Syntactic Structure and Verb Repetition Influence Syntactic Priming Effects in Spoken Chinese Sentence Production

Authors: Yu Zhou, Zhang Qingfang, Zhang Qingfang

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Abstract

The study employed a priming paradigm and picture description task, using two measures—syntactic choice ratio and sentence production latency—to examine the influence of prime sentence syntactic structure, verb identity, and delay on syntactic priming effects in Chinese spoken sentence production. The results demonstrated that, for choice ratio, the priming effect produced by syntactic structure remained stable across varying delays, whereas the increment in priming effect attributable to verb identity between prime and target sentences (the lexical boost effect) decayed rapidly, providing the first evidence for distinct syntactic selection and planning stages in sentence production processes. In terms of sentence production latency, only syntactic structure matching between prime and target sentences was found to shorten production latency, likely due to elevated activation levels of the prime sentence' s syntactic structure, which facilitated faster processing in both syntactic planning and selection stages during target sentence generation. Processing at the selection stage affects syntactic choice ratio, while both selection and planning stages jointly influence sentence production latency, with the experimental findings supporting the two-stage competition theory.

Full Text

Syntactic Structure and Verb Overlap Influence the Syntactic Priming Effect in Mandarin Spoken Sentence Production

YU Zhou, ZHANG Qingfang
Department of Psychology, Renmin University of China, Beijing 100872

Abstract

This study employed a priming paradigm and picture description task to investigate how prime sentence structure, verb overlap, and temporal delay influence syntactic priming in Mandarin spoken sentence production, using two measures: syntactic choice ratio and sentence production latency. The results revealed that, in terms of choice ratio, the priming effect induced by syntactic structure remained stable across delays, while the boost in priming caused by verb overlap between prime and target sentences (the lexical boost effect) decayed rapidly. This pattern provides the first evidence for distinct syntactic selection and planning stages in sentence production. In terms of production latency, only syntactic structure overlap between prime and target sentences shortened sentence production latency, likely because the heightened activation of the prime' s syntactic structure enabled faster syntactic planning and selection during target sentence generation. While the selection stage influences syntactic choice ratios, both selection and planning stages jointly affect production latency, supporting the two-stage competition theory.

Keywords: sentence production; two-stage competition theory; syntactic priming effect; lexical boost effect

Speech production refers to the psychological process through which individuals use language to express thoughts, involving the conversion of conceptual codes into linguistic codes and then into physiological and motor codes—producing sounds (spoken production) or written forms (written production) that represent specific meanings (Yang & Zhang, 2015). Sentence production comprises three stages: first, conceptualization, where speakers clarify the intended message and construct a preverbal information-level representation; second, formulation, where speakers transform preverbal information into linguistic representations, involving grammatical encoding and morphophonological encoding (Bock & Levelt, 1994; Levelt, Roelofs, & Meyer, 1999). Grammatical encoding includes two phases: functional processing and positional processing. During functional processing, speakers identify the most appropriate lexical items to convey information and assign them specific grammatical roles and syntactic functions. During positional processing, speakers fix the order of different constituents in the utterance, establishing hierarchical syntactic structure and final word order. The grammatical encoding process involves extracting semantic and grammatical information to express particular meanings through specific syntactic structures. Within a given syntactic structure, lexical items must be arranged according to syntactic rules to convey complete and correct meaning; when syntactic structure changes, word order changes, and the expressed meaning often changes accordingly. Therefore, the syntactic encoding process in sentence production is crucial, and the present study focuses on the cognitive mechanisms underlying this grammatical encoding process.

In research on grammatical encoding in spoken sentence production, researchers have consistently observed the syntactic priming effect using priming paradigms.

This phenomenon refers to the tendency for individuals to reuse syntactic structures they have recently processed (through reading, listening, or production) when describing a scene (Bock, 1986; Yang & Zhang, 2007). The syntactic priming effect remains stable even after controlling for semantic repetition (Bock, 1989) and prosodic repetition (Bock & Loebell, 1990) between prime and target sentences (Segaert, Menenti, Weber, & Hagoort, 2011). Syntactic priming provides a window into investigating syntactic encoding processes and representations in sentence production, with researchers typically examining how various variables affect syntactic encoding using syntactic structure choice ratios and/or sentence production latencies as dependent measures.

Early studies primarily used syntactic structure choice ratios as their measure. Bock (1986) employed a priming paradigm to investigate syntactic structure representation. Participants first heard a sentence (the prime) and repeated it, then viewed a picture and described its content. By varying the syntactic structure of prime sentences (e.g., active vs. passive, or double object [DO] vs. prepositional object [PO] datives), where either structure could correctly describe the target picture, the study found that participants tended to use the prime' s syntactic structure regardless of whether nouns in the prime and target were semantically related.

Using a written confederate scripting paradigm, researchers manipulating prime sentence structure (PO vs. DO) and verb overlap with the target sentence found that verb overlap significantly increased the rate of structural choice (45% vs. 28%) in Dutch sentence production (Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008). This lexical boost effect—where verb overlap between prime and target sentences further increases the likelihood of choosing the prime's syntactic structure—has been identified as the most important factor influencing syntactic priming magnitude in meta-analyses (Mahowald, James, Futrell, & Gibson, 2016). These findings suggest that both syntactic structure and verb overlap enhance activation levels of combinatorial nodes representing syntactic structures, indicating that verbs play an important role in syntactic structure construction.

1.1 Theoretical Accounts of Syntactic Priming

To explain syntactic priming and lexical boost effects observed in syntactic choice ratios, researchers have proposed Residual Activation Theory (Pickering & Branigan, 1998) and Implicit Learning Theory (Chang, Dell, & Bock, 2006).

Residual Activation Theory assumes that processing a specific syntactic structure temporarily increases the activation level of the combinatorial node representing that structure; if the prime and target sentences share the same verb, the activation level of the combinatorial node increases further. Higher activation levels make the syntactic structure represented by that node more likely to be selected in subsequent sentence production, though activation decays rapidly to baseline levels (Branigan, Pickering, & Cleland, 1999). This theory can explain both syntactic priming and lexical boost effects but predicts that these effects will decay over time. In contrast, Implicit Learning Theory assumes that processing prime sentences leads individuals to learn how to apply that syntactic structure to express information, strengthening the connection between information and structure (Chang et al., 2006) and increasing the likelihood of using that structure in subsequent production. This learning effect can be maintained long-term. This theory holds that the specific lexical items used in syntactic encoding are irrelevant, and verb overlap should not affect the magnitude of syntactic priming (Chang, Dell, Bock, & Griffin, 2000). Using a picture description paradigm, researchers investigating three syntactic structures in Dutch found that syntactic priming remained significant even when three unrelated filler prime-target pairs (six unrelated distractor sentences, lag = 6) intervened between prime and target (Bernolet, Collina, & Hartsuiker, 2016), providing support for Implicit Learning Theory. Overall, these two theories each have their emphases but cannot fully explain all syntactic priming effects in syntactic choice ratios.

Initially, research focused primarily on syntactic structure choice ratios, but researchers have recently begun to emphasize measurement of sentence production latencies (Segaert, Wheeldon, & Hagoort, 2016). Syntactic priming facilitates sentence production fluency and reduces cognitive resource demands (Ferreira & Bock, 2006), which affects sentence planning time as reflected in production latencies. Using a picture description paradigm, Segaert et al. (2011) examined how syntactic repetition (a post-hoc variable based on whether prime and produced target sentences shared syntactic structure), target sentence structure, and verb overlap affected production latencies. They found that both syntactic repetition and verb overlap shortened production latencies, with an interaction between syntactic repetition and target structure: when producing active sentences (a preferred structure, used more frequently in spoken production), syntactic repetition produced greater latency reduction than when producing passive sentences (a non-preferred structure), manifesting as a positive preference effect in latencies. In contrast, syntactic choice ratios showed an inverse preference effect, where priming magnitude was greater when the prime was a non-preferred syntactic structure than when it was a preferred structure (Bernolet & Hartsuiker, 2010; Ferreira & Bock, 2006).

Based on limitations of previous theories and different effects observed in syntactic choice and production latencies (Segaert et al., 2011; Segaert, Weber, Claddermicus, & Hagoort, 2014; Segaert et al., 2016), researchers integrated activation spreading theory and implicit learning theory to propose the Two-stage Competition Model. This model posits that syntactic encoding comprises a syntactic (structure) selection stage and a (content) planning stage. The selection stage' s task is to choose the syntactic structure for expressing information, selecting from among competing syntactic nodes the one whose activation level reaches a selection threshold. The baseline activation level of syntactic nodes positively correlates with sentence usage frequency, making frequency a crucial factor. Priming a syntactic structure immediately increases the activation level of the corresponding node while inhibiting competing nodes. If a frequently used syntactic structure is primed, it increases the activation difference between that node and competing nodes. According to activation spreading theory, specific verbs and nodes representing syntactic structures are interconnected, and verb overlap between prime and target sentences further increases the activation level of the target syntactic structure node. The planning stage' s task is to construct the specific sentence to be produced, inserting specific lexical items into the syntactic structure frame formed during the selection stage (Levelt & Kelter, 1982). Sentence production latency includes both selection and planning stages; selection stage duration depends on the activation level difference between syntactic structure nodes, with larger differences leading to faster selection. During the planning stage, the same verb in prime and target sentences speeds up the process of inserting specific words into the syntactic structure. Additionally, interaction between syntactic structure and specific lexical activation levels makes the target syntactic structure easier to select. Therefore, syntactic structure and verb overlap jointly influence sentence production latencies.

1.2 Research on Mandarin Sentence Production

Currently, few studies have examined syntactic priming in Mandarin sentence production, with existing research focusing primarily on interactions between semantic information and syntactic encoding. For example, Cai et al. (2012) used a confederate scripting paradigm to examine interactions between semantic repetition and syntactic structure in prime and target sentences, using syntactic choice ratio as the measure. They found that syntactic priming effects could exist independently of conceptual repetition of the overall sentence meaning. Huang et al. (2016) used syntactic choice ratio to examine interactions between lexical semantic repetition (using animacy of nouns serving as subject and object) and syntactic structure in Mandarin spoken production, finding syntactic priming effects regardless of lexical semantic repetition. None of these studies examined the influence of verb overlap on syntactic encoding processes.

Mandarin syntactic structure characteristics differ substantially from Indo-European languages, which may affect syntactic priming and lexical boost effects in sentence production. First, word order in Indo-European languages is relatively fixed, with verbs marked by suffixes indicating lexical category and aspect. When presented with a verb and its tense information, people can rapidly construct specific sentence structures based on this information (Kutas & Federmeier, 2011). In contrast, Mandarin word order is relatively flexible, verbs lack suffixes marking category and aspect, and syntactic structure is heavily influenced by semantics (Yang, Perfetti, & Liu, 2010; Shao, 2004). The connection between verbs (and their tense/aspect) and specific syntactic structures is relatively tight in Indo-European languages like English but relatively loose in Mandarin. This may result in different effects of syntactic structure activation, lexical activation, and their interaction on sentence production outcomes. Second, everyday usage frequencies differ across syntactic structures. For the active-passive structure pair, active sentences are used more frequently than passive sentences in both English and Mandarin, but passive sentence usage frequency in English is about ten times that in Mandarin (Xiao, Mcenery, & Qian, 2006). For the DO-PO structure pair, which shows relatively balanced usage in English, Mandarin shows higher PO usage frequency than DO. Previous research found that in the absence of priming, Mandarin speakers produced DO sentences about 34.26% of the time and PO sentences about 65.74% of the time (Cai, Pickering, Yan, & Branigan, 2011), whereas German speakers produced PO sentences about 40% of the time and DO sentences about 60% of the time, showing higher DO frequency (Melinger & Dobel, 2005; Segaert et al., 2014). In sentence production research, investigators often select two syntactic structures for comparison (e.g., active vs. passive, DO vs. PO). Sentence production is a dynamic process influenced by the presented prime sentence structure and task demands. Therefore, in syntactic priming research, differences in usage probabilities of the two syntactic structures affect sentence production processes, such as inverse preference effects in syntactic choice ratios and positive preference effects in latencies, because different usage frequencies lead to different activation levels of syntactic structure nodes. Different languages show different usage probabilities for syntactic structures, and the frequency differences between specific structure pairs (e.g., active vs. passive, DO vs. PO) vary across languages, which may cause differences in syntactic priming magnitude.

In summary, the present study investigated the cognitive mechanism of syntactic priming in Mandarin spoken sentence production by manipulating prime sentence structure, verb overlap, and temporal delay, using both syntactic choice ratio and sentence production latency as dependent measures. The study comprised two experiments: Experiment 1 examined the effects of syntactic structure and verb overlap on syntactic priming; Experiment 2 added the delay variable to investigate how syntactic structure, verb overlap, delay duration, and their interactions affect the persistence of syntactic priming effects. According to Implicit Learning Theory, the prime sentence' s syntactic structure strengthens the connection between information and structure, so we predicted that syntactic priming effects would not decay over time and that verb overlap would not enhance syntactic priming (i.e., no lexical boost effect). According to Residual Activation Theory, both syntactic structure and verb overlap enhance activation levels of corresponding nodes, so we predicted that both syntactic priming and lexical boost effects would decay over time. According to the Two-stage Competition Model, which posits that syntactic encoding involves syntactic selection and content planning stages and that selection occurs when activation reaches a "threshold," we predicted syntactic priming effects in both syntactic choice ratios and latencies, with syntactic repetition and verb overlap shortening sentence production latencies. While previous research primarily used syntactic choice ratio as the sole measure, our study simultaneously examined how these variables and their interactions affect both syntactic choice ratios and sentence production latencies.

Experiment 1

2.1 Participants

Twenty-five undergraduate and graduate students (ages 19–26 years, 12 male) with an average education of 17.1 years participated. All had normal or corrected-to-normal vision and spoke standard Northern Mandarin.

2.2 Materials

Experimental materials comprised critical and filler items, each including prime sentences, prime pictures, and target pictures. For critical materials, we selected 20 verbs to construct 80 prime sentence sets, each including four types (a, b, c, d) as shown in Table 1 , accompanied by 80 corresponding critical target pictures. Each critical target picture consisted of three small pictures that could be named as nouns, with the subject positioned on the left and framed, and the verb appearing below the target picture. Of the two objects, one was animate and one inanimate; animate objects appeared in the middle for half of the pictures and inanimate objects for the other half. To control for word frequency and description difficulty, each critical target picture also served once as a prime picture (without a verb below). Prime sentences and prime pictures were congruent in half of the trials and incongruent in the other half, with no noun overlap between prime sentences and target pictures. To assess syntactic preferences in the absence of priming, we included a baseline condition with 16 intransitive sentences as baseline primes (see example e in Table 1) and baseline prime pictures containing only a single small picture.

Filler materials consisted of filler prime sentences (active sentences with two nouns) and filler target pictures (two small pictures, with the subject in the left frame and the object on the right). Five pseudo-random sequences were constructed such that each critical target picture appeared only once per sequence with one priming condition, with identical baseline priming materials across all sequences. Zero to two filler trials were inserted between critical trials, with identical filler materials across the five sequences. Each participant was randomly assigned to one sequence, producing 16 sentences under each of the five priming conditions, for a total of 80 critical trials and 80 filler trials.

2.3 Design

The experiment used a 2 × 2 within-subjects design. Independent variables included prime syntactic structure type (abbreviated as "prime type," with DO and PO levels) and verb overlap (same vs. different). Dependent variables were syntactic choice ratio and sentence production latency.

Table 1 Example of critical experimental materials
a: PO-same: *The judge sent the jacket to the tailor*
b: DO-same: *The judge sent the tailor the jacket*
c: PO-different: *The judge took the jacket to the tailor*

d: DO-different: *The judge took the tailor the jacket*
e: Baseline: *The grapes ripened*

2.4 Procedure

The experiment included a learning phase, practice phase, and formal experiment. During the learning phase, participants studied each small picture and its corresponding name below, pressing a key to advance after memorizing each item. Participants controlled repetition frequency to ensure they memorized all picture names. The practice phase preceded the formal experiment and used different materials but identical procedures; practice continued until participants reported familiarity with the procedure.

During the formal experiment, participants first read the prime sentence aloud from the center of the screen. A prime picture then appeared, and participants judged whether it matched the prime sentence. Next, a target picture appeared, and participants described it using the verb provided below (experimental flow shown in Figure 1 [Figure 1: see original paper]). The duration from target picture onset to speech onset was recorded as sentence production latency.

Judge sent jacket to tailor
3000 ms → 500–1000 ms (variable duration, disappeared after response) → 500–1000 ms → Speech onset (disappeared after participant spoke, maximum 5000 ms) → 3500–4000 ms

Figure 1 Stimulus presentation sequence and timing for each trial

2.5 Instruments

The program was written in E-Prime 2.0, whose soundIN control recorded audio while simultaneously measuring the time from picture onset to speech onset. Two microphones were used: a PET-SRBOX response box with associated microphone for response time recording, and a Yamaha Steinberg CI1 sound card with Shure SM58S microphone for audio recording. All stimulus presentation, timing, and response time collection were computer-controlled.

2.6 Results

2.6.1 Coding For syntactic choice ratio analysis, we excluded 96 trials (4.8%) with no recorded sentence, incorrect prime judgments, incorrect picture descriptions, or incorrect verb usage. Produced sentences were coded as PO (1,156 sentences) if they followed the pattern "subject + verb + noun + preposition (给) + noun," and as DO (614 sentences) if they followed "subject + verb + two consecutive nouns." All other responses (110 sentences, 5.85% of total) were coded as "other" and excluded from subsequent analyses. For sentence production latency analysis, we additionally excluded 120 trials (6%) with unrecorded latencies, latencies below 400 ms, or latencies beyond ±2 standard deviations.

2.6.2 Syntactic Choice Ratio Analysis Figure 2 [Figure 2: see original paper] presents the proportion of each response type under each priming condition. In the baseline condition, participants produced PO sentences more frequently (74%) than DO sentences (26%) (^{2} = 82.76, $p < 0.001$), indicating a preference for PO structures in this experiment.

Figure 2 Proportion of different syntactic structures produced under different priming conditions

Considering the characteristics of within-subjects designs (Hardy, Messenger, & Maylor, 2017) and the advantage of low Type I error rates (Barr, Levy, Scheepers, & Tily, 2013), we employed linear mixed-effects models (LMEM) that account for random effects from both participants and items (Jaeger, 2008). Specifically, we used maximal random effects models (Barr et al., 2013), incorporating random intercepts and random slopes for fixed factors for both participants and items, assuming that baseline levels and effects of fixed factors varied across participants and items.

Given our within-subjects, between-items design, we included participants' random effects (random intercepts and slopes) and items' random intercepts as random factors, with prime type and verb overlap and their interaction as fixed factors. The dependent variable was syntactic choice (DO = 1; PO = 0), a categorical variable analyzed using the glmer() function from the lme4 package (Bates, Mächler, Bolker, & Walker, 2014) in R. Following Barr et al.' s (2013) "best path," we simplified random effects stepwise until the model converged. The optimal model included all fixed factors and random intercepts for items and participants for the interaction between prime type and verb overlap.

Fixed effect coefficients for the optimal model are shown in Table 2 . The main effect of prime type was significant: participants produced 16% DO sentences following PO primes and 58% DO sentences following DO primes. Using Hardy et al.' s (2017) method for calculating syntactic priming magnitude (DO rate after DO primes minus DO rate after PO primes), the overall syntactic priming effect was 42%. The priming magnitude for DO primes relative to baseline (32%) was greater than for PO primes (10%), showing an inverse preference effect. The main effect of verb overlap was significant: 41% DO sentences were produced when verbs were identical versus 33% when different. The interaction between prime type and verb overlap was significant: syntactic priming magnitude was 59% when verbs were identical but only 24% when different.

Table 2 Fixed effects from LMEM for Experiment 1 with syntactic choice ratio as dependent variable

Predictor		SE	Wald Z	p
Intercept	-1.45	0.21	-6.83	<0.001
Prime Type	2.13	0.28	7.53	<0.001
Verb Overlap	0.41	0.11	3.77	<0.001

Predictor		SE	Wald Z	p
Verb Overlap × Prime Type	1.45	0.22	6.68	<0.001

2.6.3 Sentence Production Latency Analysis For latency analysis, we added a post-hoc variable: whether prime and target sentence syntactic structures were repeated (“syntactic repetition”). A significant effect would indicate that the relationship between prime type and production type predicted production latency. Since production latency is a continuous variable, we analyzed data using the lmer() function from the lme4 package in R. To investigate effects of verb overlap and syntactic repetition on production latency, we included them and their interaction as fixed factors in five models: Model 0 was the null model; Model 1 included only syntactic repetition; Model 2 included only verb overlap; Model 3 included both syntactic repetition and verb overlap; Model 4 included syntactic repetition, verb overlap, and their interaction. All models converged. Based on parsimony and lower AIC values, Model 1 was determined optimal (likelihood ratio test: $^2 = 19.68$, $p < 0.001$). The main effect of syntactic repetition was significant ($= 59.83$, SE = 16.18, $t = 3.70$, $p = 0.007$), indicating shorter production latencies when syntactic structure was repeated. Verb overlap did not significantly affect production latency.

2.7 Discussion

Experiment 1 used a picture description paradigm to examine how prime type and verb overlap affect syntactic choice ratios and production latencies in sentence production. Results showed that when prime and target sentences shared syntactic structure, target sentence production latency was significantly shortened. In syntactic choice ratios, robust syntactic priming effects emerged: when prime and target verbs differed, syntactic structure alone significantly increased the likelihood of choosing the prime’ s structure; when verbs were identical, this likelihood increased further, demonstrating a lexical boost effect. Experiment 1 results could not distinguish whether syntactic priming effects stemmed from short-term activation of the prime’ s syntactic representation or from implicit learning of how to express information using the prime’ s structure. Experiment 2 further investigated this issue.

Experiment 2

Experiment 2 added a variable manipulating the temporal interval between prime and target sentences. If syntactic priming magnitude remains unaffected by delay when verbs differ, this would indicate stable syntactic structure effects supporting Implicit Learning Theory. If syntactic priming magnitude decreases with increasing delay, this would indicate rapid decay of syntactic node activation supporting Residual Activation Theory. Conversely, if syntactic priming magnitude does not increase when verbs are identical, this would indicate that syntactic priming is unaffected by lexical node activation, supporting Implicit

Learning Theory. If syntactic priming magnitude decays rapidly with increasing delay when verbs are identical, this would support Residual Activation Theory.

3.1 Participants

Thirty-nine undergraduate and graduate students (ages 17–28 years, 18 male) participated. All had normal or corrected-to-normal vision and spoke standard Mandarin.

3.2 Materials and Design

Critical experimental materials were selected from Experiment 1 (78 sets). Baseline priming materials comprised 6 items from Experiment 1. Filler materials were identical to Experiment 1. All materials were organized into 13 pseudo-random sequences, with each critical target picture paired with only one priming condition per sequence. The experiment used a block design: four prime-target pairs formed a block, with each sequence containing 78 blocks and no filler trials between blocks. Within each block, the first sentence was the prime. Depending on the number of intervening sentences, the critical target picture appeared at different lag positions: Lag 0 (immediately after the prime), Lag 2 (after one filler target and one filler prime), and Lag 6 (at the end of the block).

The experiment used a 2 × 2 × 3 within-subjects design. Independent variables included prime type (DO and PO), verb overlap (same vs. different), and lag (0, 2, and 6). Dependent variables were syntactic choice ratio and sentence production latency. There were 13 priming conditions including baseline.

3.3 Procedure and Instruments

Identical to Experiment 1.

3.4 Results

3.4.1 Coding Data exclusion and coding rules followed Experiment 1. For syntactic choice analysis, 310 trials (10.19%) were excluded. Participants produced 1,554 PO sentences and 1,047 DO sentences, with 131 "other" responses excluded from subsequent analyses. For production latency analysis, an additional 148 trials were excluded.

3.4.2 Syntactic Choice Ratio Analysis Table 3 shows the proportion of DO sentences produced under each priming condition. Following the analytical approach of Experiment 1, we used LMEM to analyze categorical data. Fixed factors included prime type (DO/PO), verb overlap, lag (0/2/6), and all two-way and three-way interactions, with participants' random effects and items' random intercepts as random factors. Results for the optimal model are shown in Table 4 .

Table 3 Proportion of DO sentences produced under different priming conditions in Experiment 2

Lag	DO-Verb Same	DO-Verb Different	PO-Verb Same	PO-Verb Different
0	0.71	0.38	0.12	0.13
2	0.56	0.39	0.15	0.16
6	0.44	0.36	0.16	0.15

Table 4 Fixed effects from LMEM for Experiment 2 with syntactic choice as dependent variable

Predictor		SE	Wald Z	p
Intercept	-1.31	0.21	-6.31	<0.001
Prime Type	1.90	0.28	6.86	<0.001
Verb Overlap	0.43	0.11	3.85	<0.001
Lag	-0.08	0.07	-1.15	0.25
Verb Overlap × Lag	-0.26	0.09	-2.82	0.005
Lag × Prime Type	-0.12	0.09	-1.28	0.20
Prime Type × Verb Overlap	1.42	0.22	6.40	<0.001
Verb Overlap × Lag × Prime Type	-0.28	0.18	-1.58	0.11

The three-way interaction between prime type, lag, and verb overlap was significant. To explore this interaction further, we estimated two separate models for verb-same and verb-different conditions. Each model included lag, prime type, and their interaction as fixed factors. When verbs were identical, the interaction between prime type and lag was significant (= -2.98, $p < 0.001$), indicating that syntactic priming magnitude was affected by lag and that the lexical boost effect decreased significantly with increasing lag. When verbs differed, the interaction between prime type and lag was not significant (= -0.28, $p = 0.47$), indicating that syntactic priming magnitude was unaffected by lag when verbs differed; the priming effect caused by syntactic structure alone did not decrease with increasing delay.

To more intuitively illustrate how the lexical boost effect (verb same vs. different) and syntactic priming effect from structure alone (DO vs. PO primes when verbs differ) change over time, we plotted the proportion of DO sentences produced (vertical axis) against the log-transformed lag-plus-one value (horizontal axis) (Figure 3 [Figure 3: see original paper]). The shaded areas represent confidence intervals for fitted curves, depicting continuous changes in syntactic choice ratios across lags more effectively than traditional mean plots.

Figure 3 Trends of lexical boost effect and syntactic priming effect across lags

3.4.3 Sentence Production Latency Analysis As in Experiment 1, we added the post-hoc variable of syntactic repetition. Random effects included random slopes and intercepts for production type on participants, and random intercepts for items. Fixed factors included syntactic repetition, lag, verb overlap, and all their interactions. The optimal model is shown in Table 5 . Results revealed a three-way interaction between syntactic repetition, lag, and verb overlap, indicating that different combinations of lag and verb overlap affected how syntactic repetition influenced production latency.

Table 5 Fixed effects from mixed-effects model for Experiment 2 with sentence production latency as dependent variable

Predictor		SE	t	p
Intercept	1,247.63	45.21	27.60	<0.001
Syntactic Repetition	-58.32	16.84	-3.46	<0.001
Lag	6.64	5.83	1.14	0.26
Verb Overlap	-15.21	16.84	-0.90	0.37
Syntactic Repetition × Lag	18.32	8.24	2.22	0.03
Syntactic Repetition × Verb Overlap	39.63	23.82	1.66	0.10
Lag × Verb Overlap	-8.21	8.24	-1.00	0.32
Syntactic Repetition × Lag × Verb Overlap	-39.63	16.48	-2.40	0.02

To analyze the three-way interaction, we split the data by syntactic repetition and estimated two separate models, each including lag, verb overlap, and their interaction as fixed factors. When prime and target sentences shared syntactic structure, the main effect of lag was significant ($= 69.26$, $p = 0.01$), indicating longer production latencies with increasing lag when syntactic structure was repeated. The interaction between lag and verb overlap was significant ($=$ -39.63, $p = 0.03$). Further analysis revealed that when verbs were identical, production latency increased with lag ($= -29.63$, $p = 0.02$), but when verbs differed, latency did not change significantly across lags ($p = 0.43$). When syntactic structure differed, no fixed factor main effects or interactions were significant. Figure 4 [Figure 4: see original paper] shows the interaction between lag and verb overlap for syntactic repetition and non-repetition conditions.

Figure 4 Effects of lag, verb overlap, and syntactic repetition on sentence production latency in Experiment 2

4 General Discussion

Using a picture description task with syntactic choice ratio and sentence production latency as measures, we investigated how prime sentence structure, verb overlap, and delay affect syntactic encoding in Mandarin spoken sentence production. Both experiments consistently found robust syntactic priming effects in Mandarin spoken production. In syntactic choice ratios, speakers were significantly more likely to use the prime’ s syntactic structure when describing target pictures, with this tendency being stronger when the prime used a less frequent syntactic structure in daily life, demonstrating an inverse preference effect. When prime and target sentences shared the verb, speakers were even more likely to use the prime’ s syntactic structure, revealing a lexical boost effect in syntactic encoding. A significant interaction emerged between delay and verb overlap: when verbs differed, syntactic choice ratios did not change significantly across delays; however, when verbs were identical, the proportion of target sentences using the primed structure decreased significantly with increasing delay, indicating rapid decay of the lexical boost effect caused by verb overlap, eventually reaching levels comparable to the verb-different condition. In production latencies, syntactic structure overlap between prime and target significantly shortened latencies. When syntactic structure was repeated, verb overlap slowed down production latency as lag increased (a lexical suppression effect), but this did not occur when verbs differed. We report the first evidence of lexical suppression effects in latency across delays. These results demonstrate that priming effects from syntactic structure alone are stable and long-lasting, whereas lexical boost effects from verb overlap are transient and decay rapidly, indicating different roles for global syntactic structure and local content words in syntactic encoding.

Syntactic priming effects arise from two variables: syntactic structure and verb overlap. Our findings show that syntactic priming from structure alone is stable and exhibits inverse preference effects, supporting Implicit Learning Theory. This theory proposes that processing prime sentences activates a specific syntactic structure, and when producing a new sentence that can be expressed with multiple structures, speakers tend to use the primed structure (Chang et al., 2006). Moreover, when the prime uses a less frequent syntactic structure, priming magnitude is greater, showing an inverse preference effect (Chang et al., 2006). Reanalyzing data from Huang et al. (2016) using Hardy et al.’ s (2017) method revealed inverse preference effects even for DO and PO structures with relatively small frequency differences in Mandarin spoken sentence production, consistent with our results. This component of syntactic priming stems from long-term experience with similar syntactic structures.

In contrast, syntactic priming effects from verb overlap were short-lived, supporting Residual Activation Theory. This theory (Pickering & Branigan, 1998) proposes that short-term activation of the prime sentence’s syntactic representation increases the likelihood of using that structure in target sentence production; when prime and target verbs are identical, activation of the combinatorial node representing the prime’ s syntactic structure increases further. Higher activation levels make the represented syntactic structure more easily selected during sentence production. This suggests that activation of specific lexical items disappears quickly but can spread to combinatorial nodes, facilitating syntactic structure construction and lexical insertion during sentence production. Note that Residual Activation Theory also predicts rapid decay of syntactic priming effects from structure alone, a prediction not supported by our findings.

Overall, our study reveals different patterns of influence from syntactic structure and verb overlap on syntactic priming across delays. The Two-stage Competition Model (Segaert et al., 2011; Segaert et al., 2014; Segaert et al., 2016) explains syntactic priming in sentence production through syntactic selection and planning stages. During the selection stage, processing the prime sentence activates the corresponding syntactic structure, providing a structural framework for target sentence production, altering activation of competing syntactic structures, and selecting the same structure as the prime for target sentence construction. This process resembles the functional processing stage in Bock and Levelt' s (1994) model, where speakers construct sentence frames based on the overall situation constituted by presented objects, manifesting behaviorally as changes in syntactic choice ratios relative to baseline. During the specific planning stage of sentence production, speakers insert corresponding content into the constructed syntactic frame, similar to the positional processing stage in Bock and Levelt' s (1994) model. Syntactic priming effects from both syntactic structure and verb overlap provide evidence for syntactic selection and planning stages. Thus, syntactic priming in sentence production results from the joint contribution of long-term syntactic structure experience and short-term lexical activation.

According to the Two-stage Competition Model, activation levels of the two syntactic structure nodes used in experiments relate to their usage frequencies and frequency differences. On one hand, larger frequency differences between two syntactic structures create larger activation level differences between their corresponding nodes. On the other hand, when a less frequently used structure in a pair is primed, it produces larger priming magnitude, manifesting as an inverse preference effect. Previous research shows that in the PO-DO structure pair, Mandarin speakers produce PO sentences about 31.48% more frequently than DO sentences in the absence of priming (Cai et al., 2011), making DO the non-preferred structure in Mandarin, whereas German shows the opposite pattern with PO being non-preferred (Segaert et al., 2014). Our study found inverse preference effects for DO sentences in Mandarin, while Segaert et al. (2014) found inverse preference effects for PO sentences in German. These combined findings support the Two-stage Competition Model' s assumptions about syntactic structure node activation.

Previous research on Mandarin syntactic priming primarily used syntactic choice ratio as the sole measure. Our study is the first to adopt latency measures, finding that neither syntactic repetition alone nor verb overlap alone produced latency differences—only the combination of both factors significantly affected latencies. In contrast, for syntactic choice ratios, either factor alone produced significant effects, with larger changes when both operated together. Findings from Indo-European languages are consistent with Mandarin results. Segaert et al. (2016) used a picture description paradigm requiring Dutch speakers to describe pictures, manipulating prime syntactic structure (active vs. passive), overall proportion of passive sentences produced during the experiment, and verb overlap. They found that only when producing passive sentences did the combination of syntactic repetition and verb overlap shorten production latency. Additionally, we found inverse preference effects in choice ratios. Within the two-stage theoretical framework, latency and syntactic choice ratio reflect different aspects of syntactic encoding. Latency reflects the combined duration of syntactic selection and planning stages; frequently used syntactic structures are faster to plan and fill with content, showing positive preference effects (Segaert et al., 2016). Choice ratio reflects the outcome of overall structure selection (selection stage); when a less frequently used structure serves as the prime, it produces larger priming effects, showing inverse preference effects (Bernolet & Hartsuiker, 2010). Our study found inverse preference effects for syntactic structure but no positive preference effects in latency. Previous positive preference effects have been found for active-passive structures; our study used DO and PO structures, and Segaert et al. (2014) also found no latency differences for DO and PO structures in German. We propose that latency differences relate closely to frequency differences between compared structures: large frequency differences produce latency differences, while similar frequencies produce minimal latency differences. Furthermore, based on our results, we suggest that choice ratio is primarily influenced by the selection stage, whereas latency differences are influenced by both selection and planning stages. Including more processing stages makes differences between conditions more difficult to detect.

This study is the first to comprehensively use both syntactic choice ratio and latency measures to investigate how syntactic structure, verb overlap, and delay jointly influence the mechanism of syntactic priming in Mandarin sentence production. We found that priming from syntactic structure alone is stable and does not decay quickly, whereas priming from verb overlap is transient and decays rapidly. These findings indicate that sentence production includes both syntactic selection and sentence planning stages: the selection stage influences syntactic choice ratios, while both selection and planning stages jointly affect production latency, supporting the Two-stage Competition Model.

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Note: Figure translations are in progress. See original paper for figures.