*Article*

# Independent Semantic and Syntactic Representations in L2 Mandarin Learners: Evidence from Structural Priming

Douglas J. Getty [1,*], Xiang Wei [2] and Lin Chen [3,4,5,*]

1. Learning Research & Development Center, Department of Psychology, University of Pittsburgh, Pittsburgh, PA 15260, USA
2. School of Foreign Languages, Sun Yat-sen University, Guangzhou 510275, China; weixiangsysu2017@gmail.com
3. Department of Educational Psychology, University of Illinois Urbana-Champaign, Champaign, IL 61820, USA
4. Beckman Institute for Advanced Science and Technology, University of Illinois Urbana-Champaign, Champaign, IL 61820, USA
5. Department of Linguistics, University of Illinois Urbana-Champaign, Champaign, IL 61820, USA
* Correspondence: djg94@pitt.edu (D.J.G.); linchen8@illinois.edu (L.C.)

**Abstract:** Structural representations in English have been shown to be quite abstract, with structural information being represented independently from semantic information. Mandarin has a relatively sparse marking of syntactic information, with no inflections for case, number, or tense. Given this syntactic sparsity, Huang et al. (2016) hypothesized that, distinct from English-language findings, Mandarin learners may have shared syntactic and semantic representations, such that semantic information can guide structure building. We examined this question in L2 Mandarin learners using a structural priming paradigm that required reading Mandarin primes. We found that L2 Mandarin learners exhibit within-language structural priming, and this effect is independent of semantic information. These findings have two implications: (1) this represents the first demonstration of within-language L2 Mandarin structural priming; (2) L2 learners can develop syntactic representations independent of semantic representations, even when the target L2 language lacks rich marking of syntactic information.

**Keywords:** structural priming; reading; bilingualism

## 1. Introduction

Structural priming refers to the tendency for readers and listeners to repeat a sentence structure they have recently read, heard, or produced [1,2]. However, structural priming refers not only to the empirical phenomenon but also to the method of eliciting structural repetition. This method provides a crucial approach to examining the nature of syntactic and semantic representations [3]. One key question, which we address in this paper, is whether language processing operates over syntactic and semantic representations that are shared or independent of one another.

In particular, this study was designed to test whether within-language structural priming occurs for L2 Mandarin learners and, subsequently, whether L2 Mandarin learners have independent syntactic and semantic representations, as has been demonstrated using English sentences [4,5]. We investigated these questions using a variant of the classic structural priming picture description paradigm, where participants read Mandarin prime sentences and then produced descriptions of ditransitive images [6,7]. We will briefly review the relevant literature on structural priming, how this method has been used to study the representation of syntactic structure, and then describe the current study.

## 1.1. Structural Priming Background

In the traditional structural priming paradigm [1], participants read or hear a prime sentence that participates in a structural alternation, such as the dative alternation (1a, 1b). The participant then describes an unrelated ditransitive image, which could be described with either version of the alternation (e.g., an image of a grandpa reading a book to a boy). The classic finding is that participants are more likely to describe the image using the structure of the preceding prime than the alternative structure (that is, they produce more DO descriptions after DO primes than after PO primes, and vice versa). This structural priming phenomenon has been widely replicated [8], and meta-analysis has shown that the effect size is the same whether the participants read prime sentences silently, read out loud, or listen to the prime sentences [9]. More recently, a growing body of research has also demonstrated that structural priming is measurable from reading comprehension, such that exposure to a structure can lead to faster processing of that structure based on reading times or eye-tracking measurements [10].

(1a)  Prepositional object (PO): The governess gave a pot of tea to the princess.
(1b)  Double object (DO): The governess gave the princess a pot of tea.

Structural priming has been widely replicated across languages [9]. Most evidence for structural priming has been found by testing L1 (first language) speakers of English (e.g., [1]), but it has also been replicated in L1 Dutch [11], L1 Swedish [12], L1 Russian [13], and others [9]. Because all these languages belong to the Indo-European language family, they share a higher degree of overlap in their syntactic features compared to languages outside of this language family. Some work has also demonstrated structural priming in L1 speakers of Mandarin and Cantonese [13], two languages in which syntactic information is realized quite differently. The observation that structural priming has been widely observed across languages supports the idea that structural priming measures universal properties of language processing.

Critically for the current work, structural priming is also useful for examining the acquisition of syntactic representations during both L1 and L2 learning. Within L1 language acquisition, structural priming has been used to examine the status of grammatical knowledge during early language acquisition [14–16]. In general, the presence of a structural priming effect is treated as evidence that the child has gained the cognitive representation of that structure. Similarly, work in second language acquisition has also used structural priming to investigate the cognitive status of syntactic representation.

## 1.2. Independence of Syntactic and Semantic Representations

Structural priming has been widely used to address a core theoretical question in language processes, which is whether language learners have shared or independent semantic and syntactic representations. The first studies investigating the overlap of structural and semantic representations were conducted using English language stimuli by Bock, Loebell, and Morey [4]. In their study, participants listened to transitive primes that varied in whether they contained animate or inanimate subjects (2a–3b).

(2a)  Active, inanimate subject: The boat carried five people.
(2b)  Active, animate subject: Five people carried the boat.
(3a)  Passive, inanimate subject: The boat was carried by five people.
(3b)  Passive, animate subject: Five people were carried by the boat.

Participants then described images that contained an inanimate object exerting an action on an animate patient (e.g., an alarm clock waking a boy). Their study showed both structural priming, where participants produced more active image descriptions after active primes than after passive primes, and animacy priming, where participants' descriptions were more likely to contain inanimate subjects after primes containing inanimate subjects. Critically, these two forms of priming did not interact; the rate of structural repetition was not influenced by whether the prime and target descriptions shared animacy features. This finding has been cited as the primary evidence for abstract structural prim-

ing and the independence of structural and semantic representation for years and was recently replicated in a high-fidelity, large-sample replication attempt [5].

Building on these findings, a relatively recent study by Huang et al. [6] tested whether native speakers of Mandarin have shared or separate semantic and syntactic representations. In their study, structural priming from dative primes with animate recipients (e.g., "The merchant lent the friend some money") was compared to priming from dative primes with inanimate recipients (e.g., "The merchant lent the factory some money"). All target descriptions necessarily contained animate recipients (e.g., a grandpa gives an umbrella to a boy). They hypothesized that, if syntactic representations depend on semantic information in Mandarin, priming would only occur when primes and targets had shared semantic features but not when there were no shared semantic features. However, across four studies, they found structural priming effects regardless of whether primes and targets had semantic features in common, which they interpret as evidence that the computation of syntactic representations in L1 Mandarin does not require semantic information. A follow-up study that included a condition where the recipient was inanimate but the theme was animate again found that shared animacy between the prime and target did not influence structural priming [7]. The current work follows the design of Huang et al. and tests the same research question in L2 Mandarin learners. Although Huang et al. found no evidence for shared representations in L1 Mandarin speakers, we use their design and re-ask their research question in a population of L2 Mandarin learners. As we detail below, Mandarin has unique syntactic features that require L2 learners to rely on semantic information to compute syntactic representations.

### 1.3. L2 Structural Priming and Mandarin Syntactic Structure

Grammatical knowledge is a difficult aspect of an L2 to acquire [17]. The declarative/procedural model of L1 and L2 linguistic representation suggests that L2 grammatical knowledge is stored largely in lexically based declarative memory systems, not procedurally as for L1 knowledge [18]. In support of this, in a masked lexical priming study, Silva and Clahsen [19] found that L1 English comprehenders were primed by morphologically inflected word forms compared to unrelated word forms, while L2 English comprehenders did not exhibit lexical priming from inflected word forms. This suggests that combinatorial syntactic knowledge is not as readily accessible during L2 language processing as it is for L1 processing.

Many studies have used structural priming to examine syntactic representations in L2 learners. However, most L2 work examines cross-linguistic structural priming (L1 to L2, or vice versa) or compares cross-linguistic priming to within-language (L1 or L2) structural priming [20,21]. In addition to the mentioned paradigms, investigating the occurrence of structural priming within the L2 is a valuable approach for examining the acquisition of L2 syntactic representations. However, there is very limited work on this aspect [22,23], and it has been largely overlooked. This might be attributed to the fact that most research has focused on the process of acquiring a second language rather than the outcomes of having acquired a second language. To address this gap, the aim of this work is to investigate the nature of syntactic representations for L2 Mandarin learners, focusing specifically on within-L2 priming.

Demonstrating the presence (or absence) of well-established phenomena in a broad variety of languages and populations is informative for developing robust theory about universal processes common across languages, because findings based on one language (typically English) result in models that fail to capture language universals [24,25]. For example, the faciliatory syntactic agreement attraction effect refers to the phenomenon that comprehenders show faster processing of ungrammatical verbs that agree with a local modifying noun but not with a head noun (e.g., the key to cabinets was…). This effect was not replicated in L1 Czech speakers [26], despite having been observed across many other languages, including closely related languages such as Russian [27]. This failure to replicate led the authors to speculate that syntactic cues may be stronger in Czech than in

Russian, given that Czech has a comparative lack of semantic agreement. That is, verbs are less likely to agree with the conceptual number of a subject (as in, the government were concerned) than with the subject's grammatical number. This surprising set of results would not have been discovered without research aimed at replicating well-known findings in new languages. Similarly, testing whether structural priming occurs across different languages is essential to understanding the universal syntactic representations for L2 learners.

In particular, Mandarin has distinct syntactic features compared to other languages, making it a valuable language of study for understanding the commonality of structural priming across languages. Mandarin has fewer syntactic markings than Indo-European languages, with no markings for syntactic features such as number, case, or tense. Additionally, individual words are frequently ambiguous with respect to their word classes, and adjacent characters in the written language can have ambiguous groupings, which lead to very different interpretations. As a result, it has been suggested that structural information may play a diminished role in Mandarin comprehension relative to semantic information [28,29], with some electrophysiological evidence in support of this [30–32].

Furthermore, while studies have demonstrated that L1 Mandarin does not rely on shared syntactic and semantic representations, this aspect has not been tested in L2 Mandarin. The question of whether L2 learners of Mandarin develop separate syntactic and semantic representations remains unclear. One possibility is that structure processing in L2 Mandarin may rely on the same representations as in other languages, namely, that structural representations do not contain semantic information. Alternatively, because of the syntactic sparsity of Mandarin and the relative inaccessibility of syntactic knowledge to L2 learners, structural representation in L2 Mandarin comprehension may rely on semantic information (similar to that hypothesized by [6]).

To date, the authors are aware of no studies investigating within-language priming for L2 Mandarin. One related study the work of [20], who investigated structural priming in L1 Cantonese-L2 Mandarin bilinguals. This study found that Mandarin-Cantonese bilingual speakers (whose L2 is Mandarin) showed a significant within-L2 structural priming effect. However, given the strong similarities between Mandarin and Cantonese, this may not serve as a strong test of within-L2 priming. Although Mandarin and Cantonese have differences in phonology, their syntactic differences are relatively small. The shared syntax model [33] suggests that when structures are highly similar across languages, the representation of those structures can be easily shared. Therefore, it is not particularly surprising to observe structural priming among L2 speakers whose L1 is a highly similar language.

*1.4. The Current Study*

The current work uses within-L2 structural priming to address whether L2 Mandarin readers have independent syntactic and semantic representations as has been demonstrated for native Mandarin speakers. Our study had two goals: first, we used a picture description paradigm to test whether L2 Mandarin learners exhibit structural priming after reading written primes. This provides important evidence regarding the replicability of structural priming across languages and linguistic populations. Second, we tested whether L2 Mandarin learners can develop syntactic representations that are independent of semantic representations by manipulating the animacy features shared by the prime and target structures.

In the present study, following the design of Huang et al. [6], we manipulated two dative constructions of prime sentences (double object/DO dative vs. prepositional object/PO dative) to investigate structural priming of dative constructions for L2 Mandarin learners. After reading prime sentences aloud, participants were instructed to describe target pictures. The structure of the produced description (double object vs. prepositional dative) was used to assess structural priming. Further, the animacy (animate vs. inanimate) of the prime sentence and target sentence was manipulated to investigate whether the syntactic information was processed independently. If the syntactic representations are guided by

semantic information, we would expect that there would be stronger structural priming when the animacy of the recipient of the prime and target sentences was consistent rather than inconsistent.

## 2. Materials and Methods

### 2.1. Participants

A total of 30 L2 Mandarin participants (23 female, mean age: 22.7 years, SD = 2.9) were recruited from Sun Yat-sen University in China to complete the experiment. The participants were recruited through advertisements and were compensated for their participation. All participants signed a consent form before the experiment.

Because the primary goal of the study is to understand whether L2 learners can acquire abstract (independent) structural knowledge, we recruited participants who had advanced Chinese language proficiency as measured by the HSK (Hanyu Shuiping Kaoshi, translated as "Chinese Language Proficiency Test"), a standardized test of Chinese language proficiency for non-native speakers that distinguishes six levels of proficiency [34]. These six levels of HSK proficiency correspond to A1, A2, B1, B2, C1, and C2 of the Common European Framework of Reference for Languages (CEF), respectively. At the time of participation in the study, three participants had passed level 4 proficiency (corresponding to B2 of the CEF), 15 had passed level 5 (the second highest level, requiring knowledge of 2500 words; corresponding to C1 of the CEF), and 12 had passed level 6 (the highest level, requiring knowledge of 5000 words; corresponding to C2 of the CEF). Even though we selected high-proficiency L2 learners, one goal of the study was to test whether there was an effect of proficiency on structural priming in our results. However, we were only able to recruit a small number of HSK 4 participants. In our analyses, we tested models with and without HSK 4 participants and found that the effect of proficiency on structural priming did not differ across these models, so we opted to keep the HSK 4 participants as part of our sample in all analyses.

The participants' L1 backgrounds varied, and the distribution is as follows: nine were fluent in Indonesian, four in Thai and four in Vietnamese, two in Russian and two in Korean, and one participant each for Mongolian, Uzbek, Cambodian, and Czech. The goal of the current study was not to study the influence of specific L1 backgrounds on processing in L2. Instead, we aimed to generalize across L1 backgrounds to understand representation in L2 Mandarin generally. To that end, we included L1 background as a random effect in our models [35]. We recognize that L1 background may have an effect on structural representation, particularly to the degree that the dative structure in participants' L1 is similar to the Mandarin dative, and suggest this as a topic of investigation in future research.

### 2.2. Stimuli and Design

The stimuli and design were derived from a structural priming study of L1 Mandarin speakers [6]. We adopted the stimuli from Huang et al. [6] by replacing some challenging words with easier ones to suit the language proficiency of the L2 learners. The full set of stimuli can be found in Appendix A. This study used a 2 (prime structure) × 2 (animacy match) design with an additional unprimed baseline condition, resulting in five total conditions. Prime structures could be either a prepositional object (PO) dative or a double object (DO) dative, while animacy could either be animate (AN) or inanimate (IN). Note that because the target sentences were always animate, the animate primes matched the animacy of target sentences, while the inanimate sentences mismatch the target sentences. The inclusion of the baseline condition allows us to test whether the priming effect arises from one of the specific structures or from both of them.

Each participant was shown four separate items from each condition, for a total of 20 items. Each prime sentence was paired with a target picture, and each pair had five versions of prime sentences corresponding to the five different conditions (Table 1). Every participant was assigned one of the five stimulus lists.

**Table 1.** Experimental conditions. Animacy manipulation is denoted by subscripts. Each prime sentence is displayed first in Mandarin characters, then Pinyin, then as an English translation. Pinyin is an alphabet-based system developed to aid in learning the pronunciation of Chinese characters.

| Condition | Prime Sentence |
| --- | --- |
| PO-AN | 商人借了一些钱给朋友。<br>(Shangren jie le yixie qian gei pengyou$_{AN}$)<br>*The merchant lent some money to the friend$_{AN}$* |
| PO-IN | 商人借了一些钱给工厂。<br>(Shangren jie le yixie qian gei gongchang$_{IN}$)<br>*The merchant lent some money to the factory$_{IN}$* |
| DO-AN | 商人借给朋友一些钱。<br>(Shangren jie-gei pengyou$_{AN}$ yixie qian)<br>*The merchant lent the friend$_{AN}$ some money* |
| DO-IN | 商人借给工厂一些钱。<br>(Shangren jie-gei gongchang$_{IN}$ yixie qian)<br>*The merchant lent the factory$_{IN}$ some money* |
| Baseline (Intransitive) | 妈妈笑了。<br>(Mama xiao le)<br>*Mother smiled* |

In Mandarin, the PO dative construction is marked by a preposition "gei" which indicates the recipient of the object (shangren jie le yixie qian gei pengyou, The merchant lent some money to the friend). The Mandarin DO construction still has "gei", but this is considered a part of the verb and not a preposition (shangren jie-gei pengyou yixie qian, The merchant lent the friend some money). Additionally, the order of the post-verbal noun phrases is shifted (as in English), with the recipient coming immediately after the verb, followed by the object.

In the animacy match conditions, the prime sentences always contained an animate recipient (e.g., the merchant lent some money to the friend; the merchant lent the friend some money). In the animacy mismatch conditions, the recipient was always inanimate (e.g., PO: the merchant lent some money to the factory; DO: the merchant lent the factory some money). In the baseline condition, the prime sentences were all intransitive and thus did not have any recipient (e.g., mother smiled). Such intransitive primes are common to use as a baseline condition in structural priming studies because they are clearly syntactically distinct from the dative structure.

Each target picture involved an animate agent and an animate recipient and could be described using both a DO and a PO structure (e.g., grandpa lent the boy an umbrella; grandpa lent an umbrella to the boy). The measurement of structural priming was implemented as a stem completion task, where participants were given the sentence stem up to the main verb (e.g., Grandpa lent_____) and instructed to complete the sentence by describing the image using the object and the recipient in the picture (as shown in Figure 1). In the target pictures, the agents were always on the left. The placement of the recipients and objects varied in order to eliminate any potential biases in structural priming. Half of the pictures had the recipients in the middle and the objects on the right, while the other half had the objects in the middle and the recipients on the right. The target picture was designed to elicit descriptions that did not share any lexical overlap with the preceding prime sentence.
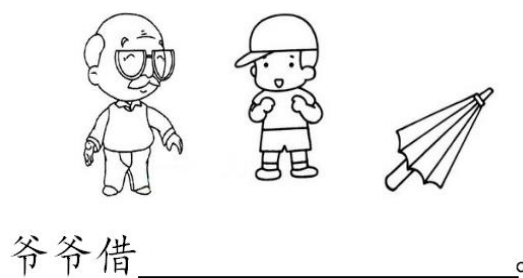
**Figure 1.** An example of the target pictures. English translation of the text: "Grandpa lent _____".

*2.3. Procedure*

The experiment was described to participants as a memory task to ensure that participants were not overly attentive to the specifics of their picture descriptions and to prevent them from deducing the intention behind testing for structural priming. The experiment had three phases. Phase one was a label-learning phase, designed to ensure that participants were familiar with the names of each of the pictures used in the following two phases. Phase two was designed to establish the cover story for a memory task wherein participants were instructed to remember sentences and sets of pictures. Phase three implemented the experimental structural priming manipulation. We measured the structural priming effect by testing how prime sentences from each of the five conditions affect the description of the picture.

The goal of phase one was to familiarize the participants with the names of the agents and objects in the pictures. There were 66 pictures in total. The names of each item were presented beneath each picture. All of the names consisted of specific vocabulary words that participants had learned in their Chinese classes. The participants were instructed to familiarize themselves with the names of each picture at their own pace until they had memorized the names of all 66 pictures.

In phase two, participants were exposed to sentences and images and told that they would be tested on them later. This phase was implemented solely to give credibility to the memory task cover story. Each trial began with a 500 ms fixation, followed by a sentence in the center of the screen that was displayed until the participant pressed the spacebar to indicate they had sufficiently read the sentence and committed it to memory. The sentences were a mix of transitive (10), intransitive (2), and dative (8). To ensure that participants did not receive cumulative priming for any one dative type sentence [36], two sentences from each of the PO-AN, PO-IN, DO-AN, and DO-IN conditions were displayed among the eight dative sentences. After the sentence was displayed, a 200 ms blank screen was followed by a set of either two or three pictures that were learned in phase one. Participants were required to memorize the pictures and then press the spacebar once again. The picture sets of three contained two animate figures and one inanimate object (as in Figure 1), while the picture sets of two showed either two animate figures or one animate and one inanimate object. To prevent participants from being aware that picture sets could be described in dative structures, these sets were not immediately preceded by a sentence with a dative structure.

In phase three, the test phase, participants were asked to recognize if the sentences and the sets of pictures were the same as they had memorized in the memory phase. In each trial, a prime sentence was presented first, and participants were asked to read it out loud and judge whether they had seen the sentence in phase two by pressing an assigned button. Then, a set of target pictures was shown, and participants were asked to describe the pictures by completing the sentence stem aloud and then indicate whether they had previously seen the set of pictures in the exposure phase. Participants' utterances were recorded and later transcribed.

The test phase included three practice trials and eighty trials, twenty of which were experimental trials (four trials for each of the five experimental conditions) and sixty were filler trials containing simple transitive prime sentences. A quarter of the sentences and the sets of pictures were from the memory phase. Filler trials were interspersed between experimental trials to prevent participants from noticing the structure of the test trials. The experiment lasted approximately 50 min.

### 2.4. Data Coding and Exclusion

The uttered descriptions of the target pictures were categorized offline as PO, DO, or OTHER based on the sentence structure. The sentences were categorized as PO if the verb was first followed by the object and then a prepositional phrase, as DO if the verb was followed by a recipient and then an object, and as OTHER if it could not be categorized as a PO or DO. For example, some participants omitted the preposition gei, and thus this could not be categorized as a DO or PO under our criteria. Only ~9% of the total structures were categorized as OTHER (Table 2).

**Table 2.** Total response frequency by five prime conditions.

| Response | PO-AN | PO-IN | DO-AN | DO-IN | Baseline | Total % |
|----------|-------|-------|-------|-------|----------|---------|
| PO | 80 | 82 | 68 | 64 | 73 | 61.17% |
| DO | 34 | 31 | 40 | 40 | 34 | 29.83% |
| Others | 6 | 7 | 12 | 16 | 13 | 9% |
| PO (%) | 66.67% | 68.33% | 56.67% | 53.33% | 60.83% | |

## 3. Results

Table 2 displays the frequency of PO, DO, and OTHER responses for each of the experimental conditions. The key results are as follows: (a) participants were more likely to use a structure when it was primed, demonstrating that within-L2 structural priming does occur for Mandarin L2 learners after reading written primes; (b) there is no evidence that structural priming was influenced by animacy. The results are supported by the statistical tests described below.

### 3.1. Data Analysis Method

We analyzed the data using logistic mixed-effects modeling [37] with the PO target description as the dependent variable (PO = 1, DO = 0). The models were implemented with the lme4 package in R [38]. The model included the main effects of prime type (PO vs. DO), animacy (animate vs. inanimate), and proficiency (lower: 4th and 5th vs. higher: 6th HSK), as well as their interactions. Note that 4th and 5th HSK levels were grouped together due to the small number of HSK level 4 participants. All three factors were effects-coded (prime type: PO = 0.5, DO = −0.5; animacy match: match = 0.5, mismatch = −0.5; HSK: high = 0.5, low = −0.5). The maximal random effects structure was first tested and then reduced until the model reached convergence for a "near-maximal" model, following [39]. The final model had random intercepts for participants, items, and first language background, a by-participant random slope for prime type, and by-item random slopes for prime type, animacy, and HSK level.

### 3.2. Structural Priming Analysis

The full model results are in Table 3. There was a significant main effect of prime type (B = 1.2, SE = 0.6, $p < 0.05$), such that rates of PO production were higher after PO primes than after DO primes. This suggests that L2 Mandarin learners reliably repeat the structure of the preceding primes. The main effects of animacy and HSK level were not significant. The interaction between prime type and animacy match was also not significant (B = −0.51, $p = 0.42$), suggesting that the overlap between animacy and prime structure did not lead to changed rates of PO production. The interaction between prime type and HSK level was

also non-significant, suggesting that there is no evidence that proficiency level influences the degree of priming. There was a marginally significant three-way interaction between prime type, animacy match, and HSK level (B = $-2.61$, SE = 1.36, $p$ = 0.055). Post-hoc analyses of this marginal three-way interaction showed that this interaction was driven by a larger priming effect among the lower proficiency group. In addition, there was a prime type $\times$ animacy interaction among the higher proficiency group, indicating that receiving inanimate primes leads to increased priming on the target trials. While this result may be surprising, we strongly suspect this marginal effect to be spurious given the small sample size of each language proficiency group. We reanalyzed the data with the language proficiency variable removed and again found that readers of L2 Chinese exhibit within-L2 structural priming and that there is no interaction between prime type and animacy.

**Table 3.** Logistic mixed effects regression output contrasting DO and PO primes.

|  | **B** | **SE** | **CI 95%** | *p* |
|---|---|---|---|---|
| (Intercept) | 1.79 | 0.70 | 0.43–3.16 | 0.010 |
| Prime Type | 1.20 | 0.60 | 0.02–2.38 | 0.047 |
| Animacy | $-0.27$ | 0.39 | $-1.03$–0.50 | 0.492 |
| HSK | 0.79 | 0.99 | $-1.14$–2.72 | 0.424 |
| Prime Type $\times$ Animacy | $-0.51$ | 0.64 | $-1.76$–0.73 | 0.421 |
| Prime Type $\times$ HSK | 0.04 | 0.88 | $-1.68$–1.76 | 0.963 |
| Animacy $\times$ HSK | $-0.81$ | 0.66 | $-2.10$–0.47 | 0.215 |
| Prime Type $\times$ Animacy $\times$ HSK | $-2.61$ | 1.36 | $-5.27$–0.06 | 0.055 |
| Observations | 439 | | | |

### 3.3. Which Structure Was Primed?

We have so far found that L2 Mandarin learners exhibit within-L2 structural priming after reading written primes, but a related question is whether one or both structures were primed. This is important for investigating which of the two forms of the dative alternation the participants have learned at this proficiency level. For example, Chinese learners at the 4th–6th level of (HSK) proficiency may have implicit structural knowledge of only the PO structure, and thus only the PO structure can be primed. To test this, we examined whether PO primes increased PO production relative to baseline and whether DO primes correspondingly reduced PO production as well. We thus fit a second model that included a five-level factor called prime condition (levels: DO-An, DO-In, PO-An, PO-In, baseline) and HSK level as fixed factors to investigate how the productions given DO or PO prime sentences differ from baseline. The levels of prime condition were treatment-coded with baseline as the reference level. As before, participants, items, and first language background were included as random intercepts. The final model had a random slope of prime condition for all three random intercepts.

The full results are in Table 4. Neither prime structure had significantly different PO production relative to the baseline condition. Numerically, animate and inanimate DO dative primes led to reduced production of POs in target descriptions. Similarly, animate and inanimate PO dative primes led to increased production of POs. These numerical results are directionally consistent with what we would expect, though, of course, without the weight of statistical significance. Of note is the observation that animacy had scarcely a numerical influence on the results. Both animate and inanimate DO primes lead to a very similar numerical decrease in PO production, while both types of PO primes lead to a very similar increase.

**Table 4.** Logistic mixed effects regression output comparing each condition to baseline.

|  | **B** | **SE** | **CI 95%** | *p* |
|---|---|---|---|---|
| (Intercept) | 1.64 | 0.75 | 0.16–3.12 | 0.030 |
| DO-AN | −0.45 | 0.55 | −1.52–0.62 | 0.406 |
| DO-IN | −0.58 | 0.58 | −1.72–0.56 | 0.317 |
| PO-IN | 0.70 | 0.76 | −0.78–2.18 | 0.355 |
| PO-AN | 0.76 | 0.95 | −1.11–2.62 | 0.427 |
| HSK | 0.74 | 0.89 | −1.00–2.48 | 0.406 |
| Observations | 546 | | | |

While we observed significant evidence of structural priming in the primary analysis in Section 3.2, we cannot draw conclusive conclusions about which specific structure is responsible for the priming effect or whether both structures lead to priming based on further analyses. We suspect that this finding is likely due to low statistical power; the change in PO production induced by each prime type compared to baseline (DO or PO vs. baseline) is relatively small compared to the change in PO production when comparing between prime types (DO vs. PO). A larger future study is needed to reliably determine whether one or both structures are responsible for the priming observed in the previous analysis. It is worth noting that, in a recent corpus analysis of Mandarin text [35], the DO structure was found to be more common than the PO structure (79% vs. 21%). The observation that the frequency distribution is reversed here suggests that the less frequent structure (the PO) could have been primed to be produced more frequently (the inverse frequency effect; [40,41]). However, this is speculative and cannot be determined without comparison to a pre-exposure baseline of structural predictions. As such, future studies may also assess the extent to which the inverse frequency effect is observable in Mandarin structure processing.

## 4. Discussion

With this study, we sought to address two research questions. First, do L2 learners of Mandarin exhibit the well-replicated structural priming effect after reading a sentence within their L2? Second, if we observe evidence of structural priming, do L2 Mandarin learners exhibit structural priming effects that depend on semantic overlap between the primes and targets? For the first question, we found that yes, we do see evidence of within-language structural priming for L2 learners of Mandarin. We observed a statistically significant effect of the prime structure, suggesting that L2 learners of Mandarin have a tendency to repeat structures that they recently read. This constitutes a replication of the structural priming effect in a novel linguistic context, adding to the growing list of contexts in which structural priming has been found. This finding is particularly informative in the case of Mandarin, given that the language has fewer salient syntactic cues compared to many other languages [28,29]. Despite this relatively reduced syntactic system, our findings suggest that L2 Chinese learners can obtain abstract structural information from language, just as in languages with more complex syntactic systems.

For the second question regarding the semantic effects on structural priming induced by manipulating animacy, we did not find evidence that shared animacy between the prime and targets influences the effect of priming. Given the syntactic sparsity of Mandarin relative to many other languages, one reasonable hypothesis would be that L1 and L2 Mandarin learners may have shared (non-independent) semantic and syntactic representations, such that semantic information can guide the structural representation that comprehenders obtain from a sentence (e.g., as proposed by Huang et al. [6]). However, consistent with the results of past work on L1 Chinese [6,7], we find no evidence in favor of this belief. This lack of evidence suggests that L2 learners of Mandarin, like L1 Mandarin and L1 English speakers, can develop syntactic representations that are independent of semantic information. The extensive syntactic structural priming effect found in both L1 and

L2 readers, as well as across a variety of languages, likely reflects shared cross-linguistic principles of the representation of syntactic information.

Our finding that shared semantic features between the prime and target do not influence structural priming in L2 Mandarin is aligned with L1 English [4,5] and L1 Mandarin findings [6,7]. The similarity of these findings suggests that structural priming, and by extension, the learning of syntactic structure, is likely to involve similar underlying mechanisms. Specifically, structural priming effects have been argued to be a dual-mechanism phenomenon [42], arising from a residual activation mechanism [43] and an implicit procedural learning mechanism [41,44]. Residual activation accounts for structural priming effects that are short-lived and are increased by shared lexical content between the prime and the target. An implicit learning mechanism accounts for changes in comprehension or production that occur over longer time frames [36,44,45], as well as the inverse frequency effect (wherein less frequent structures receive a larger boost from priming [40,41]). More work is needed to fully make this claim (e.g., a study of L2 structural priming, which manipulates the time between prime and target); however, the broad similarities in structural priming effects between English and Chinese as well as between L1 and L2 indicate that similar underlying learning mechanisms are likely responsible for structural priming.

We recognize that L1 background is a relevant factor for the degree to which we observed structural priming here. In particular, the degree to which the dative structure in participants' L1 is similar to the Mandarin dative is likely to influence how easily structural knowledge is shared from L1 to L2 [33]. However, the small sample size for each background of L2 learners precluded a systematic examination of this effect. Despite the diverse L1 backgrounds of L2 learners, which likely varied in their structural similarity to Mandarin, our findings revealed a robust structural priming effect. These findings suggest that the syntactic structure priming effect could result from shared mechanisms during L2 learning across learners with different L2 backgrounds, though more systematic investigation is needed. In particular, this type of investigation will require a sampling of languages with varied degrees of similarity to an L2 and a comparison of structural priming effects across this spectrum of similarity.

Our findings about the occurrence of structural priming in L2 Mandarin reading have implications for second-language pedagogy. While explicit syntactic instruction is the dominant teaching modality in second language instruction, structural priming can be a useful instructional tool for L2 learning [23]. L2 learners can receive and learn structural information implicitly while reading or hearing language, and this can be more beneficial than explicit instruction alone. Shin and Christianson [23] showed that there is an added benefit for L2 learners from implicit learning (via exposure to structural forms) provided by structural priming, in addition to more traditional explicit teaching methods. The finding that structural priming occurs for L2 learners of Mandarin suggests that implicit exposure to structural forms may be a useful instructional tool for this language group and presents an avenue for future research.

One limitation of this study with respect to implicit learning is that priming was assessed immediately following exposure to the prime rather than after a delay of one or more trials. At present, we cannot rule out that participants in this experiment were relying on strategies that are based on explicit memory to produce picture descriptions that tended to match the structure of the primes rather than memory processes that were based on implicit syntactic knowledge. For instance, participants could retrieve from memory the placement of gei in the prime sentence and use that information to guide their picture descriptions. For instance, if gei appeared with the verb in the prime, then participants would be more likely to produce a DO description because of the relative accessibility of the verb + gei DO construction. Note that, even if participants made use of this knowledge, this suggests they had sufficient memory of syntactic relations to produce grammatical prime structures, even if this information was not stored implicitly. To make stronger claims about whether L2 learners of Mandarin may be making use of implicit memory, a future study with a lagged priming condition will be necessary.

## 5. Conclusions

Structural priming has been found in reading, listening, and language production across a wide variety of languages [1,6,9,11–13], but this study is the first to demonstrate structural priming among L2 Mandarin learners. We also found that, as in L1 English and Mandarin [4–7], there is no evidence that shared semantic features increase the structural priming effect. This suggests that L2 Mandarin learners, like L1 English and L1 Mandarin learners, can develop syntactic representations that are abstract and independent of semantic representations, even though the target language—Mandarin—lacks rich marking of syntactic information. This adds to the body of evidence that suggests that abstract structural priming is a widely observable, perhaps universal phenomenon.

## Appendix A

**Table A1.** Experimental stimuli.

| Trial | DO-AN | DO-IN [1] | PO-AN | PO-IN | Baseline | PO Target | Target Animacy |
|---|---|---|---|---|---|---|---|
| 1 | 商人借给朋友一些钱。 The merchant lent the friend some money. | 商人借给工厂一些钱。 The merchant lent the factory some money. | 商人借了一些钱给朋友。 The merchant lent some money to the friend. | 商人借了一些钱给工厂。 The merchant lent some money to the factory. | 妈妈笑了。 Mother smiled. | 爷爷借了一把伞给男孩。 Grandpa lent an umbrella to the boy. | AN |
| 2 | 学生还给图书管理员两本书。 The student returned the librarian two books. | 学生还给图书馆两本书。 The student returned the library two books. | 学生还了两本书给图书管理员。 The student returned two books to the librarian. | 学生还了两本书给图书馆。 The student returned two books to the library. | 小狗跑了。 The puppy ran away. | 女孩还了一本书给老师。 The girl returned a book to the teacher. | AN |
| 3 | 妈妈抱给奶奶一个西瓜 Mother gave grandma a watermelon. | 妈妈抱给商店一个西瓜。 Mother gave the store a watermelon. | 妈妈抱了一个西瓜给奶奶。 Mother gave a watermelon to grandma. | 妈妈抱了一个西瓜给商店。 Mother gave a watermelon to the store. | 老师来了。 The teacher came. | 爸爸抱了一个娃娃给女孩。 Father gave a Barbie to the girl. | AN |
| 4 | 经理买给员工一些电脑。 The manager bought the employees some computers. | 经理买给公司一些电脑。 The manager bought the company some computers. | 经理买了一些电脑给员工。 The manager bought some computers to the employees. | 经理买了一些电脑给公司。 The manager bought some computers to the company. | 爷爷累了。 Grandpa was tired. | 妈妈买了一个手机给爷爷。 Mother bought a cell phone to grandpa. | AN |
| 5 | 农民卖给商人一些粮食。 The farmer sold the merchant some food. | 农民卖给工厂一些粮食。 The farmer sold the factory some food. | 农民卖了一些粮食给商人。 The farmer sold some food to the merchant. | 农民卖了一些粮食给工厂。 The farmer sold some food to the factory. | 宝宝饿了。 The baby was hungry. | 男孩卖了一把吉他给歌手。 The boy sold a guitar to the singer. | AN |
| 6 | 明星送给助理一张唱片。 The star gave the assistant a record. | 明星送给公司一张唱片。 The star gave the company a record. | 明星送了一张唱片给助理。 The star gave a record to the assistant. | 明星送了一张唱片给公司。 The star gave a record to the assistant. | 演员走了。 The actor left. | 女孩送了一些花给画家。 The girl gave some followers to the painter. | AN |
| 7 | 男孩交给老师一张请假条。 The boy handed the teacher a written request for leave. | 男孩交给办公室一张请假条。 The boy handed the office a written request for leave. | 男孩交了一张请假条给老师。 The boy handed a written request for leave to the teacher. | 男孩交了一张请假条给办公室。 The boy handed a written request for leave to the office. | 妹妹哭了。 Sister cried. | 司机交了一个钱包给警察。 The driver handed a wallet to the policeman. | AN |

**Table A1.** *Cont.*

| Trial | DO-AN | DO-IN [1] | PO-AN | PO-IN | Baseline | PO Target | Target Animacy |
|---|---|---|---|---|---|---|---|
| 8 | 老师带给学生一些玩具。<br>The teacher brought the students some toys. | 老师带给幼儿园一些玩具。<br>The teacher brought the kindergarten some toys. | 老师带了一些玩具给学生。<br>The teacher brought some toys to the students. | 老师带了一些玩具给幼儿园。<br>The teacher brought some toys to the kindergarten. | 宝宝笑了。<br>The baby smiled. | 妈妈带了一个足球给男孩。<br>Mother brought a football to the boy. | AN |
| 9 | 商人捐给穷人一些钱。<br>The merchant donated the poor some money. | 商人捐给图书馆一些钱。<br>The merchant donated the library some money. | 商人捐了一些钱给穷人。<br>The merchant donated some money to the poor. | 商人捐了一些钱给图书馆。<br>The merchant donated some money to the library. | 小明病了。<br>Xiaoming was sick. | 老师捐了一些衣服给男孩。<br>The teacher donated some clothes to the boy. | AN |
| 10 | 歌手留给助理一把吉他。<br>The singer left the assistant a guitar. | 歌手留给乐队一把吉他。<br>The singer left the band a guitar. | 歌手留了一把吉他给助理。<br>The singer left a guitar to the assistant. | 歌手留了一把吉他给乐队。<br>The singer left a guitar to the band. | 妹妹摔倒了。<br>Sister fell. | 爸爸留了一些钱给奶奶。<br>Father left some money to Grandma. | AN |
| 11 | 老师抱给男孩一个篮球。<br>The teacher handed the boy a basketball. | 老师抱给球队一个篮球。<br>The teacher handed the team a basketball. | 老师抱了一个篮球给男孩。<br>The teacher handed a basketball to the boy. | 老师抱了一个篮球给球队。<br>The teacher handed a basketball to the team. | 奶奶上当了。<br>Grandma was fooled. | 妈妈抱了一只小狗给女孩。<br>Mother handed a puppy to the girl. | AN |
| 12 | 爸爸还给叔叔一个照相机。<br>Father returned uncle a camera. | 爸爸还给照相馆一个照相机。<br>Father returned the photo studio a camera. | 爸爸还了一个照相机给叔叔。<br>Father returned a camera to uncle. | 爸爸还了一个照相机给照相馆。<br>Father returned a camera to the photo studio. | 小明得奖了。<br>Xiaoming won the prize. | 男孩还了一个笔记本给女孩。<br>The boy returned a notebook to the girl. | AN |
| 13 | 爷爷借给邻居一张桌子。<br>Grandpa lent the neighbor a table. | 爷爷借给商店一张桌子。<br>Grandpa lent the store a table. | 爷爷借了一张桌子给邻居。<br>Grandpa lent a table to the neighbor. | 爷爷借了一张桌子给商店。<br>Grandpa lent a table to the store. | 奶奶去世了。<br>Grandpa passed away. | 歌手借了一辆汽车给画家。<br>The singer lent a car to the painter. | AN |
| 14 | 经理买给老板一幅画。<br>The manager bought the boss a painting. | 经理买给公司一幅画。<br>The manager bought the company a painting. | 经理买了一幅画给老板。<br>The manager bought a painting to the boss. | 经理买了一幅画给公司。<br>The manager bought a painting to the company. | 爷爷退休了。<br>Grandpa retired. | 爸爸买了一块手表给妈妈。<br>Father bought a watch to mother. | AN |
| 15 | 农民卖给学生一些苹果。<br>The farmer sold the students some apples. | 农民卖给超市一些苹果。<br>The farmer sold the grocery store some apples. | 农民卖了一些苹果给学生。<br>The farmer sold some apples to the students. | 农民卖了一些苹果给超市。<br>The farmer sold some apples to the grocery store. | 爸爸来了。<br>Father came. | 农民卖了一个西瓜给医生。<br>The farmer sold a watermelon to the doctor. | AN |
| 16 | 大学生送给老人一些食物。<br>The college student sent the old some food. | 大学生送给养老院一些食物。<br>The college student sent the nursing home some food. | 大学生送了一些食物给老人。<br>The college student sent some food to the old. | 大学生送了一些食物给养老院。<br>The college student sent some food to the nursing home. | 老师生气了。<br>The teacher was mad. | 女孩送了一顶帽子给男孩。<br>The girl sent a hat to the boy. | AN |
| 17 | 学生交给老师一些学费。<br>The student gave the teacher the tuition fees. | 学生交给学校一些学费。<br>The student gave the university the tuition fees. | 学生交了一些学费给老师。<br>The student gave the tuition fees to the teacher. | 学生交了一些学费给学校。<br>The student gave the tuition fees to the university. | 工人失业了。<br>The worker lost his job. | 男孩交了一张卡片给老师。<br>The boy gave a card to the teacher. | AN |
| 18 | 明星带给老师一些礼物。<br>The star brought the teacher some gifts. | 明星带给学校一些礼物。<br>The star brought the school some gifts. | 明星带了一些礼物给老师。<br>The star brought some gifts to the teacher. | 明星带了一些礼物给学校。<br>The star brought some gifts to the school. | 学生下课了。<br>The students were dismissed. | 奶奶带了一些糖果给女孩。<br>Grandma gave some candies to the girl. | AN |
| 19 | 老师捐给小朋友一些书。<br>The teacher donated the kids some books. | 老师捐给图书馆一些书。<br>The teacher donated the library some books. | 老师捐了一些书给小朋友。<br>The teacher donated some books to the kids. | 老师捐了一些书给图书馆。<br>The teacher donated some books to the library. | 小狗跑了。<br>The puppy ran away. | 医生捐了一些钱给病人。<br>The doctor donated some money to the patient. | AN |
| 20 | 作家留给妻子一封信。<br>The writer left the wife a letter. | 作家留给报社一封信。<br>The writer left the newspaper office a letter. | 作家留了一封信给妻子。<br>The writer left a letter to the wife. | 作家留了一封信给报社。<br>The writer left a letter to the newspaper office. | 妹妹困了。<br>Sister was sleepy. | 奶奶留了一个蛋糕给男孩。<br>Grandpa left a cake to the boy. | AN |

[1] Some inanimate recipient words also have a collective interpretation (for example, company can be interpreted as the individuals making up the collective entity). However, Huang et al. [6] found the same pattern of results even examining only the stimuli where the inanimate recipient entities did not have a collective interpretation).

# References

1. Bock, K. Syntactic persistence in language production. *Cogn. Psychol.* **1986**, *18*, 355–387. [CrossRef]
2. Levelt, W.J.M.; Kelter, S. Surface form and memory in question answering. *Cogn. Psychol.* **1982**, *14*, 78–106. [CrossRef]
3. Branigan, H.P.; Pickering, M.J. An experimental approach to linguistic representation. *Behav. Brain Sci.* **2017**, *40*, e282. [CrossRef] [PubMed]
4. Bock, K.; Loebell, H.; Morey, R. From Conceptual Roles to Structural Relations: Bridging the Syntactic Cleft. *Psychol. Rev.* **1992**, *99*, 150–171. [CrossRef]
5. Chen, X.; Hartsuiker, R.J.; Muylle, M.; Slim, M.S.; Zhang, C. The effect of animacy on structural Priming: A replication of Bock, Loebell and Morey (1992). *J. Mem. Lang.* **2022**, *127*, 104354. [CrossRef]
6. Huang, J.; Pickering, M.J.; Yang, J.; Wang, S.; Branigan, H.P. The independence of syntactic processing in Mandarin: Evidence from structural priming. *J. Mem. Lang.* **2016**, *91*, 81–98. [CrossRef]
7. Chen, X.; Branigan, H.P.; Wang, S.; Huang, J.; Pickering, M.J. Syntactic representation is independent of semantics in Mandarin: Evi-dence from syntactic priming. *Lang. Cogn. Neurosci.* **2020**, *35*, 211–220. [CrossRef]
8. Pickering, M.J.; Ferreira, V.S. Structural Priming: A Critical Review. *Psychol. Bull.* **2008**, *134*, 427–459. [CrossRef]
9. Mahowald, K.; James, A.; Futrell, R.; Gibson, E. A meta-analysis of syntactic priming in language production. *J. Mem. Lang.* **2016**, *91*, 5–27. [CrossRef]
10. Tooley, K.M. Structural priming during comprehension: A pattern from many pieces. *Psychon. Bull. Rev.* **2023**, *30*, 882–896. [CrossRef]
11. Hartsuiker, R.J.; Kolk, H.H.J. Syntactic Persistence in Dutch. *Lang. Speech* **1998**, *41*, 143–184. [CrossRef] [PubMed]

12. Kantola, L.; van Gompel, R.P.G. Between- and within-language priming is the same: Evidence for shared bilingual syntactic rep-resentations. *Mem. Cogn.* **2011**, *39*, 276–290. [CrossRef] [PubMed]

13. Vasilyeva, M.; Waterfall, H. Beyond syntactic priming: Evidence for activation of alternative syntactic structures. *J. Child. Lang.* **2012**, *39*, 258–283. [CrossRef] [PubMed]

14. Savage, C.; Lieven, E.; Theakston, A.; Tomasello, M. Testing the abstractness of children's linguistic representations: Lexical and structural priming of syntactic constructions in young children. *Dev. Sci.* **2003**, *6*, 557–567. [CrossRef] [PubMed]

15. Messenger, K.; Branigan, H.P.; McLean, J.F.; Sorace, A. Is young children's passive syntax semantically constrained? Evidence from syntactic priming. *J. Mem. Lang.* **2012**, *66*, 568–587. [CrossRef]

16. Arai, M.; Mazuka, R. The development of Japanese passive syntax as indexed by structural priming in comprehension. *Q. J. Exp. Psychol.* **2013**, *67*, 60–78. [CrossRef]

17. DeKeyser, R.M. What Makes Learning Second-Language Grammar Difficult? A Review of Issues. *Lang. Learn.* **2005**, *55* (Suppl. S1), 1–25. [CrossRef]

18. Ullman, M.T. The neural basis of lexicon and grammar in first and second language: The declarative/procedural model. *Biling. Lang. Cogn.* **2001**, *4*, 105–122. [CrossRef]

19. Silva, R.; Clahsen, H. Morphologically complex words in L1 and L2 processing: Evidence from masked priming experi-ments in English*. *Biling. Lang. Cogn.* **2007**, *11*, 245–260. [CrossRef]

20. Cai, Z.G.; Pickering, M.J.; Yan, H.; Branigan, H.P. Lexical and syntactic representations in closely related languages: Evidence from Cantonese–Mandarin bilinguals. *J. Mem. Lang.* **2011**, *65*, 431–445. [CrossRef]

21. Hartsuiker, R.J.; Pickering, M.J.; Veltkamp, E. Is Syntax. Separate or Shared Between Languages? *Psychol. Sci.* **2004**, *15*, 409–414. [CrossRef]

22. McDonough, K. INTERACTION AND SYNTACTIC PRIMING: English L2 Speakers' Production of Dative Constructions. *Stud. Second Lang. Acq.* **2006**, *28*, 179–207. [CrossRef]

23. Shin, J.; Christianson, K. Structural Priming and Second Language Learning. *Lang. Learn.* **2012**, *62*, 931–964. [CrossRef]

24. Frost, R. Towards a universal model of reading. *Behav. Brain Sci.* **2012**, *35*, 263–279. [CrossRef]

25. Share, D.L. On the Anglocentricities of Current Reading Research and Practice: The Perils of Overreliance on an "Outlier" Or-thography. *Psychol. Bull.* **2008**, *134*, 584–615. [CrossRef]

26. Lacina, R.; Chromý, J. No agreement attraction facilitation observed in Czech: Not even syncretism helps. *Proc. Annu. Meet. Cogn. Sci. Soc.* **2022**, *44*, 2423–2430.

27. Slioussar, N. Forms and features: The role of syncretism in number agreement attraction. *J. Mem. Lang.* **2018**, *101*, 51–63. [CrossRef]

28. Li, P. The temporal structure of spoken sentence comprehension in Chinese. *Percept. Psychophys* **1996**, *58*, 571–586. [CrossRef]

29. Li, P.; Bates, E.; MacWhinney, B. Processing a language without inflections: A reaction time study of sentence interpretation in Chinese. *J. Mem. Lang.* **1993**, *32*, 169–192. [CrossRef]

30. Liu, Y.; Li, P.; Shu, H.; Zhang, Q.; Chen, L. Structure and meaning in Chinese: An ERP study of idioms. *J. Neurolinguistics* **2010**, *23*, 615–630. [CrossRef]

31. Zhang, Y.; Yu, J.; Boland, J.E. Semantics Does Not Need a Processing License From Syntax in Reading Chinese. *J. Exp. Psychol. Learn. Mem. Cogn.* **2010**, *36*, 765–781. [CrossRef]

32. Zhu, Y.; Xu, M.; Lu, J.; Hu, J.; Kwok, V.P.Y.; Zhou, Y.; Yuan, D.; Wu, B.; Zhang, J.; Wu, J.; et al. Distinct spatiotemporal patterns of syntactic and semantic processing in human inferior frontal gyrus. *Nat. Hum. Behav.* **2022**, *6*, 1104–1111. [CrossRef]

33. Hartsuiker, R.J.; Bernolet, S. The development of shared syntax in second language learning*. *Biling. Lang. Cogn.* **2017**, *20*, 219–234. [CrossRef]

34. China Education Center HSK Exams Page. Available online: https://www.chinaeducenter.com/en/exams.php (accessed on 12 December 2023).

35. Yarkoni, T. The generalizability crisis. *Behav. Brain Sci.* **2020**, *45*, e1. [CrossRef]

36. Kaschak, M.P.; Kutta, T.J.; Schatschneider, C. Long-term cumulative structural priming persists for (at least) one week. *Mem. Cogn.* **2011**, *39*, 381–388. [CrossRef]

37. Baayen, R.H.; Davidson, D.J.; Bates, D.M. Mixed-effects modeling with crossed random effects for subjects and items. *J. Mem. Lang.* **2008**, *59*, 390–412. [CrossRef]

38. Bates, D.; Mächler, M.; Bolker, B.; Walker, S. Fitting Linear Mixed-Effects Models using lme4. *arXiv* **2014**, arXiv:1406.5823.

39. Barr, D.J.; Levy, R.; Scheepers, C.; Tily, H.J. Random effects structure for confirmatory hypothesis testing: Keep it maximal. *J. Mem. Lang.* **2013**, *68*, 255–278. [CrossRef]

40. Reitter, D.; Keller, F.; Moore, J.D. A Computational Cognitive Model of Syntactic Priming. *Cogn. Sci.* **2011**, *35*, 587–637. [CrossRef]

41. Chang, F.; Dell, G.S.; Bock, K. Becoming Syntactic. *Psychol. Rev.* **2006**, *113*, 234–272. [CrossRef]

42. Tooley, K.M.; Traxler, M.J. Implicit learning of structure occurs in parallel with lexically-mediated syntactic priming effects in sentence comprehension. *J. Mem. Lang.* **2018**, *98*, 59–76. [CrossRef]

43. Pickering, M.J.; Branigan, H.P. The Representation of Verbs: Evidence from Syntactic Priming in Language Production. *J. Mem. Lang.* **1998**, *39*, 633–651. [CrossRef]

44. Bock, K.; Griffin, Z.M. The Persistence of Structural Priming: Transient Activation or Implicit Learning? *J. Exp. Psychol. Gen.* **2000**, *129*, 177–192. [CrossRef]

45. Wells, J.B.; Christiansen, M.H.; Race, D.S.; Acheson, D.J.; MacDonald, M.C. Experience and sentence processing: Statistical learning and relative clause comprehension. *Cogn. Psychol.* **2009**, *58*, 250–271. [CrossRef]