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The role of cross-language orthography and phonology in translation recognition: an ERP study with Chinese–English bilinguals

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Abstract

This study investigated the electrophysiological correlates of cross-language orthographic and phonological processing in unbalanced Chinese (L1)–English (L2) bilinguals using a translation recognition task. The critical L1-L2 word pairs were incorrect translation equivalents but orthographically or phonologically related through translation (orthographic or phonological translation neighbor). Compared with the unrelated control, the recognition of L2 words showed comparable reaction time and accuracies when coupled with L1 orthographic or phonological translation neighbors. However, both orthographic and phonological translation neighbors elicited more negative event-related potential (ERP) waveforms in the bulk of the N400 component (300-600 ms) than the unrelated control. These findings were interpreted in the framework of the Bilingual Interactive Activation Plus model (BIA+ model), according to which cross-language orthographic and phonological representations were non-selectively accessed during the recognition of the L2 words, and top-down inhibitory control mechanism impacted the cross-language lexical competition and confliction between the two languages.

1. Introduction

1.1 Theoretical background

Over the past few decades, we have witnessed a diverse array of research into the nature of lexical-semantic interaction between first language (L1) and second language (L2). Ample evidence has been found that bilinguals unconsciously and parallelly co-activate the lexical candidates of both languages (including the orthographic, phonological, and semantic representations) when bilinguals read, hear, and speak a language (Casaponsa et al., 2015; Guo et al., 2012; Sunderman & Priya, 2012; Thierry & Wu, 2007; Zhang et al., 2011; Zhou et al., 2010), leading to the non-selective lexical access account.

Relevant models on bilingualism depict the temporal dynamics and cognitive mechanism of how a bilingual's two languages interact with each other, including the Bilingual Interactive Activation model (BIA model, Dijkstra & van Heuven, 1998) and its modified versions of Bilingual Interactive Activation Plus model (BIA+ model, Dijkstra & van Heuven, 2002), of Multilink model (Dijkstra et al., 2018), and of BIA+ extended models (Degani et al., 2018). Notably, the influential BIA+ model depicts the hierarchically organized "architecture" of the bilingual lexical processing (i.e., orthography and phonology) in detail, indicating that the orthographic, phonological, and semantic representations of both languages are integrated and interconnected in the word identification subsystem. Visual word processing starts from the activation of sub-lexical orthographic information of both languages (i.e., letters or letter clusters). Subsequently, the sub-lexical orthographic information maps onto their corresponding phonological units. Then, this orthography-to-phonology mapping sends cascaded activation to whole-word orthographic and phonological representations, and finally to semantics and language nodes. Additionally, Green's (1998) Inhibitory Control model (IC model) stressed that the lexical-semantic representations are differently organized in different task contexts and that bilinguals rely on the IC mechanism for the modulation of language production processes. Based on those theories, the task schema subsystem in the BIA+ model emphasizes the impact of the top-down IC mechanism on the modulation of interference and competition between two languages' lexical-orthographical and -phonological candidates.

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1.2 Cross-language interaction in bilingual word recognition

Behavioral studies with different categories of word pairs have provided convincing evidence that bilinguals' two languages interact with each other at multiple lexical levels for same-script languages, such as interlingual homophones (Sauval et al., 2017), interlingual homographs (Bijeljac-Babic et al., 1997), or cognate word pairs (Carrasco-Ortiz et al., 2021). This manner is also apparent in the case of two different-script languages, such as Russian and English (Jouravlev et al., 2014), Chinese and English (Zhou et al., 2010), or Greek and Spanish (Dimitropoulou et al., 2011). For example, a significant masked priming effect (faster reaction time) was observed during the recognition of the target-language words when they were primed by only phonologically related prime words of the non-target language in Greek–Spanish bilinguals, while this priming effect disappeared when adding orthographic similarity to the prime-target word pairs (Dimitropoulou et al., 2011). Those results demonstrated that the co-activation of cross-language phonological codes was dependent on the input orthographic properties. The cross-language orthographic and phonological representations impacted the processing of the target words differently.

However, the influence of the prime on cross-language homophones or homographs might be driven by purely acoustic overlap between word pairs (Von Holzen & Mani, 2012). More compelling evidence came from studies investigating orthographic or phonological priming through translation, especially for different-script Chinese and English, i.e., logographic writing system and alphabetic script. In Chinese, some characters have a simple holistic structure which are composed of strikes. For example, the character "王/Wang2/[king]" is composed of one vertical and three horizontal strokes. However, most Chinese characters can be segmented into sub-lexical orthographic constituents called "radicals". For example, the character "桥/Qiao2/[bridge]" is composed of its phonetic radical "乔" and semantic radical "木". The sub-lexical orthographic constituents are the basic components in models of Chinese reading (Ding et al., 2004). Furthermore, some Chinese characters with the same phonological representations have no orthographic overlap. For example, "课[class]", "刻[carve]", and "客[guest]" have the same pronunciation "/Ke4/". In contrast, some characters with similar orthographic representations can have completely different phonological representations. For example, "课/Ke4/[class]", "踝/Huai2/[ankle]", and "果/Guo3/[fruit]" have different pronunciations. It is usually counterintuitive for alphabetic language users. Additionally, as with words in other languages, the same characters can also have different meanings, which are called polysemantic words. For example, "面/Mian4/" can mean "noodles", "face", or "surface" in different environments.

Based on the above features, studies in Chinese–English bilinguals also provided ample evidence that bilinguals' two languages' lexical representation interacted with each other at multiple levels. For example, using a masked priming paradigm, a faster response was observed to unrelated English word pairs (L2) whose Chinese translations (L1) concealed both orthographic and phonological overlap (e.g., "east[东/Dong1/]" - "thing[东西/Dong1Xi1/]"). The results suggested a rapid and automatic cross-language lexical activation at the initial stages of L2 visual word processing because the primes were presented for only 59 ms (Zhang et al., 2011). Nevertheless, in the following studies by Wen and van Heuven (2018, Exp.1 and Exp. 2), researchers found that the findings by Zhang et al. (2011) were not replicable. However, a cross-language masked priming effect (faster response time) was found with masked Chinese primes and English targets (e.g., "东/Dong/[east]" - "thing[东西/Dong1Xi1/]"). Additionally, when judging whether pairs of words were translation words or not, compared with matched control conditions (e.g., "蜡烛/La4Zhu2/[candle]" - "fact[事实/Shi4Shi2/]"), Chinese–English bilinguals showed interference (slower response time or higher error rates) to the recognition of L1-L2 word pairs who were lexically related through translation (e.g., "事业/Shi4Ye4/[career]" - "fact[事实/Shi4Shi2/]") (Wen & van Heuven, 2018, Exp. 3). Furthermore, both beginning and advanced Chinese learners of English showed interference to the recognition of L1 words when primed with L2 words whose translations were orthographic (e.g., "cup[杯/Bei1/]" - "坏/Huai4/[bad]"), but not phonological (e.g., "cup[杯/Bei1/]" - "悲/Bei1/[sad]") neighbors to the L1 words (Ma & Ai, 2018). Given the absence of overt overlap between word pairs, researchers concluded that the interference provides evidence of non-selective L1 orthographic access.

Behavioral responses only capture the endpoint of meaning access, and they cannot disentangle the brain processes underlying cross-language interactions in bilinguals. Time-locking event-related potentials (ERPs) are sensitive to pick up subtle effects (Luck, 2005). One of the best-researched ERP components is the N400 component, a negative-going component that occurs at around 300-500 ms after word onset with a central-parietal scalp distribution, which is sensitive to lexico-semantic manipulations (Kutas & Federmeier, 2000, 2011). The N400 has been employed in a range of bilingual studies, particularly for exploring the implicit and complex interplay between cross-language orthographic and phonological features. For example, monolingual and bilingual participants were instructed to determine whether English word pairs were related in meaning. Chinese–English bilinguals, but not English monolinguals, showed a reduction of the N400 component to English word pairs whose translations shared Chinese orthography and phonology (e.g., "train[火车/Huo3Che1/]" - "ham[火腿/Huo3Tui3/]") (Thierry & Wu, 2007). In a follow-up study, the N400 amplitude was reduced for English word pairs that shared the concealed phonological (e.g., "experience[经验/Jing1Yan4/]" - "surprise[惊讶/Jing1Ya4/]") rather than orthographic (e.g., "accountant[会计/Kuai4Ji4]" - "conference[会议/Hui4Yi4/]") repetition in their Chinese translation equivalents (Wu & Thierry, 2010). Follow-up electrophysiological studies substantiated this finding (Wen et al., 2018; Zhang et al., 2022). Critically, Zhang et al. (2022) revealed a significant through-translation phonologically (e.g., "壶/Hu2/[kettle]" - "lake[湖/Hu2/]"), but not orthographically (e.g., 踝/Huai2/[ankle]" - "class[课/Ke4/]), related masked priming effect, as reflected by smaller N400 (300-500 ms) amplitudes. In contrast to the study by Ma and Ai (2018) mentioned earlier, the researchers thus concluded that the phonology, but not the orthography of Chinese translations is unconsciously activated when processing English words.

Besides, Guo et al. (2012) explored the temporal dynamics of accessing the meaning of second language recognition with two L2-L1 translation recognition tasks in relatively proficient Chinese–English bilinguals. Through-translation lexical-related word pairs (e.g., "bee[蜂/Feng1/]" - "峰/Feng1/[peak]" vs. "bee[蜂/Feng1/]" - "南/Nan2/[south]") induced a larger early P200 (150-300 ms) amplitude and late positive component (LPC, 500-700 ms) amplitude when the stimulus onset asynchrony (SOA) was 750 ms (Exp. 1). The P200 component is typically thought to index the lexical-level orthographic and/or

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phonological processing between word pairs (Barnea & Breznitz, 1998; Liu et al., 2003). The LPC is found to reflect more extensively elaborate processes at post-lexical stages, such as information re-analysis (Stites et al., 2016), semantic integration difficulty (Brouwer et al., 2017), or spelling, semantic or syntactic violations (van de Meerendonk et al., 2011). However, the early P200 priming effect was not observed when the SOA was 300 ms in the lexical-related condition (Exp. 2). These findings suggested that the lexical-level orthographic and/or phonological acquisition of Chinese in the processing of English was possibly through the feedback from shared semantics/concepts to lexical representations.

1.3 The current study

To conclude, previous studies with Chinese–English bilinguals hold a generally accepted view of non-selective lexical access account, even in the context of a purely non-native language. In particular, prior electrophysiological studies with masked priming paradigm (Zhang et al., 2022) or implicit priming paradigm (Thierry & Wu, 2007; Wu & Thierry, 2010) have demonstrated that the phonological and semantic representations of Chinese translations were unintentionally co-activated during the processing of English words. Masked or implicit priming paradigm, however, is generally suitable for investigating the bottom-up and unconscious cross-language lexical co-activation when word recognition is carried out in the context of a purely non-native language. As far as we know, no study has explored the separate roles of cross-language orthographic and phonological activation in the processing of L2 words in Chinese–English bilinguals with a L1-L2 translation recognition task, during which the participants are instructed to consciously activate and compare the form-meaning systems of two languages to examine the lexical-semantic links between two languages (de Groot, 1992). Such an investigation would document both interactive and separate effects of cross-language orthographic and phonological representations. Combining previous research results, it would also be meaningful to generalize the theoretical assumptions of the BIA + model to different-script language systems. Overall, as a follow-up study of Zhang et al. (2022), the present study aims to further examine the cross-language orthographic and phonological effects on L2 word meaning access in terms of L1-L2 relationships with a translation recognition task by using time-locked ERP measures. To do so, referring to previous manipulations (Ma & Ai, 2018; Zhang et al., 2022), the Chinese words could be the translation equivalents of the English words, the orthographic or phonological neighbors of the translations of the English words (orthographic or phonological translation neighbors), or completely unrelated to the translations of the English words.

According to the BIA+ model, the recognition of a non-native visual word is assumed to co-activate the lexical-semantic representations of the native words. Thus, it is reasonable to predict that the orthographic and phonological representations of Chinese words may both exert effects on the meaning access of English word recognition. Collectively, previous studies using the translation recognition paradigm have revealed significant through-translation interference effects when word pairs are not translation equivalents but contain form similarities (Guo et al., 2012; Ma et al., 2017; Moldovan et al., 2016), as reflected by longer response time or lower accuracy, which indicates that the word pairs are more effortful to be integrated. Most relevant for the current study is the fact that the amplitude of the N400 component is proportionally relative to the effort required to integrate the orthographic, phonological, and semantic knowledge relative to a word (Holcomb, 1993). For example, the faster response time and less negative N400 amplitudes in response to cognate word pairs than to non-cognate word pairs have been demonstrated to reflect greater ease in mapping lexical-level word form onto conceptual meaning in bilingual word recognition (Midgley et al., 2011; Peeters et al., 2013). In contrast, in the production of interlingual homophones in Dutch–English, longer reaction times and more negative N400 amplitudes were observed for interlingual homophones than for control words (Christoffels et al., 2015). Moreover, monolingual and bilingual ERP studies have shown that words with more within- or cross-language neighbors elicited more negative N400 amplitudes than words with fewer within- or cross-language neighbors (Holcomb et al., 2002; Meade et al., 2018; Midgley et al., 2008; Vergara-Martínez & Swaab, 2012). The behavioral interference effects and increased N400 amplitude were interpreted to index the competition or confliction effects between two languages' lexical-semantic representations. And the modulation of such competition or confliction relied on the IC mechanism. Given that the N400 component is susceptible to top-down competition and inhibition processing (for a review, Jankowiak & Rataj, 2017), we hypothesize that both orthographic and phonological neighbors of translation equivalents of L2 words could induce interference to the recognition of L2 words, as reflected not only by behavioral performance but also by the modulation of the N400 component.

2. Method

2.1 Participants

Thirty-eight Chinese–English bilinguals were recruited to take part in the experiments (18 males, 20 females; mean age = 22.1 ± 1.8 years old). All participants were right-handed native Mandarin Chinese speakers without psychiatric or neurological disorder history. They had normal or corrected-to-normal vision. All participants signed written informed consent, following the ethics protocol of the Academic Committee of Chongqing University.

All participants began learning English in a homogeneous academic environment around the age of ten. Participants' English proficiency was assessed in three approaches. Firstly, they all passed the College English Test Band 4 (CET 4) with an average score of 519 (standard deviation (SD) = 47, the maximum score and cut-off score of the test are 710 and 425, respectively). Secondly, all participants participated in a LexTALE test downloaded from www.lextale.com. This test consists of 60 items, including 40 English legal words and 20 nonwords. Participants were asked to determine whether each item was legal or false. As an objective proficiency measure, the LexTALE test has been demonstrated to be a good predictor of English vocabulary and has a strong correlation with measuring general English proficiency (Lemhofer & Broersma, 2012). Participants scored an average of 59.4 in the LexTALE test (SD = 10.9, the maximum score of the test is 100). Finally, their English proficiency was self-assessed by using a five-point Likert scale, where one was not fluent and five was very fluent. The average scores of self-assessed English listening, speaking, reading, and writing abilities were 2.9 ± 0.7, 2.6 ± 0.7, 3.5 ± 0.6, and 3.1 ± 0.6, respectively. Combining the above subjective and objective indicators, the participants' English proficiency was thought to be in an intermediate level (i.e., unbalanced Chinese–English bilinguals).

2.2 Stimuli

A stimulus list including 240 English words selected from the SUBTLEXUS corpus (Brysbaert & New, 2009) was first generated. The list was then randomly and evenly divided into four sub-lists. In accordance with previous literature (Wu & Thierry, 2010; Zhang et al., 2022), five English major graduate students who did not participate in the formal experiment were asked to provide the translation equivalents of the English words. Then, as featured as previous study by Ma and Ai (2018) and Zhang et al. (2022), they generated the corresponding Chinese one-character words into four stimulus conditions:

(1) 60 pairs of Chinese–English translation equivalents (e.g., "国/Guo2/" and "country");
(2) 60 pairs of Chinese–English non-translation equivalents in which Chinese words are orthographic neighbors of the correct translations of the English words, and they do not overlap phonologically through translation (orthographic translation neighbor condition, e.g., "踝/Huai2/" and "class", where the Chinese word ("踝/Huai2/", meaning "ankle") shares the same radical ("果") with the translation ("课/Ke4/") of the English word ("class"). The Chinese word pair "踝/Huai2/-课/Ke4/" can also be called "partial homographs");
(3) 60 pairs of Chinese–English non-translation equivalents in which Chinese words are phonological neighbors of the correct translations of the English words, and they do not overlap orthographically (phonological translation neighbor condition, e.g., "壶/Hu2/" and "lake", where the Chinese word ("壶", meaning "kettle") shares the same pronunciation (/Hu2/) with the translation ("湖") of the English word ("lake"). The Chinese word pair "壶/Hu2/-湖/Hu2/" can also be called homophones);
(4) 60 pairs of Chinese–English non-translation equivalents in which Chinese words are completely unrelated to the English words through translation (unrelated control condition, e.g., "电/Dian4/"(meaning "electricity")-"wall"("墙/Qiang2/")).

Five other English major graduate students assessed the translation equivalence for each condition of each word pair with a five-point scale, where one was not translation equivalent and five was translation equivalent. The average scores of selected translation equivalents (60 word pairs) and non-translation equivalents (180 word pairs) were 4.9 ± 0.4 and 1 ± 0, respectively. Based on the manipulations by Guo et al. (2012), the semantic relatedness and lexical relatedness of the three non-translation equivalent conditions (i.e., orthographic translation neighbor, phonological translation neighbor, and unrelated control conditions) were further assessed with a five-point scale, where one was semantically unrelated or lexically related through translation and five was semantically related or lexically unrelated through translation. For example, for the "踝/Huai2/" -"class (课/Ke/)" word pair, participants had to score whether they were semantically related and similar in lexical-level orthography or phonology through translation. Besides, since the equivalence of translation word pairs was already assessed, they were not included in this step. The average scores of L1-L2 semantic relatedness of the three non-translation equivalent conditions were all 1 ± 0. These meant that these conditions were all semantically unrelated word pairs. The average scores of L1-L2 lexical relatedness of the three non-translation equivalent conditions were 1.17 ± 0.38, 1 ± 0, and 4.93 ± 0.25, respectively. These meant that the orthographic and phonological word pairs were highly lexically related through translation, and the unrelated word pairs were lexically unrelated through translation. Furthermore, paired sample *t*-tests revealed no significant differences in semantic relatedness among three non-translation equivalent conditions, all $ts < 1$, $p > 0.99$. Besides, the average scores of lexical relatedness of the orthographic and phonological translation neighbor conditions were remarkably lower than that of unrelated control condition, both $ts > 62.8$, $p < 0.001$.

All English words are high-frequency words with logarithmically transformed frequency calculated according to the database of $\text{SUBTLEX}_{\text{US}}$ corpus (Brysbaert & New, 2009) and strings ranging in length from 3 to 8 letters. Correspondingly, the number of strokes and logarithmically transformed frequency according to the SUBTLEX-CH-WF corpus (Cai & Brysbaert, 2010) were also calculated. The word pairs among the four stimulus conditions match in numbers of strokes, string length, and average frequencies, paired sample *t*-tests, all $ts < 1.63$, $p > 0.11$. The descriptive statistics (mean and *SD*) of the four stimulus types are shown in Table 1. The research stimuli are shown in the Appendix (https://www.jianguoyun.com/p/DYU9DOgQn8GBCxj3xKYFIAA).

2.3 Procedure

Participants were comfortably seated in a quiet EEG recording room to perform the translation recognition task. All stimuli were administered by E-prime 3.0 software (Professional version 3.0.3.60, Psychology Software Tools, USA) on a 19-inch computer screen placed at a distance of approximately 60 cm in front of the participant. In line with a previous study (Zhang et al., 2022), each participant finished a task with four blocks of 60 trials (i.e., 240 trials in total) to avoid word pair repetition effects. A rest interval occurred after every 60 trials. As is shown in Figure 1, each trial contains five sequential events. (1) A fixation cross ("+") was presented for a random duration of 1000~1500 ms. (2) The Chinese words were presented for 250 ms, followed by a 500-ms blank screen, yielding a SOA of 750 ms. (3) The English words were presented for 500 ms. (4) A blank interval was presented for 3000 ms until participants responded. Participants were encouraged to determine whether the L1-L2 word pairs were translation equivalents as accurately and quickly as possible by pressing the "F" or "J" key (counterbalanced across participants). (5) A symbol of an eye blink "(- -)" was presented for 2000 ms. Participants were instructed to blink at this period as much as possible. Behavioral and EEG data were recorded simultaneously during the formal experimental phase.

2.4 Behavioral data processing and analysis

A logit mixed model (Jaeger, 2008) was employed to analyze the accuracy (binary data, 0 or 1). As for the reaction time, trials with errors (8.08% of the trials) and with reaction times that were longer than 2500 ms or that exceeded a threshold of 2.5 *SD* of mean reaction time (2.19% of the trials) were removed. The reaction time data were first log-transformed to reduce skewness and then submitted to a linear-mixed effect regression model (Baayen et al., 2008). The analyses of accuracy and reaction time data were performed in R (R Core Team, 2019) with the *glmer* and *lmer* functions in the lme4 package, respectively (Bates et al., 2015).

Table 1. The descriptive statistics (mean and *SD*) of the L1–L2 semantic relatedness, L1-L2 lexical similarity, number of strokes, string lengths, and frequency.

L1-L2 relationships	L1-L2 semantics relatedness	L1-L2 lexical similarity	L1		L2	
			Number of strokes	Frequency	String length	Frequency
Translation 国—country	--	--	9.63 (4.02)	3.23 (0.41)	4.62 (1.03)	3.25 (0.55)
Orthography 踝—class (课)	1.00 (0)	1.17 (0.38)	9.15 (2.48)	3.22 (0.47)	4.43 (1.01)	3.31 (0.46)
Phonology 壶—lake (湖)	1.00 (0)	1.00 (0)	9.32 (3.31)	3.32 (0.39)	4.55 (1.00)	3.32 (0.57)
Control 电—wall (墙)	1.00 (0)	4.93 (0.25)	8.82 (2.72)	3.27 (0.46)	4.70 (0.91)	3.39 (0.30)

Since stimulus type did not vary with items, the by-item random slopes were not entered into the model (Winter, 2019). The final fitted model contained the fixed effect of stimulus type, and the random effects of by-item random intercepts and by-participant random intercepts and slopes.

2.5 EEG/ERP recording and analysis

Continuous electroencephalogram (EEG) data were recorded from 64 active electrodes and an actiCHamp amplifier (Brain Products GmbH, Germany). The E-prime software computer was connected to the amplifier through the parallel port to send triggers during the experiment. The ground electrode and online reference were Fpz and Cz, respectively. The vertical electro-oculogram (VEOG) was recorded from an electrode placed above the left eye. The impedances of all electrodes were less than 5 KΩ. EEG signals were amplified with a band-pass filter of 0.01 Hz-70 Hz and were sampled at 1000 Hz.

The EEG data were pre-processed using the BrainVision Analyzer 2.1 and the EEGLAB toolbox (Version 14.1.1; Delorme & Makeig, 2004) in the MATLAB environment (R2016b, MathWorks Inc.) as follows. (1) Bad data were detected and removed manually by visual inspection. (2) The data were down-sampled to 500 Hz. (3) The EEG data were re-referenced offline to the mean of the activity at the two mastoids. (4) The data were digitally filtered with a 0.5 Hz-30 Hz band-pass filter. (5) The independent component analysis (ICA) method was applied for correcting the artifact of eye blink, eye movement, muscle noise, and so on. (6) Continuous data were segmented from -200 to 800ms relative to English target words onset and baselines were corrected to the pre-target interval. (7) Epochs with voltages beyond ± 75 µV or gradients larger than 50 µV were rejected, resulting in 8.27% of the trials being discarded. Additionally, four participants were discarded from analysis due to poor EEG data. All epochs of the remaining participants were combined in a 3D matrix (channels, time points, trials by participants), which forms the basis for the further linear-mixed effect regression models. (8) Epochs were grand-averaged for ERP and topographic map presentation.

According to previous studies (Ando et al., 2015; Jouravlev et al., 2014; Zhang et al., 2022), the effects of L1 lexical representations on L2 processing have been found at both early (100-300 ms) and late (300-500 ms) time windows. Thus, referring to the manipulations by Zhang et al. (2022), the ERP waveforms were divided into 100-ms time windows from 0 ms to 600 ms after target onset (six time windows) to explore the early and late ERP effects. Furthermore, according to visual inspection, the middle line's three regions of interest (ROIs) in the frontal (Fz), central (Cz), and parietal (Pz) regions and hemispheres' four ROIs in the left frontal-central (F1, F3, FC1,

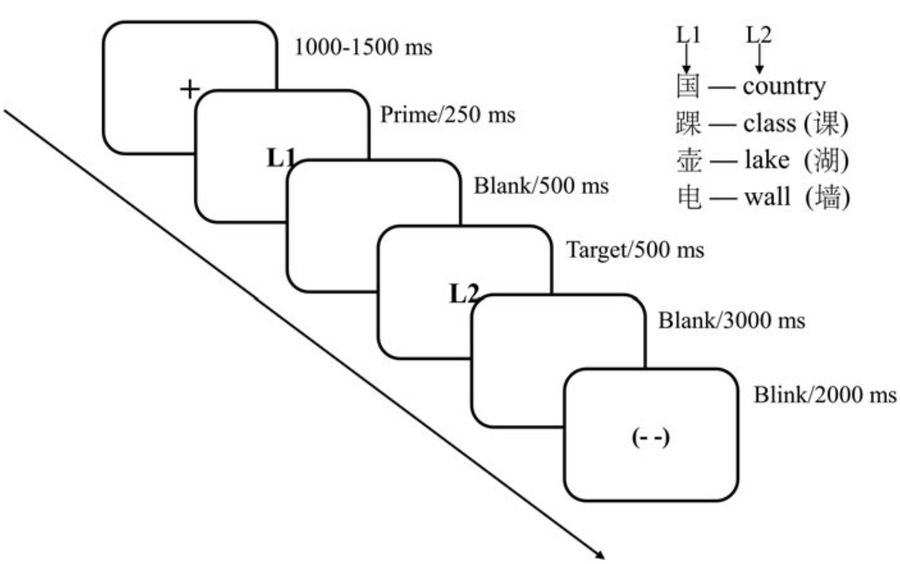

Figure 1. Illustration of the trial structure in the current experiment.

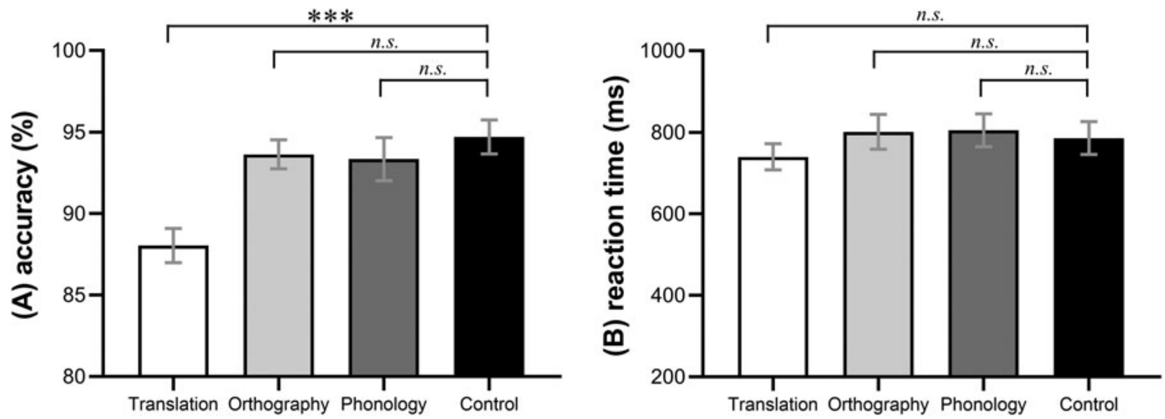

Figure 2. Accuracy rates and reaction times of the four stimulus types for the translation recognition task. The error bar represents ± standard error (*SE*). Note. **p* < 0.05, ***p* < 0.01, ****p* < 0.001, *n.s.* not significant.

and FC3), right frontal-central (F2, F4, FC2, and FC4), left central-parietal (CP1, CP3, P1, and P3), and right central-parietal (CP2, CP4, P2, and P4) regions were submitted to the linear-mixed effect regression models (Baayen et al., 2008), respectively. Note that the mean voltages in each hemisphere's ROI were first calculated. The linear-mixed effect regression models for the ERP data included the fixed effects of stimulus type, ROI, and interaction between stimulus type and ROI, as well as the random effects of by-participant and by-item intercepts. Planned post-hoc comparisons were performed on the main effects of stimulus type or the interaction between stimulus type and ROI with Tukey correction, looking at the differences between the three translation-related conditions and unrelated control condition, respectively.

3. Results

3.1 Behavioral results

The analysis yielded a significant main effect of stimulus type in accuracy, $\chi^2(3) = 19.60$, $p < 0.001$. Post-hoc test with Tukey correction revealed that participants responded more accurately to the unrelated control condition than to the translation equivalent condition, Estimate = 1.33, $SE = 0.30$, *z-value* = 4.45, $p < 0.001$. However, there were comparable overall accuracies between the unrelated control condition and orthographic translation neighbor, Estimate = 0.50, $SE = 0.26$, *z-value* = 1.95, $p = 0.21$, as well as phonological translation neighbor condition, Estimate = 0.33, $SE = 0.29$, z-value = 1.14, $p = 0.66$. On the reaction time data, the likelihood ratio test revealed a significant main effect of stimulus type, $\chi^2(3) = 11.85$, $p = 0.008$. However, post-hoc test with Tukey correction revealed no significant differences between the translation-related conditions and unrelated control conditions, all *z-values* < 2.39, $p > 0.08$. Figure 2 illustrates the overall mean accuracies and reaction times among each condition.

3.2 ERP results

Figure 3 displays the grand-averaged ERP waveforms across the four stimulus types in the middle line's three ROIs (i.e., Fz, Cz, and Pz electrode sites) and in the hemispheres' four ROIs (i.e., the grand-averaged ERPs in the left frontal-central, right frontal-central, left central-parietal, and right central-parietal regions). Figure 4 displays the ERP waveforms of two representative electrode sites (Fz and Pz) for the four conditions and topographic maps of the differences between the unrelated control condition and another three translation-related conditions. Table 2 summarized the results of the linear-mixed effect regression models within each 100-ms time window. Details of the analyses are described below.

0-100 ms time window

There were no significant main effects of stimulus type in the middle line's ROI, $\chi^2(3) = 3.12$, $p = 0.37$, and in the hemispheres' ROI, $\chi^2(3) = 2.48$, $p = 0.48$. The interaction effects were not significant either, middle line: $\chi^2(6) = 2.63$, $p = 0.85$; hemisphere: $\chi^2(9) = 4.48$, $p = 0.88$, suggesting that there were no significant differences among the four experimental conditions.

100-200 ms time window

No significant main effects of stimulus type were observed in the middle line's ROI, $\chi^2(3) = 5.04$, $p = 0.17$, and in the hemispheres' ROI, $\chi^2(3) = 6.84$, $p = 0.08$. Additionally, stimulus type significantly interacted with middle line' s ROI, $\chi^2(6) = 22.73$, $p < 0.001$, and with hemispheres' ROI, $\chi^2(9) = 19.36$, $p = 0.02$. Further planned comparisons found that the translation equivalent condition elicited more negative ERPs than unrelated control condition in the middle line's parietal ROI, Estimate = -0.89, SE = 0.27, z-value = -3.23, $p = 0.007$, and in the left hemisphere's central-parietal ROI, Estimate = -0.67, $SE = 0.25$, z-value = -2.69, $p = 0.04$. However, there were no significant differences between orthographic translation neighbor condition and unrelated control condition, all *z-values* < 2.36, $p > 0.09$, as well as between phonological translation neighbor condition and unrelated control condition, all *z-values* < 2.23, $p > 0.11$.

200-300 ms time window

The main effects of stimulus type were significant, middle line: $\chi^2(3) = 35.00$, $p < 0.001$; hemisphere: $\chi^2(3) = 31.72$, $p < 0.001$. The interaction effects were also significant, middle line: $\chi^2(6) = 26.54$, $p < 0.001$; hemisphere: $\chi^2(9) = 29.81$, $p < 0.001$. Further planned comparisons found that translation equivalent condition elicited less negative ERPs than unrelated control condition in the middle line's frontal-central ROIs, both *z-values* > 3.33, $p < 0.005$, as well as in the left and right hemispheres' frontal-central ROIs, both *z-values* > 3.05, $p < 0.01$. No significant differences were observed between orthographic translation neighbor condition and unrelated control condition, all *z-values* < 1.56, $p > 0.40$, as

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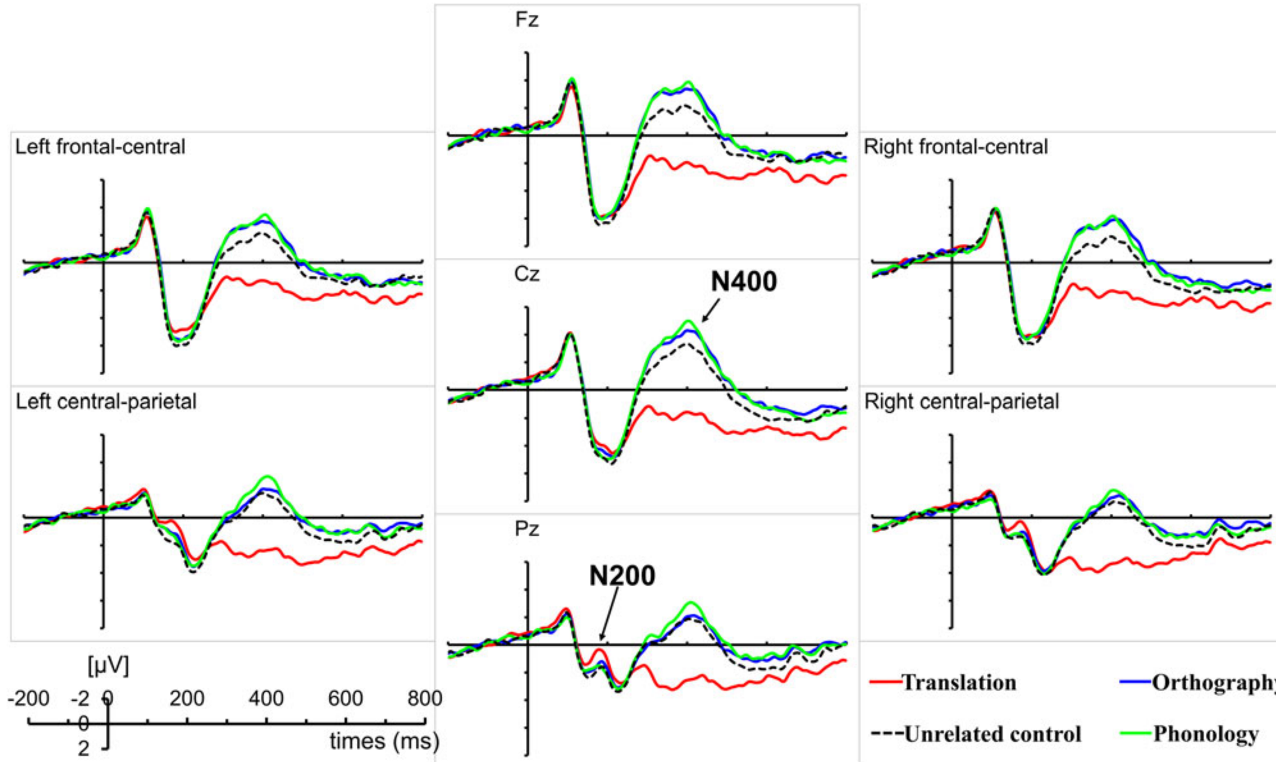

Figure 3. Grand-averaged ERPs for the four stimulus type conditions in the middle line's three ROIs (i.e., Fz, Cz, and Pz electrode sites) and in the hemispheres' four ROIs (i.e., left frontal-central, right frontal-central, left central-parietal, and right central-parietal regions).

well as between phonological translation neighbor condition and unrelated control condition, all *z-values* < 2.00, $p > 0.19$.

300-400 ms

The main effects of stimulus type and the interaction effects involving stimulus type were significant, middle line: both $\chi^2(3) > 27.02$, $p < 0.001$; hemisphere: both $\chi^2(3) > 19.92$, $p < 0.02$. Further planned comparisons revealed that translation equivalent condition elicited less negative ERP waveforms than unrelated control in all selected ROIs, middle line: all *z-values* > 10.04, $p < 0.001$; hemisphere: all *z-values* > 9.72, $p < 0.001$. Meanwhile, both orthographic and phonological translation neighbor conditions elicited more negative ERP waveforms than unrelated control condition in the middle line's frontal ROI, both *z-values* > 3.12, $p < 0.001$, and in the left and right hemispheres' frontal-central ROIs, all *z-values* > 3.20, $p < 0.007$.

400-500 ms and 500-600 ms time windows

The main effects of stimulus type were all significant in the two time windows, middle line: both $\chi^2(3) > 82.00$, $p < 0.001$; hemisphere: both $\chi^2(3) > 99.88$, $p < 0.001$. Further planned comparisons found that translation equivalent condition elicited less negative ERP waveforms than unrelated control, middle line: both *z-values* > 4.99, $p < 0.001$; hemisphere: both *z-values* > 5.54, $p < 0.001$. More importantly, both orthographic and phonological translation neighbor conditions elicited more negative ERP waveforms than unrelated control condition, middle line: all *z-values* > 3.30, $p < 0.005$; hemisphere: all *z-values* > 3.57, $p < 0.002$. The interaction effects were not significant, middle line: both $\chi^2(6) < 11.43$, $p > 0.08$; hemisphere: both $\chi^2(9) < 4.34$, $p > 0.89$, suggesting that the above overall pattern did not vary with the selected ROIs in the two time windows.

4. Discussion

The focus of the present study was to examine the roles of cross-language orthography and phonology on L2 word meaning access with Chinese–English bilinguals in a translation recognition context. For behavioral results (see Figure 2), due to the no-responses of translation non-equivalents being three times more frequent than yes-responses of translation equivalents, the participants might interpret the task as "are the word pairs translation non-equivalents?" rather than "are the word pairs translation equivalents?". Thus, the results revealed that participants were less accurate in response to translation equivalents than to unrelated controls and comparable reaction times between them. More importantly, the crucial comparisons revealed that both cross-language orthographic and phonological translation neighbors caused non-significant interference effects to the recognition of target words (i.e., comparable reaction times and accuracies), which is not consistent with our hypotheses, as well as previous translation recognition studies (Guo et al., 2012; Ma & Ai, 2018; Sunderman & Priya, 2012). In particular, Ma and Ai (2018) only found significant cross-language orthographic interference effects for both beginning and advanced Chinese learners of English in two L2-L1 translation recognition contexts. The divergent behavioral outcomes may be caused by multiple factors, such as translation direction (L1-L2 vs. L2-L1), English proficiency, or types of stimuli. It is necessary to examine whether these factors would impact the results in future research.

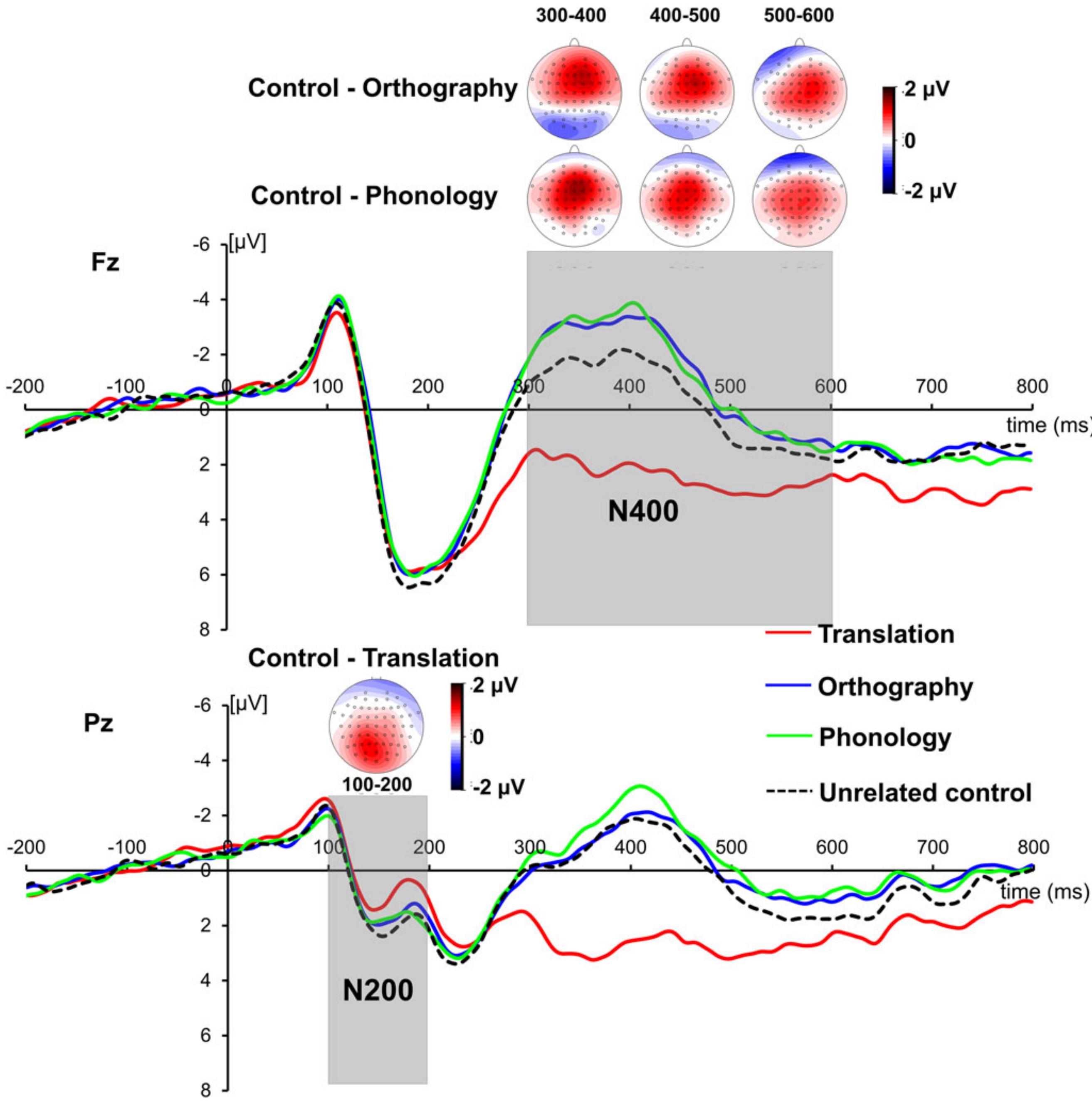

Figure 4. ERP waveforms of two representative electrode sites (Fz and Pz) for the four conditions and difference scalp maps of the unrelated control condition minus translation equivalent condition in the time window of the N200 component (100-200 ms), and unrelated control condition minus orthographic or phonological translation neighbor condition in the time window of the N400 component (300-600 ms).

Regarding the ERP data, the results showed a significant translation priming effect for translation equivalent than for unrelated control, as reflected by more negative ERP waveforms in the 100-200-ms time window in the central-parietal scalp and less negative ERP waveforms in the time window of 200-600 ms from frontal to parietal scalp, which were typical N200 and N400 components, respectively (see Figures 3 and 4). The reduced N400 component likely reflected the on-line L1 lexico-semantic activation and integration during the meaning access of the L2 words (Kutas & Federmeier, 2000, 2011). As for the enhanced N200 component, one possible explanation is that, due to the lower proportion of translation equivalents, the N200 enhancement reflected a similar cognitive mechanism to that in the Go/No-Go task, in which participants were instructed to withhold a response to infrequent stimuli or to give a speeded response to frequent stimuli. The infrequent stimuli elicited a larger N2 amplitude than frequent stimuli (Eimer, 1993; Nieuwenhuis et al., 2003). Accordingly, the N2 was explained to reflect the conflict monitoring or response inhibition of the frequent response. Similarly, in the present study, due to the higher percentage of translation non-equivalent word pairs, the enhanced N200 effect might reflect a similar neural mechanism. However, in

Table 2. Summary of the results of the linear-mixed effect regression models within each 100-ms time window.

Time window (ms)	Effects	Fixed effects in the middle's ROI: stimulus type	region	stimulus type × region	Fixed effects in the hemispheres' ROI: stimulus type	region	stimulus type × region
	df	3	2	6	3	3	9
0-100	χ^2	3.12	11.23	2.63	2.48	25.76	4.48
	p	0.37	0.004**	0.85	0.48	< 0.001***	0.88
100-200	χ^2	5.04	80.09	22.73	6.84	164.93	19.36
	p	0.17	< 0.001***	< 0.001***	0.08	< 0.001***	0.02*
200-300	χ^2	35.00	95.07	26.54	31.72	59.71	29.81
	p	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***
300-400	χ^2	239.69	270.58	27.02	233.96	414.12	19.92
	p	< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***	0.02*
400-500	χ^2	238.92	109.76	11.43	249.46	79.19	4.35
	p	< 0.001***	< 0.001***	0.08	< 0.001***	< 0.001***	0.89
500-600	χ^2	82.00	13.08	3.96	99.88	16.82	3.13
	p	< 0.001***	0.001**	0.68	< 0.001***	< 0.001***	0.96

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

comparison to the present central-parietal scalp distribution, the N2 effects in the Go/No-Go task usually had a frontal distribution. So, the interpretation of the N200 effect under the theoretical framework of Go/No-Go task is not convincing.

Alternatively, previous studies observed similar central-parietal N200 enhancement effects in repetition priming in Chinese word recognition and interpreted it as a neural marker associated with whole-word orthographic processing. For example, repeated Chinese word pairs elicited more negative N200 amplitudes and less negative N400 amplitudes than unrelated word pairs. And the N200 component was neither modulated by lower-level physical stimulus properties nor by higher-level phonological and semantic processes (Jia et al., 2013; Zhang et al., 2012). Accordingly, another more plausible explanation is that such an enhancement effect might be due to the fact that the English words activated their corresponding translation equivalents that shared the same orthographic features as preceding Chinese words, resulting in the N200 enhancement effect.

Furthermore, the time window of the N200 component is comparable with the P200 component (100-300 ms), which reflects the lexical orthographic and/or phonological processing between word pairs (Barnea & Breznitz, 1998; Liu et al., 2003). For example, in the frontal-central scalp, orthographically similar Chinese word pairs (e.g., "凉/Liang2/[cold]" – "惊/Jing1/[surprise]") elicited a less positive P200 amplitude than unrelated pairs (e.g., "凉/Liang2/[cold]" – "输/Shu1/[lose]") in a pronunciation judgment task (Liu et al., 2003). In contrast, in the central-parietal scalp, phonologically similar Chinese word pairs (e.g., "梏/Gu4/[imprison]" – "雇/Gu4/[hire]") elicited a more positive P200 amplitude than unrelated pairs (e.g., "梏/Gu4/[imprison]" – "甥/Sheng1/[nephew]") in a semantic judgment task (Kong et al., 2010). As mentioned in the introduction, when the SOA was 750 ms, Guo et al. (2012) found that through-translation lexical-related word pairs (e.g., "bee[蜂/Feng1/]" - "峰/Feng1/[peak]") also induced a more positive P200 (150-300 ms) amplitude than unrelated controls ("bee[蜂/Feng1/]" - "南/Nan2/[south]") in the central-parietal scalp. These results substantiated that variables in orthographic and phonological overlap contributed differently to the reduction or increase of the P200 amplitude, and a negative shift of the P200 component was sensitive to Chinese orthographic processing. Based on these considerations, any difference in N200 amplitude here was most likely driven by the differences in the preceding P200 component. It might suggest that there was a rapid cross-language whole-word orthographic activation during the processing of English words in Chinese–English bilinguals.

As predicted, both orthographic and phonological translation neighbors elicited significantly more negative ERP waveforms than unrelated control in the bulk of the N400 time window (300-600 ms) (see Figures 3 and 4). It has been argued that an increased N400 amplitude reflects the difficulty of retrieving target words (Jankowiak & Rataj, 2017). The pattern of the N400 effects resembles those results in earlier ERP studies. For example, Dutch–English bilinguals performed an English lexical decision task with interlingual homographs. ERP results revealed that homographs for high-frequency Dutch words resulted in slower reaction times and more negative N400 amplitudes than words for low-frequency Dutch words (Kerkhofs et al., 2006). More relevantly, word recognition in one language with many cross-language orthographic neighbors generated increased N400 amplitudes than words with few cross-language orthographic neighbors (Meade et al., 2018; Midgley et al., 2008). According to the BIA+ model, researchers explained that the increased negativity to words with higher word frequency in the non-target language or larger cross-language orthographic neighbors reflected a top-down IC mechanism operating cross-language lexical activation and competition. Accordingly, the reasonable interpretation in the present study was that the Chinese lexical representations became active in the processing of English targets and competed or conflicted with the preceding Chinese orthographic and phonological neighbors. Resolution of such competition and confliction required the participation of an IC mechanism, resulting in the enhanced N400 effects.

The N400 component has been discussed under bottom-up and/or top-down language-related processing to interpret the precise roles in language comprehension (Jankowiak & Rataj, 2017). According to the Access/Retrieval View (Delogu et al., 2019; Lau et al., 2008), the N400 component is usually thought to index the ease in extracting the lexical information of target words from long-term memory at the pre-lexical or lexical stage. For example, orthographically similar Chinese prime-target word pairs (e.g., "读/Du2/[read]" - "续/Xu4/[continue]") induced a smaller N400 amplitude relative to the control condition (e.g., "料/liao4/[material] " - "神/Shen2/[god]"), indicating a facilitation of lexical retrieval (Chen et al., 2007). However, according to the Integration View (Brown & Hagoort, 1993; Hagoort et al., 2004), the N400 component could also index the effort in integrating the meaning of target words from preceding words, which is generally thought to occur at a post-lexical stage. Thus, the amplitudes of the N400 component vary as a function of the integration effort. Finally, the "Hybrid" View (Lau et al., 2016; Nieuwland et al., 2020) integrates the perspectives of the two views. Taken together, both access and integration processes might be involved in the translation recognition task, as reflected by smaller N400 amplitudes in the translation equivalent condition and larger N400 amplitudes in the orthographic and phonological translation neighbor conditions, supporting the "Hybrid" account.

4.1 Theoretical implications

As mentioned in the introduction, the BIA+ model constructed an integrated word recognition system with two subsystems to handle lexical interactions within and across languages. It accounts for both intra- and interlingual lexical bottom-up priming and competition effects in different categories of bilinguals' word recognition, during which top-down cognitive control would deal with lexical competition or confliction. As mentioned in the introduction, previous studies using the masked priming (Zhang et al., 2022) or implicit priming paradigm (Thierry & Wu, 2007; Wu & Thierry, 2010) demonstrated the bottom-up parallel cross-language activation of Chinese phonological, but not orthographic representations during the processing of English words, as reflected by less negative N400 amplitudes. Those N400 effects have also been suggested to reflect on-line lexical retrieval. In contrast, the current findings further demonstrated that both orthographic and phonological representations of Chinese words exert effects on the meaning access of English words in a translation recognition context, as reflected by more negative N400 amplitudes. We further interpreted it as a neural index reflecting the impact of the top-down IC mechanism on lexical competition and confliction. Combined with the abundance of masked priming and implicit studies in Chinese–English bilinguals, as well as the present explicit translation recognition study, these findings suggested that both bottom-up parallel cross-language activation and the subsequent top-down IC mechanism govern the two-languages lexical-semantic organization in Chinese–English bilinguals' word recognition, which is in accordance with the framework of BIA+ modal.

Furthermore, we discussed the temporal dynamics of cross-language lexical activation during English word reading. According to the BIA+ modal, visual input first activates the sub-lexical and lexical orthographic representations and then the corresponding phonological and semantic representations of both languages. Consequently, the phonological and semantic representations are accessed slightly later than the orthographic representations in both languages. As mentioned earlier, the N200 component indexed or at least partially indexed a rapid whole-word orthographic representation access of Chinese during English reading. In contrast, the later orthographic and phonological N400 effects reflected the effort in integrating the meaning of target words from preceding words. This integration process has been demonstrated to occur at a post-lexical stage (Kutas & Federmeier, 2011). If this logic was true, we tried to explain the temporal dynamics of cross-language lexical activation during English reading in the framework of the BIA+ modal: English visual input could rapidly activate the whole-word orthographic representations of Chinese translations, leading to the earlier N200 enhancement effects. Subsequently, the activation is interactively spread to the phonological and semantics nodes. Finally, the lexical competition and interference resulted in the later orthographic and phonological N400 effects.

4.2 limitations

However, the present study has a few limitations that need to be improved in future studies. First, in the present manipulations, through-translation orthographic neighbors between Chinese and English words overlapped on the sub-lexical level partial strikes or main radicals. In comparison, phonological matching overlapped on the lexical level syllables, which was closer. The influence of different level through-translation overlapping on the ERP results cannot be fully excluded. Then, previous bilingual studies using masked priming tasks have reported less negative N250 component and N400 component for the L1-L2 translation equivalent condition than for unrelated control condition (Hoshino et al., 2010; Midgley et al., 2009). The N250 has been demonstrated to reflect the mapping of sub-lexical orthographic representation to whole word form processing (Grainger & Holcomb, 2009). The early N200 enhancement, which was explained to reflect early cross-language whole-word orthographic processing in the present study, is opposite in polarity from the N250 component. The early N200 enhancement and later N400 reduction are an intriguing phenomenon. However, whether or to what extent the N200 component would be affected by the stimulus probability requires further investigation. In future studies, one way to examine the influence of stimulus probability on the N200 effect is to keep the percentage of the translation equivalent/translation non-equivalent responses at 50/50. This would provide complementary evidence to the interpretation of the current N200 effect.

5. Conclusion

The present study examined the different roles that orthographic and phonological information of L1 play during L2 word meaning access with Chinese–English bilinguals in a L1-L2 translation recognition context. Despite some unfathomed mechanisms, the results bring further insight into bilinguals' different-script lexical organization: both orthographic and phonological translation neighbors induced more negative N400 components than unrelated control in the frontal-central regions, suggesting the modulation of top-down IC mechanism on lexical competition and confliction, which is in line with the framework of the BIA+ model.

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Data availability statement. The data or datasets generated during and/or analyzed during the current study are available from the corresponding author on request. For stimuli appendix accompanying this paper, visit https://www.jianguoyun.com/p/DYU9DOgQn8GBCxj3xKYFIAA

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