Event-related brain potential investigation of preparation for speech production in late bilinguals

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It has been debated how bilinguals select the intended language and prevent interference from the unintended language when speaking. Here, we studied the nature of the mental representations accessed by late fluent bilinguals during a rhyming judgment task relying on covert speech production. We recorded event-related brain potentials in Chinese–English bilinguals and monolingual speakers of English while they indicated whether the names of pictures presented on a screen rhymed. Whether bilingual participants focussed on rhyming selectively in English or Chinese, we found a significant priming effect of language-specific sound repetition. Surprisingly, however, sound repetitions in Chinese elicited significant priming effects even when the rhyming task was performed in English. This cross-language priming effect was delayed by ~200 ms as compared to the within-language effect and was asymmetric, since there was no priming effect of sound repetitions in English when participants were asked to make rhyming judgments in Chinese. These results demonstrate that second language production hinders, but does not seal off, activation of the first language, whereas native language production appears immune to competition from the second language.

Keywords: ERP, bilingualism, language production, cognitive control, inhibition

INTRODUCTION

Speaking is the process of transforming thoughts into speech. Current psycholinguistic models posit that speech production involves multiple stages of information processing including, conceptualization, retrieval of lexical representations, and the motor preparation for articulation (Dell, 1986; Levelt, 1989, 1999; Caramazza, 1997). For bilingual individuals, an additional task is to select words from the appropriate (i.e., intended) language to speak. Experimental psychology and electrophysiological research have made the case that when they speak in one language, information in the other language is also being activated. Therefore, how bilinguals manage to select words in the intended language and prevent interference from the unintended language has been a central question for research on bilingual language production. In the current study, we first review previous attempts to reveal the nature of the cognitive and brain mechanisms that control bilingual language production, with a focus on methodology. We argue that the tasks and measurements used in these studies do not allow teasing apart the interplay of the first and second language; instead, they often mix the effects derived from activations of both languages during speech preparation. As a result, the function of the control mechanism has not been fully specified. We then introduce an alternative paradigm, which provides insights into first and second language activation, respectively, when bilinguals make covert spoken word production.

When speaking in their relatively weaker language (i.e., the second language), bilingual speakers have been shown to make speech errors that are characteristic of their native language (Poulisse and Bongaerts, 1994; Poulisse, 1997, 1999). Although it is difficult to determine the exact source of this cross-language interference,

speech errors in bilinguals form the preliminary evidence for access to the unintended language. Further evidence derives from experimental studies that make use of interlingual materials such as cognates (words that share semantic and lexical form across languages; e.g., "café," which the same word in English and French. For example, it has been repeatedly shown that bilingual speakers name pictures faster when their names are cognates as compared to non-cognates. Given that monolinguals do not distinguish cognates from words that only exist in one language, the effect found in bilinguals must relate to representations in both the intended and the unintended languages. It has been proposed that the cognate facilitation effect originates in the additional source of activation afforded by existing representations in both the languages as compared to language-specific words (Costa et al., 2000; Kroll et al., 2000; Christoffels et al., 2006; Hoshino and Kroll, 2008, but see Sanchez-Casas and Garcia-Albea, 2005, for an alternative explanation). The cognate effect has been replicated by studies using event-related potentials (ERPs). ERPs are average recordings of brain potentials associated with mental operations. Christoffels et al. (2007) found an enhanced negativity between 300 and 400 ms when bilingual participants named pictures whose names are cognates. These ERP modulations were correlated with reduced reaction times found in both a blocked and a mixed language experiment.

In addition to the cognate effect, previous studies have shown that picture naming latency is significantly reduced when a picture is followed by or presented together with a distractor word that is the translation of the picture's name in the unintended language (i.e., the picture–word interference paradigm; Costa et al., 1999). Other studies have shown significant increase in picture naming latency when the distractor word in the non-target language is

phonologically related to the picture name in the target language (the so-called phonotranslation effect; Hermans et al., 1998; Costa et al., 2003; Hermans, 2004). In both cases, the significant effect of non-target language distractors on naming latencies, whether facilitatory or interfering, is a sign of language co-activation in the course of production. This pattern of results in bilinguals is comparable with the performance of monolinguals when the picture is named in the same language as the distractor word (the so-called phonological interference effect; Lupker, 1979; La Heij et al., 1985), suggesting that planning for speech activates both the intended and the unintended language in bilinguals. Furthermore, an ERP study has also found that translation distractors presented in the non-target language reduce the ERP amplitude as compared to the control condition, when Chinese–English bilinguals are engaged in a covert picture naming task (Guo and Peng, 2006). This cross-language identity effect, which is dependent on relative proficiency in the two languages, suggests that parallel activation of the first and second language during speaking extends beyond the level of lexical representations since there is no overlap between translation equivalents in Chinese and English.

However, cognate and picture–word interference studies do not specify the level of representations that is activated in the unintended language and the time course of its activation in relation to accessing the target language. Since cognates share lexical-semantic as well as phonological features across languages, it is difficult to pinpoint the representation level at which the cognate facilitation effect finds its source (Costa et al., 2005). For example, Strijkers et al. (2010) demonstrated, in an early temporal window (e.g., 180–200), effects of lexical frequency and cognate status on ERPs collected during bilingual speech production. However, the lexical origin of the cognate effect cannot exclude the possibility of phonological priming resulting from additional source of activations due to shared phonological representations. Another issue is that cognates, like other stimuli present in some form in two different languages, are likely to activate representations and processes in the two languages (Hermans et al., 2010; Wu and Thierry, 2010). While for some bilingual individuals (e.g., Spanish–Catalan bilinguals) dual-language is the natural speech context, bilinguals with other language pairs are exposed to a different language context (e.g., Chinese–English bilinguals). Therefore, studies involving cognates have limitations regarding result generalization. Furthermore, cognate effects, as assessed by behavioral performance or with ERPs, cannot tease apart the processes at work when bilingual produce words in each of their languages considered separately. This problem is even more salient when pictures are mixed with distractor words in the unintended language whether they are presented in the visual or the auditory modality. On the basis of effects observed in the picture–word interference paradigm it is only possible to infer that the unintended language is accessed when bilinguals prepare for speech. It is difficult, however, to characterize the independent contribution of language-specific representations or to distinguish semantic and lexical interference from cognate effects. Moreover, in a typical picture–word interference paradigm, the distractor word itself initiates a bottom-up word recognition process that intrudes into speech planning. Consequently, evidence derived from picture–word interference must be regarded as complicated by the interaction between the processing of the word and that of

the picture rather than "pure" word production (see alternative evidence for cross-language phonological activations using simple picture naming in Colomé, 2001).

To characterize the nature of the representations from the two languages accessed during speech production in bilingual individuals, the present study manipulated phonological priming in the first and second languages independently. In experiment 1, Chinese–English proficient bilinguals were engaged in a rhyming judgment task in which they had to decide whether the English name of the target picture rhymed with that of a picture prime. Pairs of pictures from four conditions were presented randomly: semantically related, semantically unrelated but rhyming in English, and semantically unrelated but rhyming in Chinese, and semantically unrelated but rhyming in neither English or Chinese (**Figure 1**). We avoided artificial effects by facial movements on ERPs during overt speech, and also enabled measurement of activity in a late time window (i.e., 600 ms+) by engaging participant in a task only requiring button presses. However, this relied on the assumption that rhyming judgment required phonological access to the name of the picture.

Previous behavioral studies are limited to overall effects on reactions times which tell us nothing of the phases of processing preceding the observed response (e.g., voice reaction time). The present study used ERPs to investigate language co-activation during production to provide insights into the time course of priming effect from stimulus presentation to response. Whilst the ERPs elicited by semantically related pictures were expected to reveal the time course of access to meaning, ERPs elicited by target pictures that rhymed in English or in Chinese with the name of the picture prime provided insight into the activation of intended versus unintended phonological representations. Indeed, if naming in English involves phonological access to Chinese (i.e., the unintended language), this process can be characterized by comparison with phonological activation of English (i.e., the intended language) and with semantic priming, since these three processes were tested independently within three different experimental conditions. This paradigm avoids the explicit dual-language context caused by the presentation of distractor words and a language-ambiguous context by the use of cognates. We also tested a group of native English speakers as control participants to (1) obtain a baseline for rhyming effects and (2) ensure that the rhyming manipulation in Chinese picture names did not induce spurious effects in English.

In experiment 2, Chinese–English bilingual participants performed the rhyming judgment task in Chinese to examine possible influences of second language activation during the production of the native language. The majority of studies in the literature have focused on the influence of the stronger language (i.e., the first or native language) on the processing of the weaker language (i.e., the second language). Therefore, it remains unclear whether a second language affects the processing of the native language during production (but see Bloem and La Heij, 2003). To investigate this, the present study tested covert word production in both languages using a fully balanced design. When bilingual participants performed the task in Chinese, priming effects triggered by English rhymes were expected to reveal the potential interference of second language information retrieval during native language
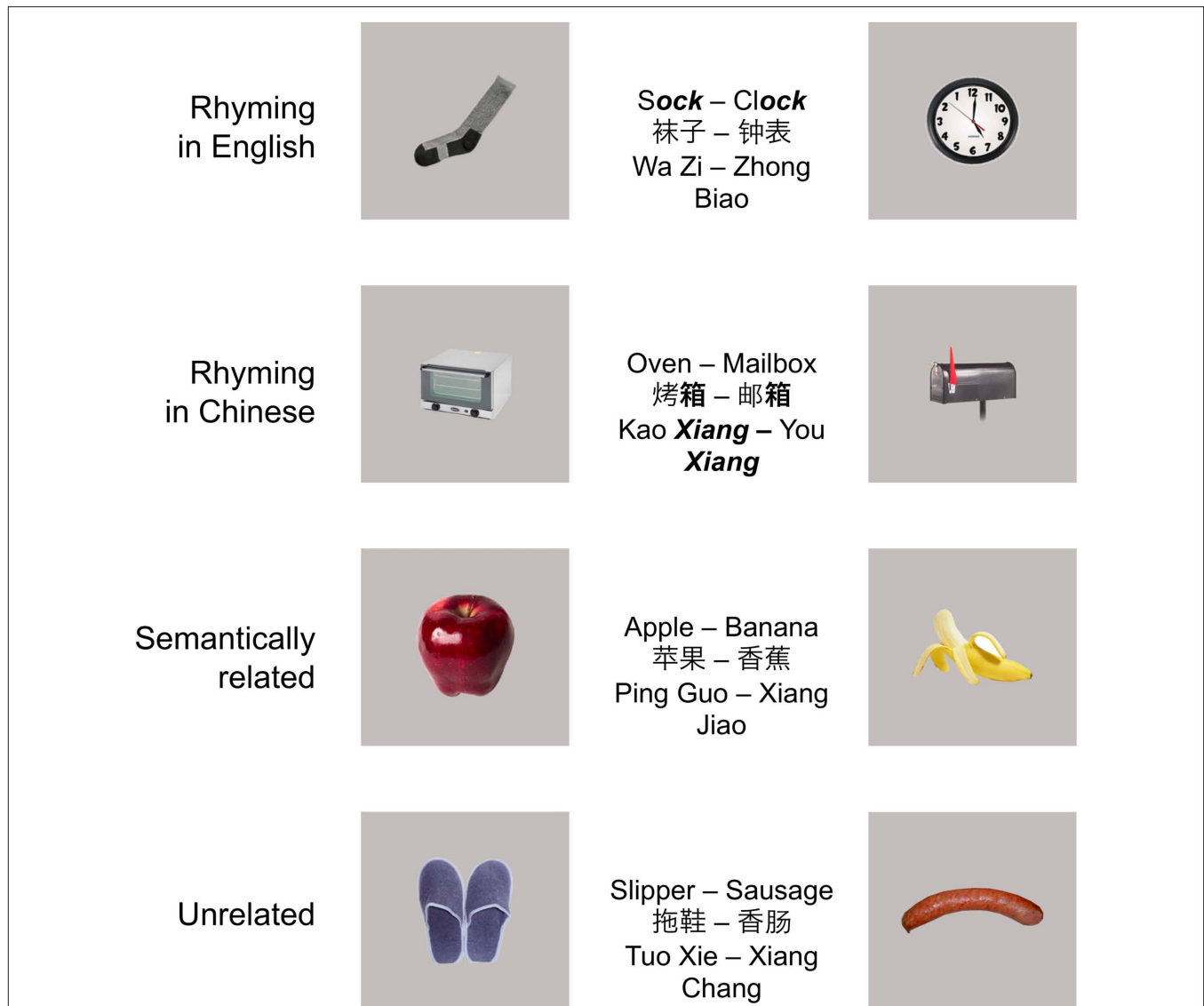
FIGURE 1 | Examples of stimuli used in the rhyming judgment tasks. Each cell contains one example of a picture pair used in the English and Chinese tasks, its English names, its simplified Chinese translations, and the corresponding Chinese Pin Yin (alphabetic transposition of the phonological form). As compared to English, Chinese characters that rhyme seldom bear overlaps in written forms (i.e., orthography). To prevent the potential confounding effects of orthographic variability on picture naming (Weekes et al., 2005; Bi et al., 2009; Zhang et al., 2009), we used Chinese words that shared a character repetition in both phonology and orthography, forming a "rhyming" condition

that is comparable to the English control condition. Color pictures of objects from real life situation were used to minimize naming difficulty, since black–white line drawings can sometimes be more difficult to name. The current experiment did not include a "familiarization" procedure in which participants were trained with the desired names of stimuli in advance. Although, as is common practice in picture naming studies, such practice helps reduce error rates, ERPs are particularly sensitive to storage in episodic memory. Also, such a procedure tends to prime a specific lexical candidate for each picture and, therefore, may artificially bias language production.

production. In the same experimental session, priming effects elicited by Chinese rhymes served as a baseline for overt priming effects in the intended native language.

MATERIALS AND METHODS
PARTICIPANTS
Fifteen Chinese students studying at Bangor University who had normal or corrected-to-normal vision and self-reported normal hearing were paid to take part in the experiment. Their age

ranged between 19 and 23, and they were controlled for handedness (right) and the level of education (undergraduate). The Chinese–English bilinguals started English formal instruction at the age of puberty (e.g., 12 or 13). At the time of testing, they were living and studying in the UK for an average of 18 (±3.2) months. In terms of English proficiency, all participants had a score of 6 as measured by the International English Language Testing System (IELTS), which is the entrance requirement for non-native speakers to study in most English-speaking institutions (www.ielts.org/

test_takers_information/what_is_ielts.aspx). The IELTS equally covers four fundamental language skills (i.e., reading, listening, writing, and speaking). The maximum score for IELTS is 9 and the majority of test takers obtain a score of between 4 and 7. Fifteen English monolinguals were recruited from students taking a psychology undergraduate course at Bangor University as control participants and they were paid with course credits for their participation. Every participant signed a consent form before taking part in the experiment that was approved by the ethics committee of the School of Psychology, Bangor University.

STIMULI

Two hundred pairs of pictures were equally allocated to four experimental conditions in terms of semantic relatedness (i.e., related or unrelated), and rhyming names (i.e., rhyming in English or Chinese). They were matched between conditions for lexical frequency and concreteness (Coltheart, 1981). The English names were matched for numbers of phonemes across conditions ($P > 0.1$) and the Chinese names were always two characters in length. Semantic relatedness between pictures was rated on a Likert scale from 1 (unrelated) to 5 (strongly related) by two independent groups of native Chinese and native English speakers (**Figure 1**). Differences in semantic relatedness ratings were highly significant between semantically related and unrelated pairs ($P < 0.001$ for all pairwise comparisons). Picture stimuli were matched across conditions for basic visual characteristics (e.g., size, resolution, and background). The variability in point of view, shape, and color of the objects presented was large in all the conditions to avoid a systematic bias in terms of inter-stimulus variance (Thierry et al., 2007). Particular care was taken in the choice of pictorial representations for each target word such that these were not biased toward Chinese or English cultural prototypes (see examples in **Figure 1**). No picture was repeated throughout the experiment.

PROCEDURE

All experiments took place in a sound-proof laboratory where the participant sat on a comfortable armchair 1.5 m away from a computer screen. After signing the consent form and receiving the instruction, participants viewed two blocks of stimuli presented in a pseudo-randomized order. Each trial began with a pre-stimulus interval of 200 ms. A picture was then flashed for 500 ms at fixation followed by the second picture of a pair, which stayed on the screen until a response was made, after a randomly selected inter-stimulus interval of 500, 600, or 700 ms. Participants were instructed to indicate whether the name of the second picture in each pair either rhymed in English (Exp 1) with that of the first picture or shared a phonological component (character) in Chinese (Exp 2) by pressing keys set under their left and right index fingers. Response side and the order of experiments were fully counterbalanced between participants. Naturally, English control participants who have no knowledge of Chinese were only given the English rhyming task. All participants were debriefed orally.

ERP RECORDING

Electrophysiological data were recorded in reference to Cz at a rate of 1 kHz from 64 Ag/AgCl electrodes placed according to the extended 10–20 convention. Impedances were kept <5 kΩ.

Electroencephalogram activity was filtered on-line band pass between 0.1 and 200 Hz and refiltered off-line with a 25-Hz, low-pass, zero-phase shift digital filter. Eye blinks were mathematically corrected, and remaining artifacts were manually dismissed. There was a minimum of 30 valid epochs per condition in every subject. Epochs ranged from −100 to 1000 ms after the stimulus onset. Baseline correction was performed in reference to pre-stimulus activity, and individual averages were digitally re-referenced to the global average reference. ERP data were collected simultaneously to behavioral data.
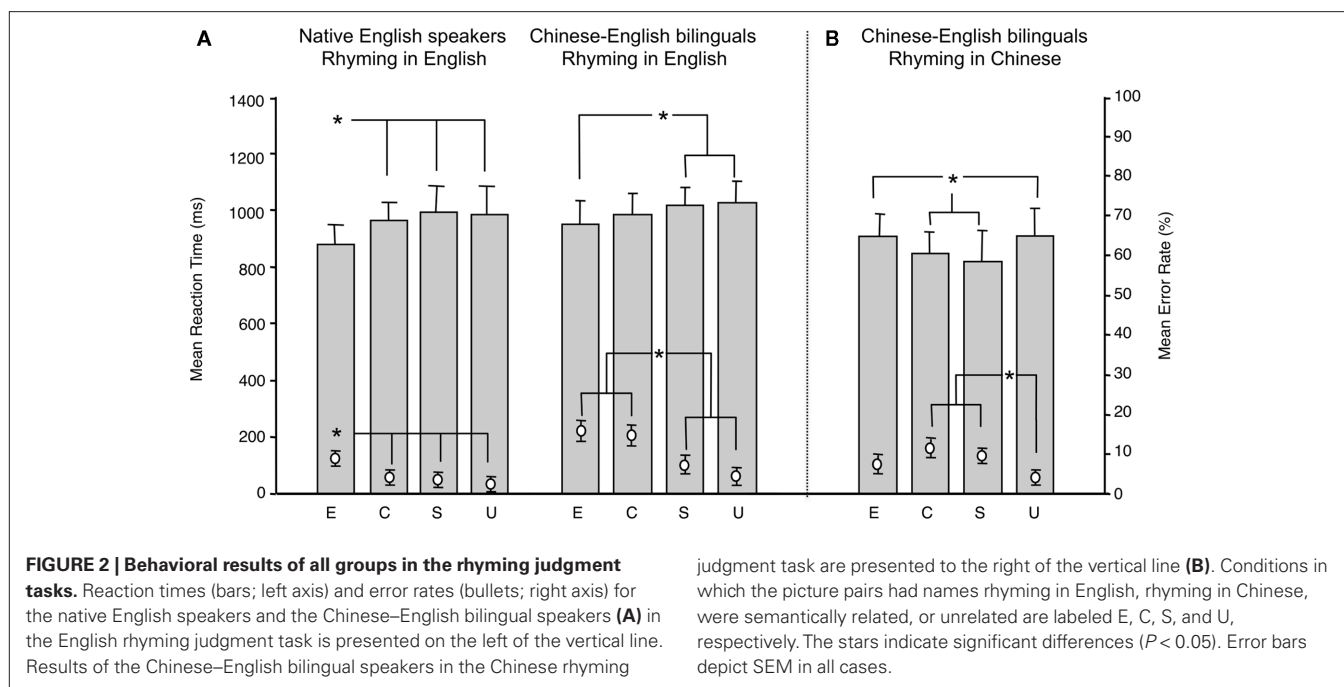
ERP DATA ANALYSIS

Peak detection was carried out automatically, time-locked to the latency of the peak at the electrode of maximal amplitude on the grand-average ERP. Temporal windows for peak detection were determined based on visual inspection of variations of the Global Field Power measured across the scalp (Picton et al., 2000; Luck, 2005). Mean ERP amplitudes elicited by the target picture were subjected to a repeated measures analysis of variance (ANOVA) with rhyming (rhyming in English/rhyming in Chinese/no rhyming but semantically related/completely unrelated) and electrode (63 levels) as within-subject factors, and group as between-subject factor (native English controls/Chinese–English bilinguals) using a Greenhouse–Geisser correction where applicable. We also analyzed ERP data by means of pairwise millisecond-by-millisecond comparisons between conditions considered significant when differences were above threshold ($P < 0.05$) for >30 ms over a minimum of nine clustered electrodes (Guthrie and Buchwald, 1991).

RESULTS

In experiment 1, when native English speakers performed the rhyming task in English, repeated measures ANOVA revealed a significant main effect of condition on reaction times ($F_{3,42} = 2.91$, $P < 0.05$). *Post hoc* analysis (LSD) showed that this difference was driven by faster reaction times for target pictures names that rhymed with prime pictures names in English as compared to all other conditions (**Figure 2**, all $Ps < 0.05$). We also found that more errors were made for the English rhyming condition ($F_{3,42} = 8.61$, $P < 0.001$) than for the other conditions (all $Ps < 0.001$). In particular, no effect of rhyming in Chinese names was found on either reaction times or error rates in native English control participants (all $Ps > 0.1$). In the Chinese–English bilinguals, rhyming in English reduced reaction times ($F_{3,42} = 3.08$, $P < 0.001$) and increased error rates ($F_{3,42} = 4.7$, $P < 0.001$) as compared to semantically related and unrelated picture pairs, but no significant reaction time difference was found between pairs of picture names that rhymed in English and those that rhymed in Chinese ($P > 0.1$). However, picture names rhyming in Chinese (i.e., in the unintended language) also increased error rates as compared to semantically related and unrelated picture pairs ($P < 0.05$).

In experiment 2, Chinese–English bilingual participants making rhyming judgments in Chinese responded significantly faster ($F_{3,42} = 2.98$, $P < 0.05$) to picture pairs with rhyming names in Chinese and semantically related pictures as compared to picture pairs that rhymed in English and unrelated pictures (all $Ps < 0.05$). Bilingual participants also made more errors ($F_{3,42} = 3.42$, $P < 0.05$) in these two conditions as compared to

FIGURE 2 | Behavioral results of all groups in the rhyming judgment tasks. Reaction times (bars; left axis) and error rates (bullets; right axis) for the native English speakers and the Chinese–English bilingual speakers **(A)** in the English rhyming judgment task is presented on the left of the vertical line. Results of the Chinese–English bilingual speakers in the Chinese rhyming judgment task are presented to the right of the vertical line **(B)**. Conditions in which the picture pairs had names rhyming in English, rhyming in Chinese, were semantically related, or unrelated are labeled E, C, S, and U, respectively. The stars indicate significant differences ($P < 0.05$). Error bars depict SEM in all cases.

the unrelated condition (both $Ps < 0.05$). No effect of rhyming in English was found either on reaction times or error rates in this experiment (all $Ps > 0.1$).

The ERP data was collected simultaneously with behavioral data. In native speakers of English performing the English rhyming task, a repeated ANOVA showed a significant effect of condition on ERP mean amplitude ($F_{3,42} = 19.2$, $P < 0.001$). *Post hoc* analysis revealed that this effect was accounted for by two differences (**Figure 3**). Firstly, target pictures that rhymed with prime pictures in terms of English names elicited significantly reduced ERP amplitudes as compared to those rhyming based on Chinese names and unrelated picture names (all $Ps < 0.001$). A millisecond-by-millisecond comparison revealed that the significant difference in this comparison started as early as 220 ms after the presentation of the target picture. Secondly, target pictures related in meaning to the prime pictures elicited reduced ERP amplitudes as compared to unrelated pairs of pictures ($P < 0.001$), with a similar time course as the priming found for rhyming in English. There was no difference between the ERPs elicited by target pictures whose names rhymed based on Chinese picture names and the ERPs elicited by completely unrelated pictures ($P > 0.1$).

Statistical analysis of ERPs recorded in the Chinese–English bilinguals performing the English rhyming task showed a main effect of condition ($F_{3,42} = 5.52$, $P < 0.001$). Rhyming in English and semantic relatedness of the pictures both reduced the ERP main amplitude against the unrelated condition (all $Ps < 0.001$). The priming effect elicited by rhymes in English was significant between 250 and 600 ms and of smaller magnitude than the same effect found in the native English participants. The priming effect of semantic relatedness started at around 250 ms and extended throughout the whole period of analysis (i.e., 1000 ms), showing a comparable time course and magnitude to that of the native English control participants.
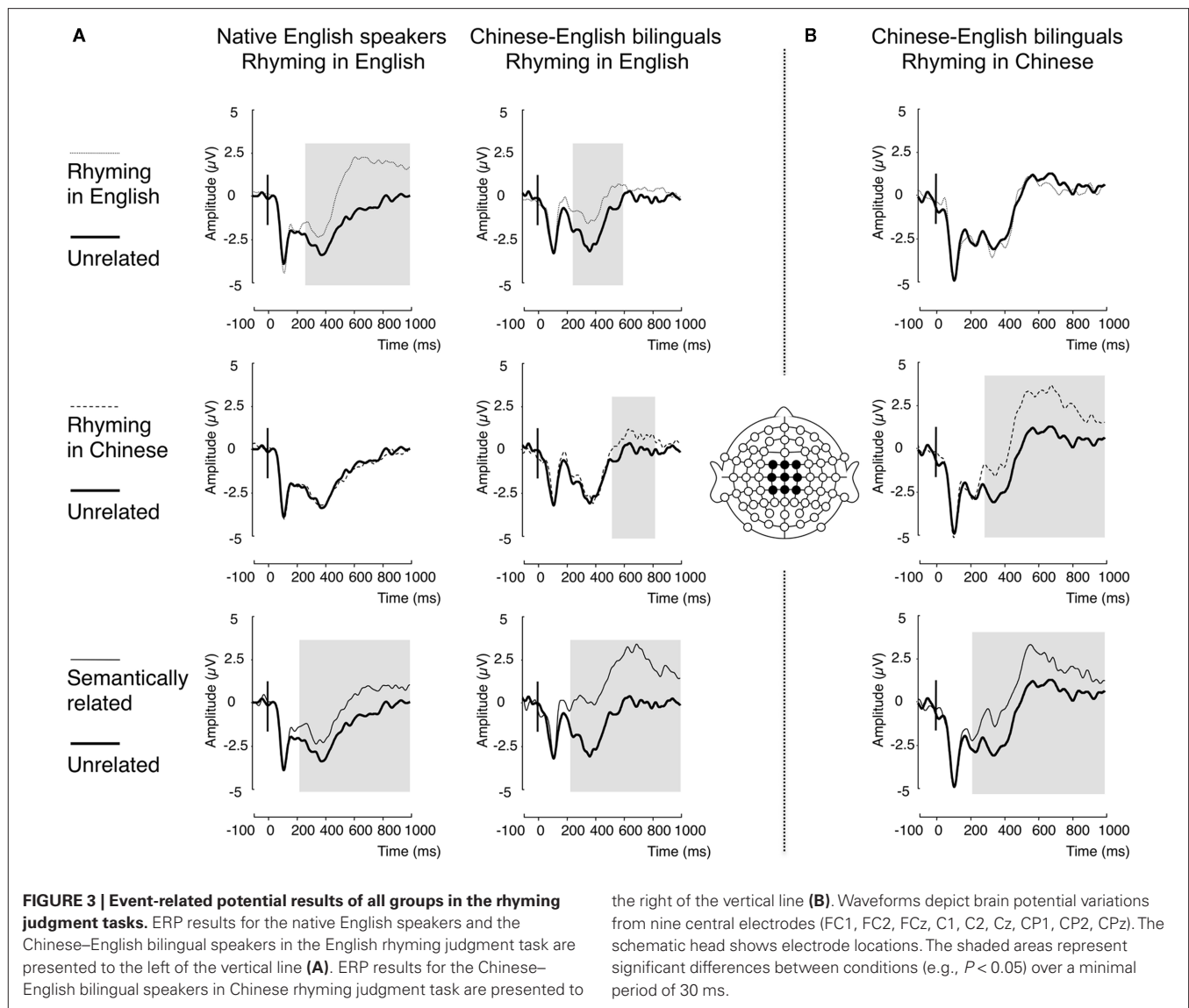
Critically, analysis of ERP modulations elicited by pictures whose names rhymed in Chinese also revealed a significant priming effect against the unrelated condition. When compared to unrelated pictures, pictures with rhyming Chinese names reduced mean ERP amplitude from 500 to 800 ms, that is later than the English rhyming effects found in both the Chinese–English bilinguals and the native English speakers. The priming effect elicited by rhyming in Chinese names was also smaller in magnitude as compared to the effects of semantic relatedness and explicit rhyming in English.

The effect of rhyming in the unintended language was further confirmed by means of a between-subject repeated measures ANOVA comparing native English speakers and Chinese–English bilinguals. The main effect of rhyming in Chinese was not significant across groups ($P > 0.1$). However, we found a significant group-by-phonological priming interaction ($F_{1,28} = 4.74$, $P < 0.05$), such that rhyming in Chinese had no effect in the native English speakers ($P > 0.1$) but, in Chinese–English bilinguals, it significantly reduced N400 amplitude for pictures that rhymed in their Chinese names as compared to pictures that were unrelated ($P < 0.001$; **Figure 3**).

When Chinese–English bilingual participants were asked to make rhyming judgment in Chinese (i.e., Exp 2), target pictures that were either semantically related or rhymed in Chinese with the prime pictures induced a significantly smaller N400 than pictures that were unrelated to the primes (both $Ps < 0.05$). Both effects became significant at around 280 ms after stimuli presentation and, together, explained the main effect of experimental conditions ($F_{3,42} = 2.77$, $P < 0.05$). Noticeably, rhyming in English yielded no significant effect on any ERP components when compared to the unrelated condition.

DISCUSSION

The purpose of the present study was to examine the mental processes underlying spoken word production in bilingual individuals. This was achieved by having participants name covertly

FIGURE 3 | Event-related potential results of all groups in the rhyming judgment tasks. ERP results for the native English speakers and the Chinese–English bilingual speakers in the English rhyming judgment task are presented to the left of the vertical line **(A)**. ERP results for the Chinese–English bilingual speakers in Chinese rhyming judgment task are presented to the right of the vertical line **(B)**. Waveforms depict brain potential variations from nine central electrodes (FC1, FC2, FCz, C1, C2, Cz, CP1, CP2, CPz). The schematic head shows electrode locations. The shaded areas represent significant differences between conditions (e.g., $P < 0.05$) over a minimal period of 30 ms.

pairs of pictures that rhymed in their first and second language, as well as those that were related in meaning. Given that the three experimental conditions were tested separately, the paradigm teases apart relative contributions of these factors to the process of speech preparation.

BEHAVIORAL RESULTS SUGGEST PARALLEL ACTIVATIONS OF BOTH LANGUAGES IN BILINGUALS

When making rhyming judgment on the English names, both native English speakers and Chinese–English bilinguals displayed reduced reaction times and increased error rates for target pictures that rhymed with the prime pictures in English as compared to other conditions. This behavioral pattern might be due to conflicts between the task-dependent expectations and the relatively low proportion of target picture pairs (25%) in the experiment. However, Chinese–English bilinguals also showed an increased error rate for target pictures that rhymed with the prime pictures in Chinese, an effect absent in the native English speakers. The Chinese rhyming effect found in the English experiment suggests that speech preparation in bilinguals is language non-selective. By contrast, when Chinese–English bilinguals made rhyming judgment on the basis of Chinese picture names (i.e., Exp 2), a reduced reaction time and increased error rate was observed only in the Chinese rhyming condition as compared to the unrelated condition. No sign of phonological access to English was found, as rhyming in English names did not affect either reaction time or error rate. These findings reveal an asymmetry in the cross-language interactions during bilingual word production: Speaking in the second language activates phonological representations in the first language, but not *vice versa*.

ERPS DISSOCIATE ACCESS TO THE INTENDED FROM THE UNINTENDED LANGUAGE

In the English rhyming task (i.e., Exp 1), ERP amplitude modulation was observed in the N400 range when the target picture was semantically related or rhymed with the prime pictures in English

in both the English monolinguals and the Chinese–English bilinguals. However, target pictures with names that rhymed with prime picture names in Chinese, the unintended language, also modulated ERPs in the Chinese–English bilinguals, suggesting that phonological representations of the native language are accessed during the planning of speech production in the second language. English monolinguals did not show any ERP modulation for pictures with names that rhymed in Chinese, indicating that the character repetition in Chinese did not spuriously interact with other conceptual or lexical variables involved in spoken word production. Therefore, the Chinese rhyming effect observed in ERPs when bilingual participants make rhyming judgment in English can only be accounted for by spontaneous access to phonological representations in the unintended language, i.e., the same conclusion as that drawn from the behavioral findings. However, unlike mean reaction times, which are the final product of a convolution of cognitive processes, the high temporal resolution of ERPs allows the analysis of millisecond-by-millisecond unfolding of mental functions. This analysis reveals that the ERP effect elicited by rhyming in English became significant 150 ms before the effect in Chinese, despite the fact that the two effects were comparable in direction and magnitude. This suggests that phonological retrieval of the intended language begins earlier than that of the unintended language during speech production in the second language.

In the Chinese rhyming task (i.e., Exp 2), target pictures that are semantically related or rhyme via Chinese names elicited reduced ERP amplitude as compared to unrelated pictures. In this instance, since Chinese was the intended language, rhyming effects emerged as early as in the case of the English rhyming task. The time course of the explicit Chinese rhyming effect suggests that the relatively late effect of Chinese phonological repetition in the English rhyming task is not due to processing differences between the two languages (Liu and Perfetti, 2003); it indeed reflects a cognitive mechanism that dissociates phonological retrieval of the intended from that of the unintended language during spoken word production. Moreover, rhyming in English names did not have an impact on the ERPs of Chinese rhyming judgment, suggesting that, consistent with the behavioral results, spoken word production in the native language does not involve access to phonological representations of the second language.

In addition to the behavioral evidence of non-selective access in covert speech production of the second language, a critical finding of the current study is that access to the intended and unintended languages involves different time courses. This novel finding provides a basis to contrast two hypotheses regarding lexical selection mechanism in bilinguals. Previous research has established that bilinguals activate both languages, to a dynamic level of representations, while speaking in one language only (for a review see Kroll et al., 2006). One explanation as to how bilinguals prevent cross-language interference posits that an inhibitory mechanism suppresses lexical competition from the unintended language that is activated initially to allow for the selection of words from the intended language (Green, 1998). Such cognitive control mechanism would not only account for bilingual lexical selection at both the behavioral and neuroanatomical levels (Abutalebi and Green, 2007; Abutalebi et al., 2008), but would also help explain bilinguals'

superior performance in a range of non-verbal tasks (Bialystok et al., 2005; Costa et al., 2008; Emmorey et al., 2008). However, a contrasting view posits that language cues or the intention to speak in one language serves to differentially activate bilinguals' two languages so that the intended language receives stronger activation than the unintended language at the conceptual level (Finkbeiner et al., 2006; see also Poulisse and Bongaerts, 1994; La Heij, 2005). According to this differential activation proposal, the observed lexical access to the unintended language reflects only a natural flow of activation, but does not functionally compete for selection with the intended language (Costa et al., 1999; Costa, 2005). While one possibility is that the two accounts represent the selection mechanisms of bilinguals at different levels of second language proficiency (Costa and Santesteban, 2004), there has been, so far, little evidence that directly supports this "selection-by-language proficiency" account.

The Chinese rhyming effect observed here in the English task suggests that the intention to speak in one language does not suffice to eliminate activation of the other language. Consistent with this view, the activation of the unintended language also influenced bilinguals' behavioral performance, which *may* involve inhibition as the underlying mechanism. Furthermore, differential activation levels of the intended and unintended languages were manifested as temporally separated ERP modulations. Overall, these results are compatible with co-activation of language representations from the two languages although there may be a temporal dynamic aspect of activation-inhibition processes that will need to be specified in the future.

Here, to avoid contaminations arising from muscle movement, spoken word production was tested via covert naming (i.e., rhyming judgment of picture names) rather than overt production (But see Costa et al., 2009; Strijkers et al., 2010, and Hoshino and Thierry, 2011). The rhyming task was chosen because previous studies in monolinguals have shown that rhyming reflects phonological analysis during spoken word preparation: it is associated with reduced negativity in the N400 range during both reading (Grossi et al., 2001) and picture naming (Barrett and Rugg, 1990a,b). Furthermore, an auditory study has shown that target words spoken in different voices than prime words elicit the same pattern of ERP variations, indicating that the rhyming is not significantly affected by physical-acoustic variables, but rather reflects a phonological matching process (Praamstra and Stegeman, 1993). However, the judgment task used here arguably involved a matching process that is not part of spoken word production in everyday life. Bilingual participants might have involuntarily named the picture in the unintended language during reanalysis of the stimuli, despite the fact that the instructions did not encourage them to access both languages. Also, the reprocessing of the picture names may have happened as part of the speech monitoring process and it could account for the delayed ERP effect in the case of Chinese rhyming. In other words, bilingual participants could have accessed Chinese picture names as they were checking for possible sources of errors and preparing for the response relative to rhyming in English, but not in the initial stage of lexical selection. In addition, the fact that, in the current study, bilingual participants were tested both in the Chinese and the English tasks may have encouraged this monitoring process. As a result, while rhyme-based

priming is an index of phonological retrieval, its ERP correlates might have been influenced by task-dependent components[1]. A potential solution is to record brain potentials while participants produce speech overtly. Despite a reduced window of reliable measurement, this methodology has been successfully applied in several studies recently (Christoffels et al., 2007; Costa et al., 2009; Strijkers et al., 2010). For example, Hoshino and Thierry (2011) showed that, when Spanish–English bilinguals name pictures in English, visually presented English distractor words phonologically related to the name of the picture in Spanish (phonotranslation condition) significantly modulated ERP mean amplitude in two temporal windows (e.g., 200–260 ms and 350–400 ms). Consistent with the current study, Hoshino and Thierry's (2011) findings suggest that phonological representations of the unintended language are accessed and that they compete for selection during second language production.

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[1]See a similar discussion regarding the N2 effect as the index of phonological or phonetic segment access in bilingual speakers engaged in the dual-choice go/nogo paradigm (Hanulovà et al., 2010).

Another finding of the current study worth considering is that no effect of rhyming in English was observed in the Chinese rhyming task, suggesting that lexical selection may be resolved shortly after the conceptual level and before access to phonological forms. This idea is consistent with previous studies showing language-selective access of spoken word production in the native language (Bloem and La Heij, 2003; La Heij, 2005; Ivanova and Costa, 2008; Colomé and Miozzo, 2010; but also see Rodriguez-Fornells et al., 2005). It also argues that rhyming judgment does not necessarily lead to artificial activation of both languages, which may be seen as a criticism of the English rhyming experiment. Further studies will elucidate the nature of representations and the relative timing of access in bilingual speech production, for instance by combining the design implemented here with overt speech.

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