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EMPIRICAL STUDY

Lexically Independent Structural Priming in Second Language Online Sentence Comprehension

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Abstract: This study examined structural priming during online second language (L2) comprehension. In two self-paced reading experiments, 64 intermediate to advanced Chinese learners of English as a foreign language read coordinated noun phrases where the conjuncts had either the same structure or different structures. Experiment 1 showed that the second conjunct was read faster when it had the same structure as the first. This effect occurred for the structurally marked adjective phrases (e.g., *a simple to grasp problem*) but only showed a numerical trend for the less marked relative clauses (e.g., *a problem that was simple to grasp*). Experiment 2 compared unmarked adjective phrases

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and relative clauses (e.g., *a simple problem* vs. *a problem that was simple*) and found significant priming for both. Together, the two experiments showed that L2 comprehension priming could occur without repetition of the lexical head. Moreover, this priming was susceptible to inverse frequency effects, with the less frequent structure exhibiting greater priming.

Keywords structural priming; second language; comprehension; coordination; inverse frequency effect; self-paced reading

Introduction

Structural priming (or syntactic priming) refers to the phenomenon whereby language users tend to repeat or more easily process a current sentence because of its structural similarity to a previously encountered one. This phenomenon has been heavily scrutinized in psycholinguistics over the past decades (Bock, 1986; Branigan & Pickering, 2017; Mahowald et al., 2016), and has received increasing attention in bilingual and second language processing (for reviews, see Jackson, 2018; Van Gompel & Arai, 2018). Structural priming is pervasive in everyday language use (Pickering & Ferreira, 2008), and it appears to serve important functions. Among other things, it may facilitate language processing and is an important mechanism behind first language (L1) and second language (L2) development (Branigan & Pickering, 2017; Ferreira & Bock, 2006; Pickering & Ferreira, 2008).

There is ample evidence that structural priming occurs in L2 production. Such an effect has been observed with various constructions and experimental tasks (Jackson, 2018). Structural priming in L2 production can occur in the absence of lexical repetition between prime and target, though verb repetition may enhance the magnitude of priming (Jackson & Ruf, 2017; Kim & McDonough, 2008). Repetition of the verb is relevant for priming of verb phrase constructions and clausal constructions because some theories maintain that different syntactic forms of the verb are associated with verb phrase and clausal alternations (e.g., MacDonald et al., 1994). To foreshadow, in our study it is a noun that is the analogous lexical head. Crucially, priming in L2 production can be long-lasting, extending to a posttest phase immediately following the priming phase or after an interval of one day to several weeks (e.g., McDonough, 2011; Shin & Christianson, 2012; Wang et al., 2021). The fact that structural priming occurs for developmentally advanced and novel constructions (McDonough & Fulga, 2015; McDonough & Kim, 2009), and that the effect can be long-lived, suggests that structural priming may lead to L2 syntactic development.

Compared with priming in L2 production, priming in L2 comprehension has received little attention. This is unfortunate, because much of L2 learning occurs in comprehension. Previous studies show that priming in L2 comprehension is more restricted compared with priming in L2 production. For instance, priming in L2 production has been frequently observed in the absence of lexical repetition between primes and targets (Jackson, 2018). In contrast, priming during online (real-time) L2 comprehension occurs only when primes and targets share the same verb (Fujita & Cunnings, 2021; Weber & Indefrey, 2009; Wei et al., 2018, 2019), suggesting that priming in L2 comprehension is highly lexicalized.

The present study builds on previous research, in an ongoing attempt to explore when and how structural priming occurs during online L2 comprehension. Specifically, we examined whether L2 comprehension priming could occur without repetition of the head word, and whether the priming effects were modulated by the baseline frequency of target constructions. We examined these questions in two self-paced reading experiments. Both experiments used coordinated noun phrases (NPs) where the conjuncts had the same or different internal structure. There was no open-class lexical repetition between the first conjunct (prime) and the second (target). In Experiment 1, the head noun in each conjunct was modified either by a multiword adjective phrase (AdjP as in *a simple to grasp problem*) or by a relative clause (RC as in *a problem that was simple to grasp*), and different head nouns were used in the conjuncts. Multiword prenominal AdjPs are structurally "marked" (i.e., they have reduced acceptability in English, presumably because of their low frequency), and are less common compared with RCs (Sturt et al., 2010). This allowed us to test whether L2 comprehension priming is modulated by the baseline frequency of structural alternatives. In Experiment 2, the head noun in each conjunct was modified by a simple AdjP (e.g., *a simple problem*) or a RC (e.g., *a problem that was simple*), with different head nouns for each conjunct. This allowed us to examine whether lexically-independent priming could occur for common, unmarked constructions.

Previous studies have established that English L1 speakers read the second conjunct faster when it shares the same structure with the first conjunct (Frazier et al., 1984, 2000; Sturt et al., 2010). The processing facilitation for coordinated phrases where the conjuncts share the same structure has been referred to as the "parallelism effect" (Frazier et al., 1984). Though early work found parallelism effects in coordination but not in subordination (e.g., Frazier et al., 2000), more recent studies showed that such effects were not confined to certain syntactic environments but rather reflected a more general

priming mechanism (Sturt et al., 2010). Crucially, parallelism effects occurred when the two conjuncts used different head nouns (Frazier et al., 2000; Sturt et al., 2010), suggesting that repetition of the lexical head is not needed for L1 comprehension priming of coordination. If similar mechanisms underlie L1 and L2 comprehension priming, one might observe lexically independent priming of coordination in L2 speakers also. This is what we aimed to test in the present study.

Background Literature

Theoretical Accounts of Structural Priming

Over the years, different theories have been developed to account for the structural priming effect, including the residual activation account (Pickering & Branigan, 1998) and the implicit learning account (Bock & Griffin, 2000; Chang et al., 2006, 2012). According to the residual activation account (Pickering & Branigan, 1998), structural priming arises as a form of residual activation of syntactic representations shared between lemmas. When the target construction contains the same head word as the prime construction, syntactic priming results from residual activation of the preactivated lemma node, the combinatorial node, and the strengthened link between the lemma and the combinatorial node, and hence the effect should be larger (relative to when prime and target involve different lexical heads). The residual activation account predicts that the priming effect should be short-lived, given that activation is normally assumed to be transient. However, as mentioned, there have been demonstrations that structural priming can persist with up to 10 fillers intervening between the prime and target (Bock et al., 2007; Bock & Griffin, 2000). This long-lived effect is incompatible with the residual activation account (Pickering & Branigan, 1998) but squares well with the implicit learning account (e.g., Bock & Griffin, 2000; Chang et al., 2006).

According to Chang et al. (2006), structural priming reflects the operation of an implicit learning mechanism, akin to the connection weight changes that characterize learning in connectionist models (e.g., Rumelhart et al., 1986). As a form of learning, structural priming has two essential features (Ferreira & Bock, 2006). First, it can cause relatively long-lasting changes to performance. Second, it is sensitive to speakers' current state of knowledge. Evidence supporting the longevity of priming comes from the experimental studies concudcted by Bock and her colleagues (e.g., Bock et al., 2007; Bock & Griffin, 2000) and from Chang's modeling (Chang et al., 2006), where structural priming has a persistent effect that survives across time. Evidence showing that structural priming is sensitive to speakers' current state of knowledge comes

from observations that less preferred structures often exhibit larger priming effects (e.g., Chen et al., 2022; Hwang & Shin, 2019; Jaeger & Snider, 2013). Such an inverse frequency (or inverse preference) effect follows directly from the error-based learning mechanism: Primes that are less preferred often result in more prediction errors, which in turn cause greater weight changes to the language processing system. This leads to a relatively larger bias toward the disfavored structure when the target sentence is processed.

There is one finding, however, that cannot be easily explained by the implicit learning account: the lexical boost (whereby priming is enhanced when lexical items are repeated between primes and targets). According to Chang et al. (2006), structural priming is caused by weight changes to the system. As lexical repetition does not trigger greater weight changes, Chang et al.'s model predicts that lexical overlap should have a null effect on structural priming. Additionally, Chang et al.'s (2006) account is built upon connectionist models, and "it is in the nature of the model to keep its learning about structures somewhat separate from particular lexical items" (p. 256), which is required to achieve a system that generalizes effectively. Nevertheless, there has been repeated observation of lexical boost, with priming effects being greater when primes and targets share the same content words, such as head verbs or nouns (e.g., Cleland & Pickering, 2003; Pickering & Branigan, 1998), or function words, such as prepositions (Ziegler et al., 2019), compared with when no lexical items are shared. These results pose specific challenges for the implicit learning account. To account for the lexical boost, Bock and Griffin (2000) suggest that the repeated words serve as an explicit memory cue, and the activation of specific words in immediate memory facilitates the reuse of a recently experienced structure, resulting in the repetition of syntactic structures.

To sum up, the residual activation account and the implicit learning account have made different predictions regarding the longevity of the priming effect and the effect of baseline frequency upon priming. Note that most evidence has come from priming during production, with evidence from comprehension being scant. Additionally, both accounts assume that immediate priming could occur without lexical repetition between primes and targets. However, priming during L2 online comprehension seems to be largely confined to cases where primes and targets share the same head verb (e.g., Fujita & Cunnings, 2021; Weber & Indefrey, 2009; Wei et al., 2018), which poses a challenge to most theoretical accounts and hence deserves close scrutiny.

Structural Priming in L2 Comprehension

As mentioned, structural priming in L2 comprehension has so far received little attention. To our knowledge, there are six previous studies investigating priming during L2 comprehension. Using reading time and functional magnetic resonance imaging measures, Weber and Indefrey (2009) investigated L1 German to L2 English and within-L2 English priming of passive constructions (e.g., *The moon was painted by the girls*). Prime and target contained the same verb or translation equivalent verbs (in the case of German–English priming). Structural priming occurred when an English passive sentence was preceded by a German or an English passive sentence, suggesting that syntactic information is shared between bilinguals' languages.

Using a sentence–picture matching task, Nitschke et al. (2010) explored whether L2 processing was subject to structural priming. L1 and L2 speakers of German and Italian were primed to interpret ambiguous RCs (in German and Italian respectively) that could be interpreted as either a subject RC, where the relativized argument is subject in the RC, or an object RC, where it is object (e.g., *Here is the ballerina*$_{[SUBJ/OBJ]}$ *that the girl*$_{[OBJ/SUBJ]}$ *scares*, which can mean either the ballerina scared the girl or the girl scared the ballerina in German and Italian). Each prime sentence was followed by two pictures, with one picture matching the object RC and the other picture being unrelated. Immediately after picture selection, participants read a target sentence that involved the same verb and the same structural ambiguity. Both L1 and L2 speakers were more likely to interpret the target sentence in the way in which the prime sentence was interpreted. These results were replicated in Nitschke et al. (2014) even when primes and targets used different verbs. Thus, L2 priming can impact the ultimate interpretation without verb repetition, though it is unclear whether verb-independent priming would be observed if measuring online reading times.

Wei et al. (2018) examined the effects of lexical repetition and L2 proficiency upon L2 comprehension priming. In a self-paced reading experiment, two groups of Chinese learners of English as a foreign language (EFL) with different L2 proficiency read English sentences involving ambiguity between a main clause (MC) and a RC (e.g., *The architect selected by the committee was educated at Yale*, with *selected* being temporarily ambiguous between a main verb and a past participle). Prime and target were adjacent and used either the same verb or different verbs. Priming occurred when the verb was repeated but not otherwise. Moreover, the priming effect was unaffected by L2 proficiency, with both intermediate and more advanced L2 learners manifesting verb-dependent priming only. These findings were taken as evidence that

L2 syntactic information is encoded in lexical heads such as verbs, such that repetition of the head verb reactivates the prime structure in the target sentence. Meanwhile, the authors suggested that the lexically dependent priming might be partly due to the structure employed in their study, given that English L1 speakers also exhibit verb-dependent priming for sentences involving MC–RC ambiguity (e.g., Tooley et al., 2009; Traxler et al., 2014). Using a similar method and materials, Wei et al. (2019) found L2 priming of RCs, but again only when the lexical head verb was repeated between the prime and target sentences. Crucially, Wei et al. (2019) showed that the importance of lexical repetition was linked to structural overlap, because a MC prime with the same verb (e.g., *The committee selected the architect who was educated at Yale*, with "selected" acting as the main verb rather than as a passive participle) did not exhibit any priming.

In a more recent study, Fujita and Cunnings (2021) also found that verb repetition was needed for L2 comprehension priming. In an eye-tracking reading experiment, both English L1 speakers and Japanese learners of English read sentences that involved direct object–subject ambiguities (DO–SUBJ as in *After the lady washed the dog started eating some food quickly*, where "the dog" is temporarily ambiguous in status between DO of the preceding verb and SUBJ of the main clause). The results showed that unambiguous prime sentences (disambiguated by a comma between "washed" and "the dog") facilitated processing of the correct interpretation of ambiguous target sentences. However, for both L1 and L2 speakers, priming occurred only when prime and target shared the same verb.

To summarize, structural priming does occur in L2 comprehension and can be observed with various tasks and structures. It is important to note, however, that L2 comprehension priming seems to be more restricted compared with priming in L2 production. As noted earlier, priming in L2 production has been observed to occur without lexical repetition (Jackson, 2018), whereas the priming observed in L2 comprehension typically occurred when prime and target used the same verb as the relevant lexical head. Of the six studies reviewed, five reported verb-dependent priming only. Though Nitschke et al. (2014) observed priming without verb repetition, the sentence–picture matching task reflects the outcome of interpretation rather than the online processing itself. It remains to be explored whether priming during online L2 comprehension can occur when the lexical head of the primed construction is not repeated.

The fact that priming in online L2 comprehension occurred only when primes and targets used the same lexical head is not predicted by current

models of structural priming (e.g., Chang et al., 2006; Pickering & Branigan, 1998). It is possible that priming in comprehension is relatively weaker compared with priming in production,[1] and hence lexical repetition is often needed to boost the effect (Pickering & Ferreira, 2008). Additionally, the lexically dependent priming in L2 comprehension may be partly due to the target structures employed in those studies. For instance, priming of the MC–RC and DO–SUBJ ambiguities in L1 comprehension also occurred only when primes and targets used the same verb (e.g., Fujita & Cunnings, 2021; Tooley et al., 2009; Traxler et al., 2014). For these structures, the verb differs in tense and voice (MC–RC: past tense vs. passive participle) or subcategorization (DO–SUBJ: transitive vs. intransitive). Thus, recognizing the appropriate syntactic form of the verb is crucial to avoiding a garden-path effect. In contrast, the head noun is the final word of a multiword NP such as "a challenging to pass quiz," and it is unclear if head repetition would facilitate processing in such a case.

Additionally, it remains to be investigated whether priming during online L2 comprehension is modulated by the baseline frequency of the target constructions, with less frequent structures being more susceptible to priming. Such an inverse frequency effect has been taken as evidence for the error-based learning account of structural priming, according to which "systems learn more about representations that are not yet well known" (Pickering & Ferreira, 2008, p. 448). The inverse frequency effect has been repeatedly observed in L1 priming (e.g., Bernolet & Hartsuiker, 2010; Chen et al., 2022; Hartsuiker & Kolk, 1998; Jaeger & Snider, 2013), though demonstrations of such an effect in L2 priming (especially L2 comprehension priming) have been few and far between.

The Present Study

The present study examined when and how structural priming occurred during online L2 comprehension. Specifically, it investigated whether L2 comprehension priming could occur in the absence of open-class lexical repetition between primes and targets, and whether it was modulated by the baseline frequency of the target constructions.

Although most theoretical accounts predict that structural priming can occur without lexical repetition, L2 comprehension priming seems to be crucially dependent on repetition of the head word between prime and target (e.g., Fujita & Cunnings, 2021; Weber & Indefrey, 2009; Wei et al., 2018). Additionally, the inverse frequency effect has been taken as a benchmark of the error-based, implicit learning account of structural priming (Ferreira & Bock,

2006; Pickering & Ferreira, 2008). Such an inverse frequency effect has been observed in L2 production priming (e.g., Kaan & Chun, 2018), though there is also evidence that L2 speakers are primed more by structures that are more frequent in their L2, which is a frequency effect (Hurtado & Montrul, 2021; Jackson & Ruf, 2017). If structural priming during online L2 comprehension exhibits the inverse frequency effect, it provides good evidence of implicit learning among L2 learners. The present study addresses the following two major research questions:

1. Does structural priming during online L2 comprehension occur in the absence of lexical repetition between the prime and target stimuli?
2. Does structural priming during online L2 comprehension exhibit the inverse frequency effect, such that the less frequent structure is more susceptible to priming?

To examine these questions, we conducted two self-paced reading experiments among Chinese EFL learners. Both experiments used coordinated NPs where the conjuncts had the same or different structures (e.g., *a challenging quiz and a simple problem* vs. *a challenging quiz and a problem that was simple*). The two conjuncts appear within the same sentence, which differs from most previous studies, wherein prime and target involved two independent sentences. This within-sentence context might provide the optimal condition for immediate priming, given recent demonstrations that even lexically independent priming decays with the increase of interval between prime and target (Bernolet et al., 2016). As argued by Bernolet et al. (2016), syntactic priming in immediate conditions originates from multiple sources, one of which is the explicit memory of the prime structure. If priming in L2 comprehension also involves a memory component that tends to decay, then coordinated NPs (with the interval between prime and target minimalized) should give us a better opportunity to observe immediate priming.

Experiment 1

Method

Participants

Thirty-two undergraduates (28 females) majoring in English at Xi'an Jiaotong University were paid to participate. All participants were native Chinese speakers who had started learning English as their L2 at around the age of 7 ($SD = 2.0$, *range* = 4–11). Their mean age was 20 years ($SD = 0.6$, *range* = 20–22), and they had received formal English instruction in China for a mean length of

Table 1 Participants' demographic information and second language (L2) proficiency

Variable	*M*	*SD*	Range
Experiment 1 ($N = 32$; 28 females, 4 males)			
Age	20	0.61	20–22
Age of acquisition	7	1.96	4–11
Formal L2 learning (years)	14	1.92	9–16
OPT score (max. = 50)	41	3.93	33–49
Self-rated overall L2 proficiency (out of 10)	6.98	0.88	4.75–9.25
Experiment 2 ($N = 32$; 24 females, 8 males)			
Age	20	0.89	18–22
Age of acquisition	7	2.05	3–10
Formal L2 learning (years)	13	2.24	9–19
OPT score (max. = 50)	40	4.91	24–48
Self-rated overall L2 proficiency (out of 10)	6.61	1.21	2.25–8.13

Note. OPT = Oxford Placement Test.

14 years ($SD = 1.9$, *range* = 9–16). They had normal or corrected-to-normal vision and reported no history of learning or reading difficulty.

Immediately after the experiment, all participants rated their English language skills (listening, speaking, reading, and writing) on a scale of 1–10 and completed Part I of the grammar section of the Oxford Placement Test (OPT; Allan, 2004). The OPT used in the current study consists of three cloze passages involving 50 multiple-choice questions testing knowledge of English grammar (e.g., tense, aspect, number agreement, articles, and prepositions), with a total score of 50. Additionally, the participants completed an English learning questionnaire. Sixteen participants had stayed in English-speaking countries (for periods varying from 3 days to 9 months), and the remaining participants reported having no immersion history. The mean OPT score in Experiment 1 was 41 ($SD = 3.93$); hence, their L2 proficiency ranged from intermediate to advanced levels. Table 1 presents participants' demographic information together with their OPT scores and self-rated L2 proficiency (averaged across the four skills).

Materials

Thirty-six experimental items were constructed, each of which began with a coordinated NP. Twenty-four of them were adapted from the study by Sturt et al. (2010, Experiment 1). The experimental design manipulated the syntactic structure of the coordinated NPs such that the two conjuncts had either the same structure or different structures. Each head word of the conjunct was

modified either by an AdjP (e.g., *a simple to grasp problem*) or by a RC (e.g., *a problem that was simple to grasp*). By crossing the syntactic forms of NP1 and NP2, each item yielded four types of sentences, as shown below (see Appendix S1 in the Supporting Information online and Wei et al., 2023a-b for a complete list):

1. NP1 = AdjP; NP2 = AdjP.
   A challenging to pass quiz and a simple to grasp problem were solved by Bill.
2. NP1 = RC; NP2 = AdjP.
   A quiz that was challenging to pass and a simple to grasp problem were solved by Bill.
3. NP1 = AdjP; NP2 = RC.
   A challenging to pass quiz and a problem that was simple to grasp were solved by Bill.
4. NP1 = RC; NP2 = RC.
   A quiz that was challenging to pass and a problem that was simple to grasp were solved by Bill.

A NP modified by an AdjP and one modified by a RC are truth-conditionally equivalent and involve the same list of open-class lexical items, thereby ruling out a lexico-semantic account of the priming effect. If structural priming occurs in L2 sentence processing, reaction times (RTs) on NP2 should be reduced when NP1 and NP2 have the same internal structure (1, 4) than otherwise (2, 3).

The materials used in this experiment involved multiword prenominal AdjPs (e.g., *a simple to grasp problem*) as the less frequent structure. Multiword prenominal AdjPs are structurally marked and less common compared with their postmodifier RC counterparts (e.g., *a problem that was simple to grasp*; Sturt et al., 2010). This structural markedness might give us a better opportunity to detect priming, given the prior finding of inverse frequency effects (for recent demonstrations, see Chen et al., 2022; Hwang & Shin, 2019). To examine how multiword AdjPs and RCs are perceived by Chinese EFL learners, we conducted an acceptability judgment test that included the 144 items (36 items in each of the four conditions) prior to the main experiment. Twenty participants from the same population as for the main experiments took part in the test (they did not participate in the main experiments). The results showed that items modified by RCs were rated as more acceptable than items modified by multiword AdjPs: The former were rated, on average, at 3.80 on a 5-point scale (1 = *totally unacceptable*, 5 = *totally acceptable*), whereas the latter were

Table 2 Segmentation of experimental sentences (slashes indicate region boundaries)

		Critical region	Final (spillover) region
		Experiment 1	
A challenging to pass quiz/	*and/*	*a simple to grasp problem/*	*were solved by Bill.*
		Experiment 2	
A challenging quiz/	*and/*	*a simple problem/*	*were solved by Bill.*

rated, on average, at 2.12 (see Appendix S2 in the Supporting Information online and Wei et al., 2023a-b for details).

The AdjPs and RCs employed in the current study can be regarded as structural alternations in English. In contrast, Chinese has only a single sequence of words that approximately corresponds to an English AdjP in terms of its surface constituents (e.g., *yi1ge4 rong2yi4 li3jie3 de wen4ti2*, where the numerals represent tones; literally, "one-CLASSIFIER easy grasp DE problem"). This allows us to examine whether L2 comprehension priming is affected by crosslinguistic differences in syntactic structures.

Experiment 1 also contained 54 fillers with varying syntactic structures, including simple sentences, compound sentences, and existential sentences. Some fillers contained conjunctions (e.g., *and*, *but*), but none of them involved parallel constructions. The experimental items and fillers were pseudorandomized, with no two experimental items being adjacent. A simple yes/no question was constructed for all experimental and filler sentences (e.g., *Did Bill solve the problem?*). There were 10 practice sentences to help participants get familiar with the procedure.

Procedure

Each sentence was presented in four segments (see Table 2). Participants first saw a series of fixation points (plus signs) appearing at the center of the screen, indicating where the sentence segments would be displayed. When the participants pressed the space bar, the fixation points would be replaced by the first segment of a sentence. This segment remained until the participants pressed the space bar, at which it was replaced by the second segment. Each segment appeared at the center of the screen. At the end of each sentence, there was a yes/no question. Participants pressed 1 (yes) or 3 (no) on the keyboard to answer the question and received no feedback. The display mode was similar

to that of Frazier et al. (1984) and Crible and Pickering (2020), apart from the manner of segmentation, which is illustrated in Table 2.

We adopted this segmentation scheme to keep each linguistic unit (e.g., NP1, NP2) as a display region. Additionally, the current display regions correspond to the statistical analysis regions. The word *and* was presented independently because it might get overlooked if presented together with the first segment. Furthermore, *and* could serve as a signal indicating the coordination relationship between the two segments. The critical region of analysis was the third segment (i.e., NP2). The self-paced reading experiment took about 25 min. Participants had a 2-min break halfway through the experiment. After finishing the experiment, all participants completed an English learning questionnaire and the grammar part of the OPT. The questionnaire and OPT took about 30 min.

Data Analysis

We analyzed three regions for each experimental sentence. The first region corresponds to the first conjunct. The second region consists of the second conjunct and is equivalent to the critical region in prior research (e.g., Frazier et al., 2000; Sturt et al., 2010). The third and final region consists of the remainder of the sentence, which was included to capture potential spillover effects.[2] Prior to data analysis, we excluded individual RTs that were lower than 50 ms or higher than 10,000 ms on a trial-by-trial basis, which affected 0.95% of the data. We then defined the cutoff value at 2.5 standard deviations under or above the mean by the participant, and replaced outliers with the corresponding cutoff values (117 cases, distributed among the four regions,[3] affecting 2.54% of the data). Raw RTs were log-transformed for the statistical analysis to more closely satisfy the assumption of normality. However, in the figures below we present the results using the raw RTs.

Data were analyzed with the linear mixed-effects regression model in R using the lme4 package (Bates et al., 2015) together with the lmerTest package (Kuznetsova et al., 2017) for estimating p values. To evaluate statistical significance, we set the alpha level to .05. We used the Wald approximation to compute 95% confidence intervals. The critical predictors were the syntactic forms of NP1 (RC vs. AdjP) and NP2 (also RC vs. AdjP), both of which were categorical. To reduce collinearity, all numerical predictors were mean-centered and all categorical predictors were centered using contrast coding (e.g., AdjP $= 0.5$, RC $= -0.5$). The random effects structure was determined using the back-off procedure adapted from Bates et al. (2015). We included the by-participants and by-items random intercepts as well as random slopes

for all main effects and interactions in a maximal model (Barr et al., 2013). If the maximal model could not converge or showed singularity, we first dropped the random correlation terms in one go. If the model without random correlation could not converge either, we began to drop one random effect at a time, starting from the most complex terms in the random model. When there were multiple terms with the same complexity, we compared the variances of the random effects in the last model and dropped the term that accounted for the least amount of variance. We repeated the above operation until the model converged and showed no singularity. Materials, data, and analysis scripts for the two experiments reported in this article are publicly available via the Open Science Framework (https://osf.io/tc2yd).

Prediction

As stated, AdjPs and RCs in English can be regarded as structural alternations, whereas Chinese has only a single sequence of words that roughly corresponds to an English AdjP in terms of its surface constituent order. If L1 syntactic structures are activated and interfere with L2 processing (e.g., Grüter & Hopp, 2021; Lago et al., 2021), then AdjPs might elicit greater priming than RCs. However, given the inverse frequency effect in L2 production priming (e.g., Kaan & Chun, 2018), it is also possible that L2 learners are more likely to show priming for structures that have different constituent orders across the L1 and L2, in which case RCs might show greater priming than AdjPs.

Results

All participants scored above 80% for the comprehension questions (M = 95.4%, SD = 2.7), suggesting that they were reading carefully during the experiment. Table 3 presents mean RTs by condition for the critical region (NP2). Mean RTs were reduced when NP2 had the same structure as NP1, and this tendency was more remarkable when NP2 was modified by an AdjP relative to when it was modified by a RC. The general pattern is illustrated in Figure 1.

This pattern was confirmed by the model fit to the critical region (see Table 4 for details). We report the significance of the effects based on the fixed effect estimate of the models using contrastive coding (Schad et al., 2020). Crucially, the model showed an interaction between NP1 and NP2 syntactic forms, $b = -0.140$, $SE = 0.047$, 95% CI [−0.232, −0.049], $t = -3.012$, $p = .005$, indicating an across-the-board effect of structural priming. We performed two post hoc tests to examine the interaction between NP1 and

Table 3 Mean reaction times (RTs, in ms) by condition for the critical region (NP2) in Experiment 1

NP1	NP2	*n*	RT	*SD*	*SE*	CI	*LL*	*UL*
AdjP	AdjP	32	2,402.026	723.605	127.917	260.888	2,141.139	2,662.914
RC	AdjP	32	2,730.990	943.616	166.809	340.210	2,390.780	3,071.200
RC	RC	32	2,540.163	717.211	126.786	258.582	2,281.581	2,798.745
AdjP	RC	32	2,611.370	710.786	125.650	256.266	2,355.107	2,867.639

Note. NP = noun phrase; CI = confidence interval; *LL* = lower limit; *UL* = upper limit; AdjP = adjective phrase; RC = relative clause.

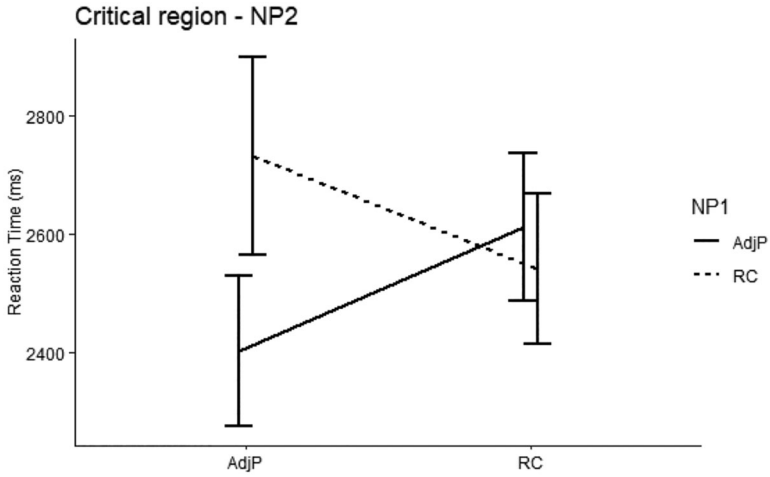


Figure 1 Mean reaction times by condition for the critical region in Experiment 1. Error bars show standard error for the by-participant analysis. NP = noun phrase; AdjP = adjective phrase; RC = relative clause.

NP2, and the results showed that the priming effect was significant when NP2 involved an AdjP, $b = -0.118$, $SE = 0.034$, 95% CI [−0.185, −0.051], $t = -3.454$, $p = .003$, but not when NP2 involved a RC, $b = 0.022$, $SE = 0.029$, 95% CI [−0.035, 0.079], $t = 0.749$, $p = .459$. In other words, the second conjunct was read faster when it was preceded by another conjunct with the same structure, but such facilitation occurred only for the marked multiword AdjP. The results also showed a significant effect of region length, $b = 0.016$, $SE = 0.007$, 95% CI [0.003, 0.030], $t = 2.410$, $p = .021$, indicating that RT is a function of the number of letters in the critical region. Finally, the results showed a significant effect of NP1, $b = -0.048$, $SE = 0.022$, 95% CI

Table 4 Fixed effects for the critical region in Experiment 1

Variable	*b*	95% CI	*SE*	*df*	*t*	*p*
(Intercept)	7.745	[7.631, 7.859]	0.058	41.068	133.495	< .001
NP1	−0.048	[−0.092, −0.005]	0.022	18.348	−2.162	.044
NP2	0.068	[−0.041, 0.177]	0.055	62.787	1.227	.224
Length (centered)	0.016	[0.003, 0.03]	0.007	36.205	2.410	.021
NP1 × NP2	−0.140	[−0.232, −0.049]	0.047	33.634	−3.012	.005

Note. NP = noun phrase. The formula of the final model for the critical region, with centralized region length as a fixed effect, is as follows, where "||" indicates a random effect model without random correlations: log(RT) ∼ NP1 × NP2 + cLength + (1+NP1 + NP2 ||Subject) +(1+ NP1 + NP2 + NP1 × NP2 ||Item).

[−0.092, −0.005], $t = -2.161$, $p = .044$, indicating that participants read NP2 faster when NP1 was modified by an AdjP than when it was modified by a RC. The effect of NP2 was not significant.

Mean RTs on the first conjunct were comparable for AdjP (2,660 ms, $SE = 175$) and RC (2,667 ms, $SE = 135$). This was confirmed by the model (with centralized region length as a fixed effect), which returned a null effect of condition, $b = 0.046$, $SE = 0.055$, 95% CI [−0.062, 0.153], $t = 0.832$, $p = .408$. Hence, any differences in the critical region should not be attributed to spillover effects from the first conjunct. Mean RTs for the final region are shown in Figure 2. The model results showed a significant effect of region length, $b = 0.031$, $SE = 0.008$, 95% CI [0.016, 0.046], $t = 4.058$, $p < .001$. No other effects reached significance (for details, see Appendix S3 in the Supporting Information online).

Finally, as an exploratory analysis, we included in the model item order (numerical predictor, divided by 36) as a continuous covariate to examine whether the priming effect accumulated from one trial to the next. The results showed a significant effect of item order, $\chi^2 = 6.808$, $df = 1$, $p = .009$ (for details, see Appendix S3), suggesting that RTs became reduced as participants encountered more trials. However, the interaction between priming and item order was not significant. Hence, there is no evidence of cumulative effects. We will return to this issue in the General Discussion.

Discussion

Experiment 1 showed that participants read the second conjunct faster when it was preceded by a conjunct with the same structure. Assuming that the mechanism underlying parallelism effects is structural priming (Dubey et al., 2008;

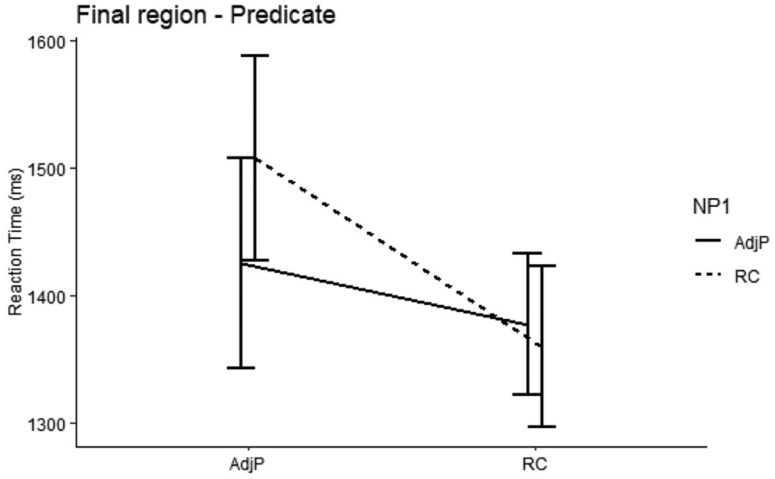


Figure 2 Mean reaction times by condition for the final region in Experiment 1. Error bars show standard error for the by-participant analysis. NP = noun phrase; AdjP = adjective phrase; RC = relative clause.

Sturt et al., 2010), this provides the first demonstration of lexically independent priming during online L2 comprehension. However, this priming effect was observed only for multiword AdjPs and not for RCs.[4] As stated earlier, multiword prenominal AdjPs are structurally marked and less common compared with RCs (Sturt et al., 2010), and the asymmetric priming for the two structural alternatives might be attributed to the structural markedness of the AdjPs. This can be interpreted as inverse frequency effects, with the less common AdjPs being more sensitive to priming. To examine whether lexically independent priming could be observed for common, unmarked constructions, we conducted Experiment 2, which used simple AdjPs and RCs.

Experiment 2

Method

Experiment 2 was the same as Experiment 1, except that the experimental items were conjuncts involving simple, unmarked AdjPs and RCs (e.g., *a simple problem* vs. *a problem that was simple*). This experiment allowed us to examine whether lexically independent priming in L2 comprehension would generalize to unmarked constructions.

Participants

Thirty-two undergraduates (24 females) from the same population as Experiment 1 were paid to participate. Eight of them reported having stayed in an English-speaking country for a brief period of time (ranging from 7 to 45 days). Table 1 presents a summary of their demographic information and L2 proficiency.

Materials

Experimental sentences were the same as those in Experiment 1 except for two changes. First, we used a less marked structural alternation, comparing simple AdjPs and RCs. Second, to enhance power, we increased the number of items such that there were 12 items under each condition (there were 9 items per condition in Experiment 1). Forty-eight experimental items were constructed, some of which were adapted from the study by Sturt et al. (2010, Experiments 2 and 3).

Similarly to Experiment 1, we conducted an acceptability test on the 192 items (48 items in each of the four conditions). Twenty additional participants from the same population as for the main experiments took part in the test (they did not attend the main experiments or the acceptability test of Experiment 1). The results showed that simple AdjPs were rated, on average, at 4.07 (SD = 0.57) on a 5-point scale (1 = *totally unacceptable*, 5 = *totally acceptable*), and RCs were rated at 3.60 (SD = 0.75). Hence, both structural alternatives were perceived as highly acceptable by L2 speakers (see Appendix S2 for details).

Each item yielded four types of sentences, as shown below (see Appendix S1 for a complete list):

1. NP1 = AdjP; NP2 = AdjP
   A challenging quiz and a simple problem were solved by Bill.
2. NP1 = RC; NP2 = AdjP
   A quiz that was challenging and a simple problem were solved by Bill.
3. NP1 = AdjP; NP2 = RC
   A challenging quiz and a problem that was simple were solved by Bill.
4. NP1 = RC; NP2 = RC
   A quiz that was challenging and a problem that was simple were solved by Bill.

Experiment 2 also contained 72 fillers of various syntactic structures, none of which involved parallel constructions. The experimental items and fillers were pseudorandomized such that no two experimental items appeared adjacent to

each other. A simple yes/no question was constructed for each experimental and filler sentence.

Procedure

The procedure was identical to that of Experiment 1. The self-paced reading experiment took about 35 min. After the main experiment, participants completed an English learning questionnaire and the grammar part of the OPT, which took about 30 min.

Data Analysis

As in Experiment 1, we analyzed the two conjuncts and the final region for each experimental sentence. The region boundaries for a sample sentence are shown in Table 2. Similar data-trimming criteria as for Experiment 1 were adopted, which affected 3.93% of the data.

Prediction

If lexically independent priming is a general mechanism in L2 comprehension, then both simple RCs and AdjPs should produce significant priming. Further, as simple RCs and AdjPs are both highly acceptable to Chinese EFL learners (see Appendix S2 for details), the two structures should produce comparable priming effects. If, however, L2 comprehension priming is affected by L1 transfer, the priming effects for RCs and AdjPs might differ, given that AdjPs have the same constituent order in Chinese and English whereas RCs have different constituent orders across the two languages.

Results

All participants scored above 80% in answering the comprehension questions ($M = 95.4\%$, $SD = 3.1$). Table 5 presents mean RTs by condition for the critical region (the second conjunct NP). Crucially, RTs for NP2 were reduced when NP2 had the same structure as NP1, both when NP2 was modified by an AdjP and when it was modified by a RC. Moreover, RTs for NP2 were shorter when it was modified by an AdjP than by a RC. This general pattern is illustrated in Figure 3.

This pattern was confirmed by the model fit to the critical region (Table 6), which showed an interaction between NP1 and NP2, $b = -0.153$, $SE = 0.034$, 95% CI [−0.220, −0.089], $t = -4.606$, $p < .001$. We performed two post hoc tests to further examine the interaction, and the results indicated that the priming effect was significant both when NP2 was modified by an AdjP, $b = -0.079$, $SE = 0.031$, 95% CI [−0.141, −0.017], $t = -2.497$, $p = .018$, and

Table 5 Mean reaction times (RTs, in ms) by condition for the critical region (NP2) in Experiment 2

NP1	NP2	*n*	RT	*SD*	*SE*	CI	*LL*	*UL*
AdjP	AdjP	32	1,446.653	490.398	86.691	176.807	1,269.846	1,623.460
RC	AdjP	32	1,552.708	488.666	86.385	176.183	1,376.526	1,728.891
RC	RC	32	1,889.799	491.321	86.854	177.140	1,712.659	2,066.939
AdjP	RC	32	2,037.931	576.954	101.992	208.014	1,829.917	2,245.945

Note. NP = noun phrase; CI = confidence interval; *LL* = lower limit; *UL* = upper limit; AdjP = adjective phrase; RC = relative clause.

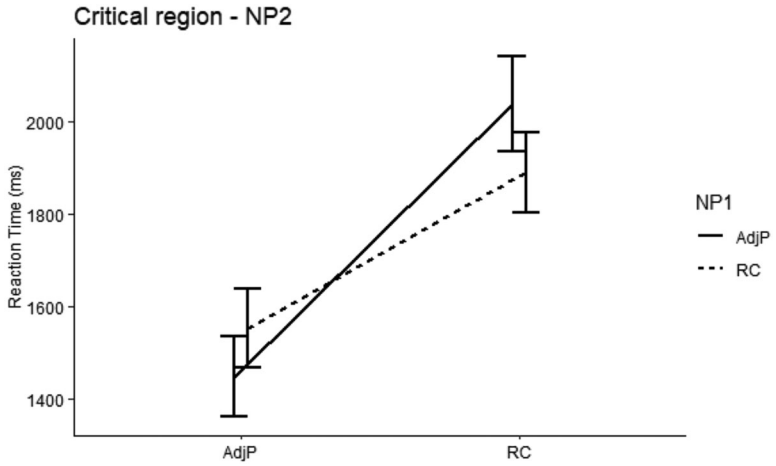


Figure 3 Mean reaction times by condition for the critical region in Experiment 2. Error bars show standard error for the by-participant analysis. NP = noun phrase; AdjP = adjective phrase; RC = relative clause.

Table 6 Fixed effects for the critical region in Experiment 2

Variable	*b*	95% CI	*SE*	*df*	*t*	*p*
(Intercept)	7.333	[7.226, 7.439]	0.054	43.430	134.797	< .001
NP1	−0.002	[−0.042, 0.038]	0.021	28.540	−0.095	.925
NP2	−0.094	[−0.195, 0.007]	0.051	77.770	−1.829	.071
Length (centered)	0.031	[0.018, 0.044]	0.007	50.540	4.761	< .001
NP1 × NP2	−0.154	[−0.22, −0.089]	0.034	1,349.000	−4.606	< .001

Note. NP = noun phrase. The formula of the final model for the critical region is as follows, where "||" indicates a random effect model without random correlations: log(RT) ~ NP1 × NP2 + cLength + (1 + NP1 + NP2 ||Subject) + (1 + NP2 ||Item).

when it was modified by a RC, $b = 0.075$, $SE = 0.022$, 95% CI [0.031, 0.119], $t = 3.350$, $p = .002$. To explore whether the size of priming effects differed between NP2 conditions (RC vs. AdjP), a further model was fitted in which NP2 (RC vs. AdjP) and prime condition (primed vs. unprimed, with primed defined as NP2 having the same structure as NP1 and unprimed as NP2 having a different structure from NP1) were included as predictors. Both predictors were centered using contrast coding, with one level coded as 0.5 (primed for prime condition and AdjP for NP2) and the other level as −0.5. The final model showed a main effect of prime condition, $b = -0.077$, $SE = 0.017$, 95% CI [−0.110, −0.044], $t = -4.545$, $p = .000$, but no NP2 × Prime Condition interaction, $b = -0.004$, $SE = 0.034$, 95% CI [−0.070, 0.062], $t = -0.116$, $p = .908$. Thus, the size of priming did not differ between NP2 conditions. This is expected given that both simple AdjPs and RCs were perceived as highly acceptable by L2 speakers, as confirmed by our acceptability test (see Appendix S2).

Mean RTs on the first conjunct were longer for RCs (2064 ms, $SE = 120$) than for AdjPs (1,594 ms, $SE = 115$). This is probably due to the fact that the first conjunct was two words longer in the RC than in the AdjP condition. The model (with centralized region length as a fixed effect) showed a significant effect of region length, $b = 0.049$, $SE = 0.007$, 95% CI [0.035, 0.063], $t = 6.792$, $p < .001$, but no effect of condition, $b = 0.015$, $SE = 0.056$, 95% CI [−0.096, 0.125], $t = 0.260$, $p = .795$.

Mean RTs for the final region are illustrated in Figure 4. The final region was read faster when NP2 was modified by a RC than when it was modified by an AdjP. Moreover, RTs for the final region were reduced when NP2 had the same structure as NP1. This pattern was confirmed by model results (for details, see Appendix S3), which showed a significant effect of NP2, $b = 0.045$, $SE = 0.021$, 95% CI [0.003, 0.087], $t = 2.099$, $p = .045$, as well as an interaction between NP1 and NP2, $b = -0.118$, $SE = 0.039$, 95% CI [−0.195, −0.041], $t = -3.009$, $p = .004$. The effect of region length was also significant, $b = 0.027$, $SE = 0.005$, 95% CI [0.016, 0.037], $t = 5.026$, $p < .001$.

As in Experiment 1, we included in the model item order (numerical predictor, divided by 48) as a continuous covariate to examine whether the priming effect accumulated from one trial to the next. The results showed a significant effect of item order, $\chi^2 = 10.004$, $df = 1$, $p = .002$, but no Priming × Item Order interaction, $\chi^2 = 0.141$, $df = 1$, $p = .708$ (for details, see Appendix S3). Hence, there was no sign of cumulative effects accrued through the experiment.

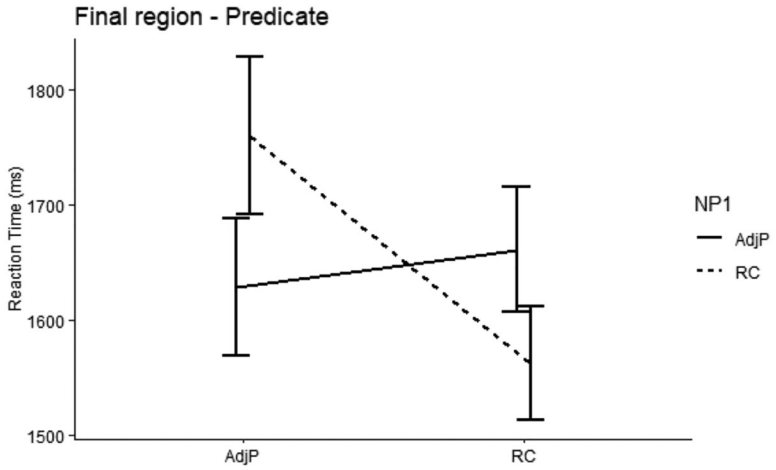


Figure 4 Mean reaction times by condition for the final region in Experiment 2. Error bars show standard error for the by-participant analysis. NP = noun phrase; AdjP = adjective phrase; RC = relative clause.

Cross−Experiment Analysis of AdjPs

We compared the size of priming effects elicited by the two AdjP conditions across the two experiments to examine whether the more marked multiword AdjPs exhibited larger priming than simple AdjPs (which would provide further evidence of inverse frequency effects). The descriptive data showed that multiword AdjPs exhibited larger priming than simple AdjPs (with a mean of 329 ms for multiword AdjPs vs. 106 ms for simple AdjPs). However, the cross-experiment comparison returned a nonsignificant Priming × Experiment interaction, $b = -0.039$, $SE = 0.045$, 95% CI [−0.127, 0.049], $t = -0.868$, $p = .390$ (see Appendix S3). This null effect might be related to the log transformation of the data. As stated earlier, raw RTs in each region were log-transformed to meet the distributional assumptions of the statistical model. When reanalyzing the data using normalized RTs, we did find a significant Priming × Experiment interaction, $b = -0.192$, $SE = 0.081$, 95% CI [−0.350, −0.034], $t = -2.381$, $p = .022$ (see Appendix S3), indicating that multiword AdjPs indeed showed greater priming than simple AdjPs.

Discussion

Experiment 2 found significant priming when the two conjuncts had the same structure, both for AdjPs and for RCs. This replicates Experiment

1 and extends it to simple, unmarked constructions, suggesting that lexically independent priming in L2 comprehension is not restricted to marked constructions but rather reflects a more general mechanism underlying L2 processing. Crucially, the priming effect for the two types of constructions is of similar magnitude despite the fact that AdjPs have the same constituent order in English and Chinese whereas RCs have different orders across the two languages. This suggests that the larger priming for multiword AdjPs observed in Experiment 1 should be attributed to their structural markedness rather than L1–L2 similarity in constituent order. The priming effect lasted to the final region, as evidenced by the significant interaction between NP1 and NP2. Additionally, the final region was read faster when it was preceded by a NP2 with a RC relative to a NP2 with an AdjP, resulting in a significant effect of NP2. We refrain from further discussion, as the effect of NP2 in the final region was confounded with wrap-up effects and is of limited theoretical interest.

General Discussion

In two self-paced reading experiments, we investigated when and how structural priming occurred during online L2 comprehension. Both experiments employed coordinated NPs where the conjuncts had the same or different syntactic structures. The results showed that the second conjunct was read faster when it had the same structure as the first conjunct compared with when the two conjuncts had different structures. Importantly, such facilitation occurred in the absence of open-class lexical repetition between the two conjuncts, providing evidence for lexically independent priming during online L2 comprehension. Moreover, the results showed that the priming effect was modulated by the baseline frequency of target constructions, with the less frequent structure (multiword prenominal AdjPs) being more prone to structural priming.

L2 Comprehension Priming in the Absence of Open-Class Lexical Repetition

To start with, both experiments showed that processing of the second conjunct was faster when it had the same structure as the first conjunct. Crucially, such priming effects occurred without open-class lexical repetition between the first conjunct (prime) and the second (target). To our knowledge, this is the first demonstration of lexically independent priming during online L2 comprehension. As stated earlier, previous studies showed that L2 comprehension priming occurred when prime and target shared the same head verb but not otherwise (e.g., Fujita & Cunnings, 2021; Weber & Indefrey, 2009; Wei et al., 2018, 2019;

though see Nitschke et al., 2014, for demonstrations of verb-independent priming using a sentence–picture matching task).

One reason why previous research failed to find lexically independent priming may be related to the target structures used in those studies (Fujita & Cunnings, 2021; Weber & Indefrey, 2009; Wei et al., 2018, 2019). Specifically, prior research used structures involving MC–RC ambiguity (e.g., *The speakers selected by the group would be perfect for the program*) or SUBJ–DO ambiguity (e.g., *After the lady washed the dog started eating some food quickly*). As stated earlier, for these structures, the verbs (e.g., *selected*, *washed*) differ in morphosyntactic form or subcategorization. Thus, recognizing the appropriate form of the verb is crucial to parsing. In fact, priming of structures with MC–RC and Subj–DO ambiguities in L1 comprehension has also been shown to be dependent upon verb repetition (e.g., Tooley et al., 2009; Traxler et al., 2014). In contrast, priming of other types of structures (e.g., Pickering et al., 2013; Traxler, 2008)—including coordinated NPs under the current investigation—seems to be less dependent upon lexical repetition.

Additionally, as stated earlier, the current study examined priming of coordinated NPs with prime and target appearing within the same sentence. This differs from prior research in which prime and target involved two independent sentences. Particularly, the interval between prime and target is much shorter for within-sentence than for between-sentence priming. Recent research shows that (lexically independent) priming in production tends to decay with the increase of interval between prime and target, suggesting that immediate priming originates partly from explicit memory of the prime structure (Bernolet et al., 2016). If priming in L2 comprehension also involves an explicit memory component, then coordinated NPs might be optimal for immediate priming, given the minimal interval between prime and target. Future studies are needed to explore to what extent the observed priming was caused by explicit memory (and to what extent by implicit learning).

Before moving on to a discussion of the broader implications, it is important to examine the loci of the priming effects observed in our study. The prime and target shared an indefinite article *a*/*an* and the preposition *to*, and hence the observed priming effects are not entirely independent of lexical repetition. Moreover, the degree of parallelism that the parser cares about is a controversial issue (e.g., whether it is necessary for the two conjuncts to share the indefinite article *a*/*an* and preposition *to* in addition to the global structure), and consequently the exact loci of the priming effects remain unclear. We propose that it is a "structural frame" (i.e., indefinite article + adjective + infinitival verb) that was primed, without any open-class words being repeated.

In a language like English, in which grammatical relationships are often expressed syntactically rather than morphologically, function words are part of the structural frame, so of course they are repeated.

Theoretical Implications

The finding of lexically independent priming in L2 comprehension has important implications for the mechanism of L2 structural priming as well as for how L2 syntactic information is mentally represented. First, the fact that priming in L2 comprehension could occur without repetition of the lexical head is consistent with previous L1 studies in which lexically independent priming has been repeatedly observed (Branigan & Pickering, 2017; Pickering & Ferreira, 2008), suggesting that the mechanism underlying L1 and L2 comprehension priming is fundamentally the same. Further, the finding that L2 comprehension priming can occur without lexical repetition suggests that L2 syntax must involve some nonlexical abstractions, and that L2 syntactic information is not inextricably bound to specific lexical items (cf. Wei et al., 2018).

Second, L2 comprehension priming exhibited inverse frequency effects, with the less frequent structure being more susceptible to priming than the more frequent structural alternative. As stated earlier, a head noun modified by a multiword AdjP is structurally marked and less common than a noun modified by a RC (Sturt et al., 2010). Our acceptability judgment test also showed that multiword AdjPs were perceived as less acceptable than RCs by L2 speakers. Experiment 1 revealed that AdjPs elicited significant priming whereas RCs merely exhibited a numerical but statistically nonsignificant trend. Additionally, comparing multiword AdjPs and simple AdjPs across the two experiments revealed that the former exhibited larger priming than the latter, which provides further evidence of inverse frequency effects.

The finding of inverse frequency effects lends support to the implicit learning account of structural priming (e.g., Chang et al., 2006, 2012). According to Chang et al. (2006), structural priming does not result from residual activation of syntactic representations but rather reflects the operation of an implicit learning mechanism. The basic idea is that for people to produce and comprehend language, they must learn how their linguistic and language-related representations map onto one another. These mappings are acquired through experience, such that if a language user encounters an utterance in which a particular meaning is expressed through a particular structure (say, a head noun modified by a RC), the mappings between meaning and structure should be strengthened, thereby allowing the same meaning to be expressed through the same structure (another noun modified by a RC). On this account, structural priming reflects

this extended mapping process. Inverse frequency effects, whereby structures that are encountered less often exhibit greater priming, have been taken as a hallmark of implicit learning, under the assumption that systems learn more about representations that are not yet well known (Pickering & Ferreira, 2008).

In a similar vein, Nitschke and colleagues (Nitschke et al., 2010, 2014) found that L2 learners were primed more than L1 speakers in comprehension, which they attributed to the L2 learners' comparative lack of experience of using the target structure. The present study provided more direct evidence for inverse frequency effects by comparing the priming of L2 constructions with different baseline frequencies. It should be noted, however, that not all studies observed inverse frequency effects. For instance, Hurtado and Montrul (2021) found that Spanish L2 speakers were primed to produce more recipient (e.g., *Pedro le da un lápiz a María*; literally, "Pedro gave Mary a pencil") than nonrecipient constructions (e.g., *Antonio le lava la camiseta a Carmen*; literally, "Antonio washes Carmen's T-shirt"), which was interpreted as a frequency (rather than inverse frequency) effect given that recipient constructions are more frequent than nonrecipient ones in Spanish. Additionally, Jackson and Ruf (2017) observed greater priming with the more frequent fronted temporal phrases (e.g., *In winter the grandpa drinks hot chocolate*) than with the less frequent fronted locative phrases (e.g., *On the mountain the grandpa drinks hot chocolate*) in L2 German speakers. Obviously, further studies are needed to uncover the possible reasons for these conflicting results.

Finally, the present study showed that L2 comprehension priming was unaffected by L1 transfer. As stated earlier, AdjPs have the same constituent order in the participants' L1 (Chinese) and L2 (English), whereas RCs have different orders. If L2 comprehension priming was affected by L1 transfer, we might expect to find greater priming for AdjPs than for RCs.[55] In Experiment 1, AdjPs elicited significant priming whereas RCs merely exhibited a numerical trend, which apparently attests to the effect of L1 transfer. However, this interpretation was ruled out in Experiment 2, which showed that simple AdjPs and RCs exhibited comparable priming. Hence, the greater priming for multiword AdjPs was probably due to their structural markedness rather than to L1–L2 overlap in constituent order. This finding is consistent with prior research (Nitschke et al., 2010, 2014), which showed that L1 transfer in L2 processing could be overridden by structural priming. Priming in L2 production also seems to be unaffected by L1 transfer. For instance, Flett et al. (2013) found that German and Spanish L2 speakers of English were

equally likely to produce double object targets (e.g., *The girl passed the man a brush*) following double object primes despite the fact that German allows both prepositional object (e.g., *The girl passed a brush to the man*) and double object constructions whereas Spanish only allows a prepositional object construction. Similarly, Shin and Christianson (2012) found that Korean L2 speakers of English could be primed to produce both double object and phrasal verb constructions (e.g. *The girl is turning the heater down*), although there are no equivalent structures using phrasal verbs in Korean.

Limitations and Future Research

The present study found immediate priming but with no indication of cumulative effects, as shown by the absence of interaction between item order and priming. This finding is consistent with prior research on L2 comprehension priming of RCs (e.g., Wei et al., 2018), which also found no evidence of cumulative priming. This casts doubt on the longevity of the observed priming effects. Additionally, the design and materials adopted in the present study are suitable for examining immediate priming but may not be appropriate for investigating long-term effects (e.g., with prime and target separated by unrelated fillers). Hence, it remains to be explored whether priming in L2 comprehension can accumulate and lead to long-term learning.

Conclusion

The present study showed that structural priming during online L2 comprehension can occur in the absence of head word repetition between prime and target, and that L2 comprehension priming exhibited inverse frequency effects, with the less frequent structure being more susceptible to priming. The current findings suggest that L2 syntactic representations are not inextricably bound to specific lexical items, and that adult L2 learners can learn abstract syntactic rules while reading for comprehension, attesting to the accessibility of the implicit learning mechanism to late L2 learners.

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materials that the authors have used and have the right to share are available at https://osf.io/tc2yd. All proprietary materials have been precisely identified in the manuscript.

Notes

1 According to Pickering and Ferreira (2008, p. 446), "priming in comprehension versus production are at least quantitatively different—priming is weaker in comprehension than it is in production. This follows from the fact that in nearly every case, to observe priming within comprehension, some 'boost' is needed." In a similar vein, prior work shows that lexical boost (especially head verb repetition) is often needed for priming in L2 comprehension but not for priming in L2 production, suggesting that priming in L2 comprehension is weaker than in L2 production.

2 As pointed out by one of our reviewers, the spillover region overlapped with the sentence-final region, making it difficult to disentangle spillover effects from wrap-up effects. However, the critical region for analyses is NP2, which is where the priming effect consistently occurred across the two experiments, and it is free from wrap-up effects.

3 The by-participant cutoff values were calculated based on the RTs for all four regions instead of the critical and final regions only. This is because the distribution of RTs was homogeneous among the regions. Hence there is no need to consider the RTs separately.

4 The reasons for the null effect of RCs are unclear. One possibility is that the statistical power of our first experiment was not strong enough to detect priming for RCs. Future studies involving more participants and/or items are needed to examine this possibility.

5 Alternatively, one could argue that RCs should exhibit greater priming if L2 learners are less familiar with the word order of RCs. It must be noted, however, that although RCs have different orders across the L1 (Chinese) and L2 (English), there is no evidence that Chinese EFL learners are less familiar with RCs (relative to multiword AdjPs). In fact, a NP modified by a RC is perceived as more acceptable than a NP modified by a multiword AdjP, as confirmed by our acceptability judgment test (see Appendix S2 for details). Hence, despite the different constituent orders across the L1 and L2, RCs are the preferred structural alternate among Chinese EFL learners, just as they are for English L1 speakers.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Accessible Summary
Appendix S1. Experimental Items.
Appendix S2. Acceptability Judgment Test.
Appendix S3. Model Comparison Results.