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The Role of Phonological Priming in Backward Priming Effects of Chinese Four-Character Words

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***Abstract*—The backward priming effect is found in the masked lexical decision tasks deploying Chinese four-character words as targets and the backward-presented words as primes. To explore whether phonology plays a role in this backward priming effect, we conducted two experiments using the masked priming lexical decision tasks. Thirty-two and sixty-three native Chinese speakers participated in the two experiments. Experiment 1 was designed to investigate the phonological priming in backward conditions and to ensure the exclusion of phonology in Experiment 1, the primes were presented forward in Experiment 2. The results showed that no significant phonological priming effect was found whether the primes were backward-presented or forward-presented. Therefore, it can be concluded that phonological priming did not contribute to the backward priming effect in lexical decision tasks.**

***Index Terms*—Backward priming effects, Chinese four-character words, phonological priming**

I. INTRODUCTION

Reading is an important cognitive activity for humans, and visual word recognition is the foundation of reading. To successfully identify a word, both the letter identity and the letter position must be encoded by the readers. The letter identity processing refers to identifying the features that make up the letter, and encoding the position means processing the relative order of the letters in a word.

As shown by our ability to read the famous "Cmabrigde Uinervtisy" emails, readers have a high tolerance for letter order variations [1–2]. This issue concerning words with transposed letters has been studied experimentally using the masked priming lexical decision task [3], in which a forward mask is presented for 500 ms, followed by the prime for a very short time, usually 50-70 ms, and then the target stimulus. It is accepted that the unconscious processing of the primes in masked priming reduces the difficulty of processing the target word or nonword [4–6].

In the study of letter position encoding, the transposed-letter effect was found through masked priming task. A prime containing transposed two letters of the target word (jugde-JUDGE) promotes the activation more than a prime where the same two letters are replaced with other letters (substituted-letter prime, junpe-JUDGE) [7–8]. This excludes the classical solution to this problem, that is, each letter in a word has its position-specific code [9]. Three main alternative letter-coding models explaining this effect are the Open-Bigram Model [10], the Spatial Coding Model [11], and the Overlap Model [12].

Open Bigram Model codes letter order as a set of bigrams, for example, JUDGE is coded as JU, JD, JG, UD, UG, UE, DG, DE, and GE. The transposed-letter nonword "jugde" has eight same bigrams as JUDGE, whereas the substituted-letter nonword "jupte" only has two. One major challenge for Open Bigram Model is that "fo" primed the target word OF, even if they did not share any bigram [13]. By contrast, this result can be expected from other models. In the Spatial Coding Model, the relative letter order is coded dynamically as a gradient of activation over letter nodes [8]. The values assigned to letter nodes correspond to the serial-position letters. For example, in JUDGE, the value 1 is coded to the first letter J, and the value 2 is coded to the second letter U, etc. The nonword "jugde" has the same letter notes j, u, d, g, and e as JUDGE, therefore the two spatial activation gradient patterns share a greater similarity. However, though substituted-letter nonword "jupte" has the same three letter nodes as the target word, its spatial encoding pattern is different from those of JUDGE where letter nodes p and t are not activated. Therefore, the transposed-letter nonword facilitates the activation of the target word more than the substituted-letter nonword. The Overlap Model considers the representation of letter position information to be normally distributed, with a wider distribution and greater uncertainty in the early stages of processing [9]. The accuracy of the letter identity and position gradually increases over time. For example, there is some possibility that letter d in JUDGE is in the third letter position, but also in the second and fourth letter positions. Due to the wide distribution of letter position information, transposed nonwords are easily confused with targets during the short period of prime presentation, thus explaining the transposed letter effect.

However, it is worth noting that the above models of letter position encoding are based on alphabetic-script languages, while the encoding mechanism of letters in logographic-script languages, such as Chinese, has yet to be explored. Three characteristics of Chinese may differentiate the coding of Chinese character position from those of alphabetic-script languages for three reasons. First, the Chinese writing system consists of Chinese characters, which are more complex and numerous than letters [14], and the complexity and frequency of different characters vary greatly. Most Chinese characters correspond to graphemes, making it difficult to distinguish between word-level and grapheme-level positional coding effects [15]. Second, compared to the number of letters contained in English words, Chinese words contain fewer Chinese characters, with the proportion of single-character words and two-character words reaching over 90% [16]. In contrast, most words in the alphabetic-script languages contain more letters, which may make the position coding systems different. Finally, the lack of spaces or other explicit visual cues between words in Chinese text allows word

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boundaries to be a factor that may affect the positional encoding of Chinese characters.

For all the reasons above, some studies have found that Chinese character order encoding is not strict. Reference [12] used a masked priming paradigm and a gaze-contingent display-change paradigm to investigate the character coding at an early stage of processing in Chinese reading. The results showed that it took more time to process the target word which is primed by unrelated words than transposed-character words, indicating that character order is processed at an early stage of Chinese reading, but the encoding of character position is not strict. Priming effects from more extreme transposition primes have been reported [17]. They used four-character Chinese words as targets. At the same time, they used backward presented (right-to-left) and standard forward presented (left-to-right) words as primes to investigate the impact of visuospatial orientation on the priming effect. A significant transposed-character effect was found in this experiment. In addition, such extreme backward conditions have been observed in alphabetic languages as well. For example, the priming effect was not found when reversing the order of the first and last four letters in the target (edisklaw-SIDEWALK) [18], implying that the character position coding in reading Chinese is considerably different from letter position coding in reading English.

Based on the previous research mentioned above, an important question to consider before focusing on the impact of Chinese reading results on orthographic coding models of alphabetic languages is whether this effect is actually orthographic coding effects or whether it is influenced by priming from another source. The assumption that phonology may contribute to backward priming effects can be explained on the basis of both theoretical and experimental levels. On the theoretical level, the first point that should be considered is that most word recognition models involve phonological representations. The second point is that according to the interactive-activation model [19], one of the connectionist cognitive models, words are represented by a pattern of activations across a number of nodes rather than by a single node. Therefore, phonological information is relevant to the target processing in lexical decision tasks. On the experimental level, masked phonological priming effects prove the possibility that phonological processing emerges in lexical decision tasks in alphabetic languages from an empirical level [20–22].

Therefore, the core of the present study is to exclude the phonologically priming effect in Chinese backward priming effects, which arouses controversy and has no consistent answer. On the one hand, phonological processing is generally considered quite slow in the reading of logographic scripts, suggesting that phonological codes may not even be activated during such a short time in lexical decision task [23–26]. Orthographic masking priming effects were found to precede phonological effects in experiments deploying the masked priming paradigm [27–29]. In contrast, other models assumed the connections between phonological units and character units do exist and work in character recognition [30, 31]. Studies have shown a substantial role for phonological codes in Chinese reading, which brings Chinese character recognition closer to other languages than is often believed [32–35]. In the lexical decision task, the response accuracy data suggested that phonological processing takes place automatically in identifying Chinese characters [36]. Further, Recent studies have shown that although performance in the target task (a masked priming same-different task) may be mainly based on orthographic processing, phonological information can play a role in logographic script word recognition [16, 37, 38]

However, as the failure to identify veiled phonological priming effects in lexical decision tasks [39, 40], it is still necessary to confirm whether phonological activation plays a role in this process. Therefore, the present research aims to explore whether the backward priming effect of Chinese words is, to some extent, a phonological priming effect.

Experiment 1 was designed to investigate the backward phonological priming using four-character Chinese words as primes and targets. This is a masked priming lexical decision task and attempts to replicate the backward priming effect [41]. Based on their results, we would expect that a backward priming effect could be significantly revealed, that is, it took less time to process the targets primed by backward primes than by backward unrelated primes. In addition, we hypothesized that the response to syllabically related backward primed would be faster than syllabically unrelated primes. Furthermore, if no priming effect is detected in the syllabically backward condition, the significance of this experiment is that the backward priming effect is orthography and/or meaning-related rather than phonological-related. To make sure that syllable features did not indeed contribute to priming the targets in the masked priming lexical decision task in Experiment 1, Experiment 2 was designed. Both syllabically related and syllabically unrelated primes were presented backward as prime words. If there was no significant difference in participants' response time in the two conditions, it would indicate that syllabic/phonological information does not play a role in this task.

II. METHODOLOGY

A. *Participants*

Thirty-two students aged 18-24 years (average age of 21.2, 33 female and 3 male) from Beijing Foreign Studies University participated in Experiment 1. Sixty-three students aged 18-24 years (average age of 21.8, 54 female and 9 male) from the same school participated in Experiment 2. The participants in these two experiments were completely different. They were all chosen at random and paid the same in each experiment. They were all native Chinese speakers, right-handed, and had a normal or corrected-to-normal vision with no reading disorder.

B. *Materials*

Two hundred and forty-eight simplified Chinese four-character words were chosen as the target words in Experiment 1. Two hundred and forty words were used in Experiment 1, and the other eight words were selected from the SUBTLEX-CH database [42], the same database used by Yang. All of the nonword stimuli were selected from the nonword in the Chinese Lexicon Project [43]. The mean word frequency (per million) of these target words is 1.63 (range: 0.03-48.5).

There were four priming conditions for each target word:

(a) syllabically related backward priming condition; (b) syllabically unrelated backward priming condition; (c) backward priming condition; and (d) backward unrelated priming condition. Syllabically related backward primes, for example, 盛部吴栈(shèng bù wú zhàn)-战无不胜(zhàn wú bù shèng), have four characters with the same pronunciation as each of the target words, but are presented in the exact backward order. Syllabically unrelated backward primes have no repeated phonology with the target words, but they can be understood as meaningful four-character Chinese words when produced in the reverse order, for example, 启在删冬 (qǐ zài shān dōng)-战无不胜 (zhàn wú bù shèng). The backward primes, for example, 胜不无战 (shèng bù wú zhàn)-战无不胜 (zhàn wú bù shèng) are the right-to-left presentation of the four Chinese characters in the target word. The backward unrelated primes are nonwords, the presentation of meaningful Chinese words in the right-to-left orientation, for example, 起再山东 (qǐ zài shān dōng)-战无不胜 (zhàn wú bù shèng). The four priming conditions of each target word were counterbalanced into four lists. Each participant is required to perform the lexical decision task for all items in one list only (240). Besides, another 240 four-character simplified Chinese nonwords were selected as filler target words. They were made randomly by combing the separated characters in the Chinese Lexicon Project [43]. 120 of them were primed by unrelated primes, 60 of them were primed by syllabically backward primes and the other 60 were primed by backward primes. The primes for the first two conditions are set in the same way as the primes for the target words. These nonwords targets appeared in all four counterbalance lists, which means that each participant needed to make 480 lexical decisions, with 240 target words and 240 target nonwords.

Ninety-four character simplified Chinese words which are target words in Experiment 1 are chosen as targets in Experiment 2, with the mean word frequency (per million) of 3.38 (range: 1.28-48.5) in the SUBTLEX-CH database (Cai & Brysbaert, 2010). Experiment 2 was designed to exclude the effect of syllabic information on the lexical decision task, there were only two priming conditions for each target word: (a) syllabically related priming condition, for example, 栈吴部盛 (zhàn wú bù shèng)-战无不胜 (zhàn wú bù shèng); (b) syllabically unrelated priming condition, for example, 冬删在启(dōng shān zài qǐ)-战无不胜(zhàn wú bù shèng). To counterbalance the target words, three lists, each containing 60 target words primed by either of the two conditions, were created. It is guaranteed that 90 target words are equally distributed among the three lists for a total of 180 decision tasks under both priming conditions. 60 nonword targets used in Experiment 1 were also used as filler words in Experiment 2. The two priming conditions of the target words are likewise used as primes to precede the target nonwords. Half of them are syllabically related primes, whereas the other half are syllabically unrelated primes. Overall, each participant made 120 lexical decisions, with 60 target words and 60 target nonwords.

C. *Apparatus*

Stimulus presentation and response registration were controlled by a laptop with a 13.3-inch display. CRT monitor with a resolution of 1280 X 960 pixels and a refresh rate of 60 Hz.

D. *Procedure*

The data were collected using E-Prime 2.0 software (Psychology Software Tools). All the stimulus was white and presented in the center of the screen against the black background. Each trial began with a white fixation point that was presented for 500 ms, and participants were asked to fixate on it. Then, a mask consisting of six hash marks (#######) was presented for 500 ms. The primes (35-point Boldface font) were immediately followed for 50 ms, and then the targets (40-point Song font) for 3000 ms or until the participants responded. Participants were asked to determine as quickly and as accurately as possible whether the stimuli presented on the screen were meaningful Chinese four-character words. Pressing the “L” button on the keyboard meant they agreed the stimulus was a meaningful Chinese word, otherwise the “A” button would be pressed. The target words presented to each participant were randomly ordered. Response times and accuracy were collected by the software.

In both Experiments 1 and 2, each participant received 16 practice trials before experimental trials. They would not move on to the experimental trial until they got over 90% correct in the practice trial. A total of 480 trials in Experiment 1 were used, therefore participants were allowed to rest for 6000 ms for every 120 trials. The experimental procedure took approximately 25 min. There were 120 trials in Experiment 2, and it took approximately 5 minutes to complete.

III. RESULTS

A. *Experiment 1*

When analyzing the latency and accuracy data, the generalized linear mix-effects model from lme4 package in R was used [44–45]. Subjects and items were random effects [46] whereas prime type and relatedness were treated as fixed effects [47]. The two prime types are backward or forward presentation and the relatedness concerning the syllabically related or syllabically unrelated priming conditions. Prior to fitting the model, sum-to-zero contrasts were set up to the R-default treatment contrasts [48]. The model for the latency analysis was: RT = glmer (RT ~ Primetype × Relatedness + (Relatedness|Subject) + (Relatedness|target), family = Gamma (link = “identity”), control = glmerControl (optimizer = “bobyqa”, optCtrl = list (maxfun = 1e6))). The model for the accuracy analysis was: Accuracy = glmer (accuracy ~ Primetype × Relatedness + (Relatedness|Subject) + (Relatedness|target), family = “binomial”, control = glmerControl (optimizer = “obyqa”, optCtrl = list (maxfun=1e6))). Both models were running after a restart of R. This model is simplified from the more complex model we started with which included all the fixed factors in it. The reason for removing some of the factors was that the previous model failed to fit the data very well. The emmeans package in R was used in the post hoc analyses [49].

During the latency analyses, the latencies with three standard deviations larger than the mean latency for that participant, less than 300 ms were removed. We also excluded those trials in which participants made an incorrect response (2.7% of the data). RTs were shorter overall in the backward priming conditions and for related primes (see Table I). The detailed information about the results of the mixed-effect model analysis is reported in Table II. The main effect of Prime Type was significant, *ß* = 9.654, *SE* = 1.511, $z = 6.391$, $p < 0.001$. The main effect of Relatedness was also significant, *ß* = −6.653, *SE* = 2.237, $z = -2.974$, $p < 0.01$. The interaction between Prime Type and Relatedness was also significant, *ß* =6.034, *SE* = 1.557, $z = 3.874$, $p < 0.001$. The backward priming effect which was indicated by the 17 ms latency in reaction time was significantly larger than the backward syllabic priming effect (2 ms). The result of post-hoc analyses could also prove it. The 2 ms backward syllabic priming effect was not significant, with *ß* = −1.24, *SE* = 5.48, $z = -0.226$, $p = 0.821$, whereas the backward priming effect was rather significant, with *ß* = ‐ 25.37, *SE* = 5.42, $z = -4.682$, $p < 0.001$.

TABLE I. THE *MEAN REACTION TIMES (IN MILLISECONDS) AND ERROR RATES BY PRIME TYPE AND RELATEDNESS FOR EXPERIMENT 1*

	Syllabic condition		Backward condition	
	RT	%E	RT	%E
Related	627(97)	2.4(3)	599(89)	1.6(2)
Control	625(98)	1.9(2)	616(93)	1.0(2)

The number in parentheses is standard deviations. RT = reaction time; %E = percentage error rate. The overall mean RT and error rate of the nonword targets were 684 ms and 1.3% respectively.

TABLE II. THE *DETAILS OF RANDOM EFFECT AND FIXED EFFECT FOR RTS ANALYSIS IN EXPERIMENT 1*

Groups	Name	Variance	SD	Corr
Random effects				
Item	Intercept	851	29.294	
	Relatedness	195	13.958	0.01
Participant	Intercept	1428	37.786	
	Relatedness	18.4	4.288	0.00
Residual		0.035	0.187	
Correlation of fixed effects				
		(Intr)	Prime type	Relatedness
Prime Type		0.039		
Relatedness		0.042	0.037	
Interaction	625(98)	-0.018	-0.176	0.03

We further used Bayes Factor analysis as another means to qualify the interaction between Prime Type and Relatedness. The Bayes factor analysis was conducted based on the Bayesian Information Criterion (BIC) approximation of the Bayes Factor [50]. In most experiments using this method of analysis, Bayes Factor was calculated using the BIC value when assuming there is an interaction between the two main effects (the alternative hypothesis *H1*) and when assuming there is no interaction (the null hypothesis *H0*). The formula for the calculation is: $BF_{01} = \exp((\mathrm{BIC}(H1) - \mathrm{BIC}(H0))/2)$. When BF_{01} is less than 1, the data supports *H1*, while when BF_{01} is greater than 1, it indicates that *H0* is supported. The present research used one common classification scheme to interpret the Bayes Factors [51]. The Bayes Factor for the Prime Type by Relatedness interaction in Experiment 1, $BF_{01} = 0.0867$, suggesting "strong" evidence for the *H1*, that is, there is an interaction between the two factors.

In addition, there was a 2 ms null effect in syllabic priming. We wanted to verify this null effect, so we performed a Bayes Factor analysis using only Relatedness as the factor. The Bayes Factor BF_{01} was calculated using the BIC values for the model with an effect of Relatedness (the alternative hypothesis *H1*) and with no effect (the null hypothesis *H0*). The formula for this calculation is: $BF_{01} = \exp((\mathrm{BIC}(H1) - \mathrm{BIC}(H0))/2)$. In this analysis, the Bayes Factor was $\mathrm{BF}_{01} = 51.52$, suggesting "Very Strong" evidence for the absence of a relatedness effect*.

As shown in Table I, error rates were higher in syllabic conditions and related conditions. The main effect of Prime Type was significant, *ß* = −0.225, *SE* = 0.052, $z = -4.37$, $p = 0.002 < 0.01$. There were more errors in the syllabic conditions (2.7%) than in the backward conditions (1.4%). However, the main effect of Relatedness was not significant, *ß* = -0.092, *SE* = 0.207, $z = -0.443$, $p = 0.656$, with less errors in the unrelated conditions (1.9%) than in the related conditions (2.3%). The interaction between these two factors was also not significant, *ß* = 0.044, *SE* = 0.103, $z = 0.425$, $p = 0.671$. In the post-hoc analyses, backward related priming condition elicited more errors (1.6%) than backward unrelated priming condition (1.0%), with *ß* = ‐ 0.095, *SE* = 0.441, $z = -0.216$, $p = 0.829$. In the syllabic conditions, the error rate was also higher for targets primed by syllabically related primes (2.4%) than syllabically unrelated primes (1.9%), *ß* = −0.271, *SE* = 0.482, $z = -0.562$, $p = 0.574$.

B. Experiment 2

Experiment 2 only had one single fixed effect, Relatedness (syllabically related or syllabically unrelated) to be analyzed. Therefore, the model for the latency analysis was: RT = glmer (RT ~ Relatedness + (Relatedness|Subject) + (Relatedness|target), family = Gamma (link = "identity"), control = glmerControl (optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). The model for the accuracy analysis was: Accuracy = glmer (accuracy ~ Relatedness + (Relatedness|Subject) + (Relatedness|target), family = "binomial"). The details of the analysis method are the same as in Experiment 1. The mean RTs (in ms) and error rates by relatedness are presented in Table III.

When analyzing the reaction time, trials with RTs that were shorter than 300 ms or more than 3 standard deviations from the participant's mean reaction time, as well as those in which participants made incorrect responses (2.1% of the data) were excluded from the analyses. RTs were shorter for syllabically unrelated primes (654 ms) than syllabically related primes words (663 ms). This 9 ms difference was not significant by Relatedness, *ß* = 5.068, *SE* = 3.815, $z = 1.328$, $p = 0.184$. In the error rate analysis, the 0.1% difference between the related condition (2.1%) and the unrelated condition (2.2%) was also not significant, *ß* = −0.125, *SE* = 0.211, $z = -0.594$, $p = 0.553$.

TABLE III. THE *MEAN REACTION TIMES (IN MILLISECONDS) AND ERROR RATES BY RELATEDNESS FOR EXPERIMENT 2*

Condition	RT	%E
Syllabic related priming	663(122)	2.1(3)
Syllabic unrelated priming	654(111)	2.2(3)

The number in parentheses is standard deviations. RT = reaction time; %E = percentage error rate. The overall mean RT and error rate of the nonword targets were 752 ms and 1.8% respectively.

To evaluate the statistical evidence for this null effect, a Bayes Factor analysis was conducted. The BIC values for the model with an effect of Relatedness (the alternative hypothesis H_1) and a model with no effect (the null hypothesis H_0) were used to calculate the Bayes Factor. The formula for the calculation is: $BF_{01} = \exp((\mathrm{BIC}(H_1) - \mathrm{BIC}(H_0))/2)$. The other calculations and interpretations are consistent with those in Experiment 1. According to the classification we followed, the Bayes Factor in Experiment 2, $BF_{01} = 34.39$, shows "Strong" evidence for the absence of a Relatedness effect.

C. The Analysis of Relatedness and Orientation

Since half of the priming conditions in Experiment 1 ware backward and the priming conditions in Experiment 2 were all forward, we analyzed it with the two syllabic conditions (syllabically related and syllabically unrelated) in both experiments. Orientation (backward or forward) and Relatedness (related or unrelated) were treated as fixed effects, and subjects and items were treated as random effects. The model for the latency analysis was: RT = glmer (RT ~ Primetype × Orientation + (Relatedness|Subject) + (Relatedness|target), family = Gamma (link = "identity"), control = glmerControl (optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). The model for the accuracy analysis was: ACC = glmer (ACC ~ Primetype × Orientation + (Relatedness|Subject) + (Relatedness|target), family = "binomial", control = glmerControl (optimizer = "bobyqa", optCtrl = list (maxfun=1e6))). In the analysis of RT, none of the main effects or the interaction was significant, with all the p value greater than 0.1. In the analysis of error rate, only the main effect of Orientation was significant, $ß = 0.641$, $SE = 0.263$, $z = 2.434$, $p = 0.015$. More errors were made in the backward condition (6.5%) than in the forward orientation (3.5%).

IV. DISCUSSION

Two priming experiments were carried out to investigate whether phonological information plays a role in the backward priming effect found in lexical decision tasks deploying logographic scripts. The results of Experiment 1 show that no significant phonological backward priming effect was found in the lexical decision task of four-character Chinese words, strongly suggesting that the syllabic information presented in a backward direction is not a source for priming. The results of Experiment 2 produced no evidence for phonological priming in a lexical decision task even when the characters were presented in the standard left-to-right orientation in the primes. The results of these two experiments together show that the backward priming effect of Chinese words in lexical decision tasks is not phonological in nature. It needs to be stressed that the results do not confirm the activation of the phonology by the primes in these two experiments, while, the case is that phonology did not play a role in the backward priming effects in the Chinese lexical decision task.

The results seem to argue against a few studies in which a substantial role for phonological codes is revealed [24, 34, 35]. However, the finding that the backward priming effect in the lexical decision task is not phonological may not come as a huge surprise on an empirical level, as some of the previous experiments using Chinese as a target have reached similar conclusions [28, 32]. The major difference between the present study and previous studies is that previous experiments, regardless of the paradigm used, have only verified the presence or absence of phonological priming in single-character word or two-character word recognition. For example, the priming effect did not appear when replacing both characters of two-character compound words with homophonic characters by pseudohomophone primes in a lexical decision task [40]. For the four-character Chinese word back word priming effect, the present study provides evidence from the empirical perspective that it is not activated by phonological resources.

However, the failure to detect a phonological priming effect in the lexical decision tasks may not be caused by the fact that the phonological effect has been observed in reading Chinese. As stated previously, the character takes longer than phonology to be recognized in some experiments conducted using other paradigms. Reference [25], for example, observed a homophone priming effect at the 57-ms stimulus onset asynchrony (SOA), with the target remaining on the screen until participants made a response. But the researchers were unable to observe a semantic priming effect until the 85-ms SOA. They concluded, "graphic information was activated first, within 43 ms, followed by phonological information within 57 ms and by semantic information within 85 ms." Then, in a homophone judgment task, it was assessed that homophone "yes" response latencies as a function of prime SOAs [23]. The fact that the majority of participants responded favorably to homophones at the SOA of 57 ms suggests that the phonological activation might occur very early. In addition, recent evidence from event-related potential shows that phonology plays at least a limited role in Chinese character recognition [52]. In the masked priming same-different task, a phonological priming effect was reported with primes presented in Japanese Katakana and English target words [37]. However, Others claimed that these findings reveal little about the size of phonology's contribution to priming when both the prime and target are given in the same script [53]. Only by searching for phonological priming under conditions when the prime and target are written in the same script can it be known if phonological priming effects will be observed.

Therefore, our findings raise a challenge to existing orthographic coding models, which would rarely predict priming when the letter order in the target is totally reversed in the prime. First, according to practically all of the current Open-bigram Models, these primes and their targets share no open bigrams; hence, these primes provide no priming for their targets because the letter sequence "ab" could only activate the bigram "ab", but not the reversed bigram "ba". In addition, the Overlap Open-bigram Model [6] posits that the reverse open-bigrams are active, assuming that the activation levels are relatively low.

According to position overlap models, it may be possible to address this challenge by assuming that Chinese readers have a high tolerance for character position variation. There are very few anagrams in Chinese which means that the density of Chinese is quite low than in English and other alphabetic languages [15]. Recent studies in Hebrew [54, 55] and Korean [56] reveal that letter position processing flexibility may not be a universal aspect of reading, but rather may rely on the orthographic density of a writing system. In other words, when a Chinese reader sees a character string such as “同不众与”, there is a high likelihood that the four characters will form the accurate Chinese word “与众不同”. In contrast, when an English reader is given a string of letters like “ekil,” he or she may consider innumerable other words composed of these four characters. Thus, English readers place greater emphasis on letter position, whereas Chinese is not a position-sensitive language [57, 58]. In order to attempt to model orthographic coding in Chinese, the value of their parameters that reflect position uncertainty will be increased in the Noisy Position Models. Finding the optimal setting for these parameters is not an easy task since it should be taken into consideration the fact that the model should anticipate the repetition priming and backward priming effects in Chinese character reading.

V. CONCLUSION

The current study demonstrates that the backward priming effects of four-character Chinese words are highly unlikely to be phonologically based. Instead, the backward priming effect tends to be orthographically-based or semantically-based. Future research could focus on whether semantic information plays a role in this effect found through the lexical decision task. Additionally, according to the argument that the flexibility to letter position coding is related to the density of the writing system, more empirical research is needed to determine whether the backward priming effect that indicates an extreme transposition condition exists in other languages, such as Arabic and Hebrew. Another alternative question to be addressed is that when modeling the letter position coding, attempts should be made with regard to the change in existing models, especially in the parameters in Noisy Position Models in order to explain evidence from Chinese reading.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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