homophone boost in priming. However, M. Wang et al. (2020) recently argued that the homophone boost might instead reflect lemma associations between homophone words that language learners develop as a result of phonological identity. In particular, they showed comparable structural priming when the prime and the target had homographic homophone verbs (i.e., verbs identical in both phonology and orthography) and when they had heterographic homophone verbs (i.e., verbs identical in phonology and but different in orthography), suggesting that additional orthographic identity in homophone words does not contribute to structural priming. M. Wang et al. (2020) proposed that, when hearing

speakers learn a language in childhood, they develop associated lemmas for homophones as a result of their shared phonological form. The association between homophone lemmas due to phonological overlap is relatively stabilised and is thus not further enhanced by orthographic overlap when hearing speakers subsequently learn the written forms of the homophones (which happen between primary school and adulthood; Cai, Huang, Xu, & Zhao., in press). Thus, homographic homophones do not enjoy a closer lemma association than heterographic homophones, hence their equivalence in the boosts they caused in structural priming.

Syntactic and lexical influences on syntactic encoding in written language production

But is syntactic encoding sensitive to the syntactic and lexical factors in written language production as it is in spoken language production? In general, written language tends to be assumed to be secondary to spoken language (e.g., Bloomfield, 1933). There is also evidence that people recognise written language via the spoken language, with quicker or more accurate visual word recognition when a written word is more regular (e.g., *hint* vs. *pint*; Frost, 1998; Stone, Vanhoy, & Orden, 1997). In language production, people tend to assume that the same core cognitive representations and processes underlie both speaking and writing (e.g., Levelt, 1989; Levelt et al., 1999; Pickering & Branigan, 1998) and dissociations between the two modes of communication are mainly at the wordform level (e.g., Shelton & Caramazza, 1999).

Cleland and Pickering (2006) used structural priming to investigate whether speaking and writing employ the same syntactic representations. They had participants repeat and complete a DO prime (e.g., *The neighbour lends the friend ...*) or a PO prime (e.g., *The neighbour lends the mower ...*) then repeat and complete sentence preamble (e.g., *The cook lends ...*). They observed that similar priming effects when the prime and the target was completed in the same modality (e.g., spoken prime completion and spoken target completion, or written prime completion and written target completion) and when they were completed in different modalities (e.g., spoken prime completion and written target completion). In addition, they observed that the lexical boosts (i.e., larger priming when the verb was the same than different between the prime and the target) was comparable for spoken and written target completion. These findings strongly suggest that, in hearing

speakers, written production employs the same set of syntactic and lexical representations as spoken production does.

What is rarely asked is whether deaf speakers employ the same syntactic and lexical representations in written production as those in hearing speakers. More specifically, do deaf speakers differ from hearing speakers in the use of syntactic and lexical information when making a structural choice (e.g., between DO and PO) in written language production? Deaf speakers are likely to develop abstract lexico-syntactic representations (i.e., lemmas) from exposure to written language input only (e.g., treating *give* and *gave* as different forms of the same verb) and combinatorial knowledge regarding lexical use (e.g., *give* can be used in either a DO or PO structure). If this is the case, we should expect deaf speakers to have a greater tendency to repeat a prime structure (i.e., the lexical boost) when the prime and the target share the same verb than when they don't, as hearing speakers do in both spoken and written production (e.g., Cleland & Pickering, 2006; Pickering & Branigan, 1998).

What is much less clear is whether deaf speakers may be influenced by wordform (phonological and orthographic) information from prior language use. Regarding phonological influence, there is evidence that deaf speakers who do not produce spoken language nonetheless have some access to phonological representations in reading (e.g., Gutierrez-Sigut et al., 2017; Thierfelder et al., 2020b). However, it is also possible that the phonological information deaf speakers have access to is just too little for it to have any influence in written production at all. These two possible scenarios thus have different predictions regarding whether structural priming will be boosted by phonological identity in deaf speakers, as it is shown to be in hearing speakers (Santesteban et al., 2010; M. Wang et al., 2020).

Regarding orthographic influence, there is evidence that deaf speakers are very sensitive to orthographic information in reading (e.g., Bélanger, Mayberry, & Rayner, 2013; Gutierrez-Sigut et al., 2019). Thus, it is possible that they may make particular use of orthographic information in syntactic encoding. If that's the case, they may show a boost in structural priming as a result of orthographic identity (e.g., stronger priming when the verbs in the prime and the target were

homographs than heterographs), in contrast to the lack of such a boost in hearing speakers in written production (M. Wang et al., 2020).

In this study, we reported two structural priming experiments comparing syntactic encoding in writing by deaf and hearing speakers. In Experiment 1, we investigated whether deaf speakers show a similar lexical boost in structural priming as hearing speakers do. In Experiment 2, we investigated whether deaf speakers show similar (in)sensitivity to phonological and orthographic information as hearing speakers do in syntactic encoding in writing.

Experiment 1

In this experiment, we tested whether we could observe similar lexical boosts in structural priming in written language production by deaf and hearing speakers of Chinese. We had a group of deaf speakers and a group of hearing controls to first read and repeat (by typing) a prime sentence (e.g., 1a-d in Table 1) and then type a sentence (e.g., 2a/b) to describe a picture (see Figure 1). The prime sentence (in target trials) had either a DO structure (e.g., 1a/c) or a PO structure (e.g., 1b/d) and had either same verb as the target description (e.g., 1a/b) or a different verb (e.g., 1c/d). We were interested whether people produced a DO description (e.g., 2a) or a PO description (e.g., 2b).

Table 1: Exemplar prime and target descriptions in Experiment 1

1a. Same verb, DO:
厨师颁给了男生一张证书。(lit. The chef awarded the boy a certificate.)
1b. Same verb, PO:
厨师颁了一张证书给男生。(lit. The chef awarded a certificate to the boy.)
1c. Different verb, DO:
厨师挑给了男生一件衣服。(lit. The chef chose the boy an item of clothing.)
1d. Different verb, PO:
厨师挑了一件衣服给男生。(lit. The chef chose an item of clothing to the boy.)
2a. DO description:
公主颁给了医生一个奖牌。(lit. The princess awarded the doctor a medal.)
3b. PO description:
公主颁了一个奖牌给医生 (lit. The princess awarded a medal to the doctor.)

Method

Participants. Thirty-four deaf Chinese speakers and forty-one hearing Chinese speakers took part in the experiment. One deaf and seven hearing participants were excluded from analyses for having too many excluded trials (see *Results and discussion* below), leaving 33 deaf participants (19 females) 34 hearing ones (22 females), with comparable age between the two groups: (deaf participant average age = 33.7, range = 25 – 43; hearing participant average age = 31.4, range = 20 – 48; $t(63.9) = 1.42$, $p = .160$). Deaf participants were recruited from the Shanghai deaf community. All participants reported to be native speakers of Chinese and to have no other language disorders except for being deaf. One participant failed to fill in a post-experiment questionnaire regarding deafness but was nonetheless included in the analysis as interaction with him/her in the experiment revealed that he/she as indeed deaf and a signer of the Shanghai Sign Language. For the rest, 30 participants were born deaf or prelingually deaf (i.e., deaf before 3 years old), one became deaf at 5 years old and another at 7.5 years old. Thirty-one reported to be profoundly deaf (hearing loss > 90dB) and one reported to be severely deaf, (hearing loss of 71 - 90dB). Thirty participants attended the deaf schools, where they were instructed with the Shanghai Sign Language and learned to read and write in Chinese; two participants attended a mainstream school. All surveyed deaf participants reported to have used sign language since childhood and also to be proficient users of written Chinese in reading and writing.

Materials. The materials were adapted from materials used in M. Wang et al. (2020, Experiment 3) and are accessible on Open Science Framework (<https://osf.io/vg9sn/>). There were 32 target items and 96 filler items. An item consisted of a written prime sentence and a target picture. In the target items, the prime sentence was either a DO or a PO sentence. The target picture was grey-scale line drawing depicting a ditransitive event involving two human beings as the agent and the recipient and an object as the theme (e.g., a princess giving a chef a medal). A sentence preamble consisting of the agent noun phrase and a verb, together with an underline, was printed underneath the picture (e.g., 公主颁_____ [lit. the princess awarded _____]). The verb was the same as the verb in the prime sentence in the same-verb conditions but differed from the prime verb in the

different-verb conditions. The primes in the filler items were mainly transitive (e.g., 画家击倒了囚犯 [lit. the artist punched the prisoner]) and intransitive sentences (e.g., 公主在睡觉 [lit. the princess was sleeping]), but were DO dative sentences in 12 of the filler items in order to boost productions of DO responses (for a similar manipulation, see Cai et al., 2011, 2015; Wang et al., 2020). The target pictures depicted transitive event (e.g., a chef lifting a mug), with the subject noun phrase and a verb in the sentence preamble (e.g., 厨师举起_____ [lit. the chef lifted _____]) or depicted an intransitive event (e.g., a nun sweating), with the subject noun phrase only in the preamble (e.g., 尼姑_____ [lit. the nun _____]). The verb was the same between the prime sentence and the target description in 32 filler items and different in 64 fillers items. Therefore, across the target- and filler-item trials in the experiment, half of them had the same verb between the prime sentence and the target description.

Procedure. The experiment was run on Qualtrics. After indicating their consent to take part in the experiment, participants were given three practice items before the main experiment. In a trial (see Figure 1), participants read a sentence; the sentence disappeared at a click on a → sign and participants repeated the sentence by typing it in a text box. They clicked on the → sign to submit the repetition; then they saw a picture with a sentence preamble. They described picture by repeating and continuing the preamble in writing. The experiment took about 50 minutes and participants were paid 50 Chinese RMB.

Figure 1: Trial structure in Experiment 1. Participants read a prime sentence, repeated the sentence by typing into a text box, and finally typed a sentence in a text box to describe a picture by repeating and continuing a sentence preamble.

Data coding. We first checked the repetitions of the primes in the target trials. A repetition was coded as correct if the sentence was repeated in a grammatical way and retained the original structure and the verb (e.g., 颁给 in the DO structure and 颁 in the PO structure); omission of the grammatical aspect (e.g., 颁给了 repeated as 颁给) and accidental typo in the nouns were tolerated. We then coded the descriptions of the target pictures in the target trials. Following prior practice (e.g., M. Wang et al., 2020), a description was coded as a DO, PO or “other” response. A description was coded as a DO response if the provided sentence preamble was correctly repeated and grammatically followed first by a noun phrase denoting the recipient and then by a noun phrase denoting the theme (e.g., 公主颁给了厨师一块奖牌; lit. the princess awarded the chef a medal). A description was coded as a PO response if the provided sentence preamble was repeated and grammatically followed first by a noun phrase denoting the recipient and then by a noun phrase denoting the theme (e.g., 公主颁了一块奖牌给厨师; lit. the princess awarded the chef a medal). Trials with either an incorrect repetition or with an “other” response in picture description were excluded from further analyses. Following earlier practice (Cai et al. 2011; M. Wang et al., 2020), we further coded a DO and PO response as a primed or unprimed response. A (DO or PO) response was primed if it had the same structure as the prime sentence and unprimed if it had a different structure. Compared to traditional analyses using DO vs. PO response as the dependent variable (DV), the use of primed vs. unprimed responses as the DV would reduce the complexity of analyses as prime structure was subsumed in the DV (i.e., a primed response was when a DO response followed a DO prime or a PO response following a PO prime). For example, traditional analyses using DO vs. PO response as the DV would look for a main effect of prime structure to demonstrate a structural priming effect and an interaction between prime structure and verb type (same vs. different verbs) to demonstrate a lexical boost. With primed vs. unprimed response as the DV, one can test whether there are generally more primed than unprimed responses to demonstrate structural priming and the main effect of verb type to demonstrate whether more primed responses when the prime verb is the same as the target verb than when it is

different from the target verb (i.e., a lexical boost as a main effect of verb type instead of interaction between prime structure and verb type).

Results and discussion

We first calculated each participant's proportion of removed trials (either as a result of an incorrect or repetition or an "other" response) and removed participants with a proportion of more than 40% excluded target trials. This resulted in the exclusion of 1 deaf participant and 7 hearing participants. For the remaining 33 deaf and 34 hearing participants, respectively 9.6% and 14.2% of the target trials were removed as incorrect trials. All data and analytical scripts are available on Open Science Framework (<https://osf.io/vg9sn/>).

Trial-level (primed vs. unprimed response) data were subjected to logit mixed effects (LME) modelling, using group (hearing = -0.5, deaf = 0.5) and prime verb (different = -0.5, same = 0.5) as interacting predictors. Following Matuschek, Kliegl, Vasishth, Baayen, and Bates (2017), we used the maximal random effect structure justified by the data, adopting an alpha level of .20 (instead of .05) in forward model comparisons to determine whether a particular random effect should be added into the random effect structure (see our analytical scripts for details).

Figure 2: Priming effects as a function of prime verb in the deaf and hearing groups in Experiment 1.

Table 2: LME results of Experiment 1.

	β	SE	z	p
Main analysis (random effect structure including by-participant slope for verb)				
Intercept	0.51	0.06	8.11	< .001
Group	0.12	0.13	0.92	.255
Verb	0.56	0.10	5.37	< .001
Group: Verb	0.26	0.21	1.25	.211
Separate analysis: hearing participants (random effect structure including by-participant slope for verb)				
Intercept	0.44	0.08	2.98	< .001
Verb	0.41	0.14	5.37	.003
Separate analysis: hearing participants (random effect structure including no random slopes)				
Intercept	0.58	0.09	6.10	< .001
Verb	0.71	0.16	4.46	< .001

The LME results (see Table 2) revealed a significant intercept, indicating more primed than unprimed responses (1170 vs. 719), with a priming effect of 61.9% (in other words, responses were primed 61.9% of the time; see also Figure 1). There was no significant main effect of group, with similar structural priming effects between the deaf and hearing participants (63% vs. 61% in priming effects respectively). There was a significant main effect of prime verb, with larger structural priming when the prime verb was the same as the target verb than when it was different (68.0% vs. 55.7% in priming effects, a lexical boost of 12.3%). The lack of a significant interaction between group and verb suggests that the lexical boost in structural priming was comparable between the deaf and hearing groups.

We also performed separate analyses on deaf and hearing speaker. Hearing speakers produced more primed and unprimed responses as revealed by the significant intercept and a lexical boost (10%) in structural priming, as revealed by the significant main effect of verb. Deaf speakers have exactly the same pattern, with a general tendency of structural priming and a lexical boost (15%) in structural priming.

Finally, we compared the two groups separately for the different-verb and the same-verb conditions and found no difference no significant between-group difference in priming in either

condition (different-verb: $\beta = -0.01$, $SE = 0.13$, $z = -0.10$, $p = .922$; same-verb: $\beta = 0.24$, $SE = 0.17$, $z = 1.37$, $p = .169$).

The results first of all show that both deaf and hearing participants tended to repeat the structure of a prime sentence when they produced written descriptions of pictures and such a tendency was enhanced when the verb in the prime sentence was the same as the verb used in the description (a lexical boost). More importantly, structural priming and the lexical boost were comparable between deaf and hearing speakers.

Experiment 2

In this experiment, we contrasted, between deaf and hearing participants, structural priming boosts due to wordform identity in written picture descriptions. Apart from participant group (deaf vs. hearing) and prime structure (DO vs. PO), we also manipulated whether a depicted event was to be described using a homographic homophone verb (4a in Table 3) or heterographic homophone verb (4b). A homographic homophone verb is one for which there is another verb that has the same phonology and the same orthography (e.g., 打, *da3*, means “knit” in 4a but “fetch” in 3a/b); a heterographic homophone verb is one for which there is another verb that has the same phonology but different orthography (e.g., 颁, *ban1*, “award” in 4b and 搬, *ban1*, “carry” in 3c/d). We also manipulated the prime verb to be related to the target verb (i.e., homophone verbs; e.g., 3a/b as prime and 4a as target, or 3c/d as prime and 4b as target) or unrelated (e.g., 3a/b as prime and 4b as target, or 3c/d as prime and 4a as target).

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)

As homographic homophone verbs, compared to heterographic ones, are additionally identical in orthography, M. Wang et al. (2020) used compared the two types of verbs to examine whether the additional identity in orthography further enhances structural priming hearing speakers. M. Wang et al. showed that hearing participants are sensitive to phonological but not orthographic identity between prime and target in structural priming, with similar boosts in structural priming for homographic and heterographic homophone prime-target pairs, compared to prime-target pairs with unrelated verbs. Here, using a design of 2 (group: deaf vs hearing) x 2 (structure: DO vs PO) x 2 (target verb: heterographic vs homographic homophone verb) x 2 (prime verb: related vs unrelated to target verb), we tested whether deaf speakers are sensitive use of phonological and/or orthographic identity in structural priming and whether the boosts due to phonological and/or orthographic identity, if any, differ from those in hearing participants.

Methods

Participants. Forty-seven deaf participants and 63 hearing participants were recruited from the same populations as those in Experiment 1. Four deaf participants and 14 hearing participants

were removed for having > 40% of the target trials excluded (see below). For the remaining 43 deaf participants (31 females; average age = 31.6, range = 21 - 43) and 49 hearing participants (21 females; average age = 29.9, range = 22 - 41), there was no difference in age ($t(80.0) = 1.49, p = .140$). Two deaf participants failed to fill in a questionnaire regarding deafness, though again interaction with them in the experiment revealed that they were deaf and speakers of Shanghai Sign Language. For the remaining 41 deaf participants, 21 were born deaf and 22 became deaf prelingually. All reported to be profoundly deaf (hearing loss > 90dB), except for one reported to be severely deaf (hearing loss of 71 - 90dB). Forty participants attended deaf schools and three attended mainstream schools. As in those in Experiment 1, all surveyed deaf participants all reported to have use sign language since childhood but to and also to be proficient users of written Chinese in reading and writing.

Materials, procedure, and data coding. The materials (available on <https://osf.io/vg9sn/>) were similar in makeup to those in Experiment 1 and the procedure and data coding was the same as those in Experiment 1.

Results and discussion

We removed 4 deaf participants and 14 hearing participants for having more than 40% of the target trials where they either incorrectly repeated a prime or produced an “other” response. For the remaining participants, we further removed 18.3% of the target trials with an incorrect prime repetition or “other” target response. Trial-level primed vs. unprimed responses for the remaining trials were entered into LME modelling, using group (hearing = -0.5, deaf = 0.5), target verb (heterographic = -0.5, homographic = 0.5) and prime verb (unrelated = -0.5, related = 0.5) as interacting predictors. As in Experiment 1, we determined the maximal random effect structure justified by the data via forward model comparisons.

The significant intercept revealed more primed than unprimed responses in general, with a priming effect of 56.6%. There was no significant effect of group, suggesting that the two groups did not differ in the magnitude of structural priming (59% vs. 55% for hearing and deaf respectively). There was no significant main effect of target verb, with similar priming effects for target pictures with heterographic vs. homographic homophone verbs (56.0% vs. 57.2% in priming effects). There

was a significant main effect of prime verb, with larger structural priming when the prime verb was the related than unrelated with the target verb (59.3% vs. 53.7% in priming effects, a homophone boost of 5.6%). No two-way interactions reached statistical significance. Critically, there was a three-way interaction among participant group, target verb and prime verb (see Figure 3). To investigate this interaction, we conducted separate analyses on hearing and deaf participants.

Table 4: LME results of Experiment 2.

	β	SE	z	p
Main analysis (random effect structure including no random slopes)				
Intercept	0.27	0.05	5.63	< .001
Group	0.18	0.10	1.85	.064
Target Verb	0.05	0.08	0.65	.515
Prime Verb	0.23	0.08	2.79	.005
Group: Target Verb	-0.03	0.17	-0.15	.878
Group: Prime Verb	-0.01	0.17	-0.07	.946
Target Verb: Prime Verb	0.22	0.17	1.33	.182
Group: Target Verb: Prime Verb	0.66	0.33	1.98	.048
Separate analysis: Hearing speakers (random effect structure including no random slopes)				
Intercept	0.18	0.06	3.24	0.001
Target Verb	0.06	0.11	0.55	0.581
Prime Verb	0.23	0.11	2.09	0.036
Target Verb: Prime Verb	-0.11	0.22	-0.48	0.633
Separate analysis: Deaf speakers (random effect structure including no random slopes)				
Intercept	0.37	0.09	4.34	0.000
Target Verb	0.04	0.12	0.32	0.746
Prime Verb	0.23	0.12	1.84	0.066
Target Verb: Prime Verb	0.57	0.25	2.27	0.023

Figure 3: Priming effects as a function of target verb and prime verb in the deaf and hearing groups in Experiment 2.

For hearing participants, the significant intercept suggests a general tendency of structural priming. There was no significant effect of target verb, but there was a significant effect of prime verb, with more structural priming when the prime verb was related than unrelated with the target verb (57.4% vs. 51.7% in priming effects; see also Figure 3). Importantly, the interaction between target verb and prime verb was not significant, suggesting that the homophone boost for homophone verbs (as compared to unrelated verbs) was comparable regardless whether the homophones were homographic ($\beta = 0.18$, $SE = 0.16$, $z = 1.16$, $p = .246$) or heterographic ($\beta = 0.29$, $SE = 0.16$, $z = 1.79$, $p = .074$).

For deaf speakers, the significant intercept suggests a general tendency of structural priming. There was no significant effect of target verb, but there was a significant effect of prime verb, with more structural priming when the prime verb was related than unrelated with the target verb (57.4% vs. 51.7% in priming effects; see also Figure 3). Importantly, the interaction between target verb and prime verb was significant, suggesting that the homophone boost was different in magnitude for

homographic and heterographic homophones. Separate analyses showed a homophone boost for homographic homophones (as compared to unrelated verbs; $\beta = 0.51$, $SE = 0.18$, $z = 2.86$, $p = .004$) but not for heterographic homophones ($\beta = -0.05$, $SE = 0.17$, $z = -0.31$, $p = .760$). In other words, there was more structural priming for related than unrelated prime verb when the target verb was homographic (i.e., a boost in priming when the prime and target had homophone verbs of the same orthography) but not when the target verb was heterographic (i.e., no boost in structural priming when the prime and target had homophone verbs of different orthographies).

The results of the hearing participants first of all replicated those of M. Wang et al. (2020): There were comparable boosts regardless whether the verbs between the prime and the target were heterographic or homographic, which suggests that hearing participants are not sensitive to orthographic identity in the homophone boost (otherwise one should observe a larger boost for homographic than heterographic homophone verbs). In contrast, for deaf participants, we did not observe a boost in structural priming when the prime and the target had heterographic homophone verbs (compared to unrelated verbs) but we did observe a boost in structural priming when the prime and the target had homographic homophone verbs. These findings suggest that, in contrast to hearing participants, deaf participants are sensitive to orthographic identity but not phonological identity in the homophone boost.

General discussion

In Experiment 1, deaf and hearing speakers had comparable tendency to repeat a previous structure when the prime and the target had different verbs and comparable lexical boosts when the prime and the target had the same verb. In Experiment 2, while hearing speakers showed a boost in structural priming due to the phonological but not orthographic identity between the prime and target verbs, deaf speakers showed sensitivity to orthographic but not phonological identity: there was a boost in structural priming when the prime and target verbs were homographic homophones but not when they were heterographic homophones.

Our results first of all suggest that deaf speakers are similarly sensitive, as hearing speakers are, to prior syntactic experience when formulating words into a syntactic structure in writing. This is

shown in the equivalence in structural priming involving different verbs in the prime and the target. Given that structural priming taps into the use of abstract syntactic knowledge in language production and comprehension (e.g., Bock & Griffin, 2000; Pickering & Branigan, 1998), our finding suggests that deaf speakers do not have syntactic deficits at least in the use of combinatorial knowledge of verbs (Miller et al., 2012). Indeed, there is much evidence that non-native users of a language (e.g., second language learners) also show structural priming in combinatorial arrangement of arguments around a lexical head (e.g., Shin & Christianson, 2012; for reviews, see Hartsuiker & Bernolet, 2017, and Jackson, 2018). Thus, it is possible, that, like second language learners, deaf speakers can acquire lexically-embedded syntactic knowledge such as argument structures but may fail to attain native-like knowledge for syntactic properties that are not lexically embedded, such as morphological markings, articles, and auxiliaries (e.g., Marschark et al., 1994; Thierfelder & Stapleton, 2016).

Indeed, we have also shown that deaf speakers can keep track of lexical prior use as well as hearing speakers do: both groups were boosted in structural priming (and to similar extents) when the target sentence used the same verb as the prime sentence. This finding suggests that lexical entries are linked to possible syntactic structures in a similar way in the lexicon between deaf and hearing speakers.

There are also differences in structural priming in writing between deaf and hearing speakers. In particular, we showed that hearing speakers were boosted in structural priming when the prime and the target had verbs that were identical in phonology, but they were not further boosted when the verbs had additional identity in orthography. In contrast, deaf speakers were boosted in structural priming when the homophone verbs were identical in orthography but not when they differed. These results are, on the one hand, consistent with previous findings that deaf speakers can make good use of orthographic information in reading (Bélanger et al., 2013; Gutierrez-Sigut et al., 2019) and extend this conclusion to production. On the other hand, the results suggest that, despite findings that deaf speakers access phonology in word reading (e.g., Mayberry et al., 2011), they do not make use of phonological information in words in language production.

How the effects of phonological and orthographic identity arise in structural priming is currently being debated. Earlier studies have assumed that these effects arise as a result of online

feedback from wordform encoding to syntactic encoding; that is, the retrieval of a wordform based on a lemma (e.g., animal *bat*) would activate a homophone lemma (e.g., cricket *bat*), hence further increasing the likelihood of the structure in which the homophone lemma has been used with in the prime (e.g., Bernolet, Hartsuiker, & Pickering, 2012; Santesteban et al., 2010). According to this account, for hearing speakers, an activated lemma leads to the activation of its orthographic form, which in turn leads to the activation of its homophone lemma and also the syntactic structure in which the homophone lemma was previously used, leading to a boost in structural priming based on orthographic identity. However, on the same account, deaf speakers have only limited access to phonological information, hence the lack of an effect of phonological form on structural priming.

It should be noted that a more recent account by M. Wang et al. (2020) instead argued that the homophone boost in hearing speakers reflects lemma associations developed due to phonological identity between homophone words. Under this account, then, deaf speakers develop lemma association based on orthographic identity between words but not on phonological identity due to the lack of exposure to spoken language; these associations then lead to a boost in structural priming for homographic homophones but not for heterographic homophones. Thus, this account differs from the online feedback account in the mechanism of the homophone boost, though it is beyond the scope of the current research to adjudicate between the two accounts.

In conclusion, we showed that deaf speakers are equally sensitive to syntactic and lexical influences in syntactic encoding in writing as hearing speakers are. Unlike hearing speakers who use phonological information in syntactic encoding, deaf speakers instead make use of orthographic information.

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