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PHONOLOGICAL ACTIVATION IN CHINESE READING: AN EVENT-RELATED POTENTIAL STUDY USING LOW-RESOLUTION ELECTROMAGNETIC TOMOGRAPHY

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Abstract—The aim of the present study was to examine the pattern of phonological activation during Chinese sentence reading. Terminal words in high cloze sentences were manipulated across six conditions defined by word frequency and ending types. The P200 was smaller for the congruent targets than for the unrelated control targets, while there were no differences between the homophonic and unrelated control targets. No frequency effect on the P200 was observed. More importantly, a reduced N400 to the homophonic words was observed independent of word frequency. Source analysis by low resolution electromagnetic tomography (LORETA) revealed that the highly activated areas for the P200 were located at bilateral superior frontal (BA 6) and occipital (BA 17, 18 and 19) areas, while the N400 was located at left medial frontal (BA 6) area. These findings suggest that phonology is activated automatically for both high- and low-frequency words during Chinese sentence reading, even when the task is not focused on pronunciation.

Key words: phonology, reading, Chinese, P200, N400, LORETA.

The role of phonology in visual word recognition has long been an important issue in psycholinguistic research. This issue has provoked a large amount of research for alphabetic writing systems, especially for English. Although there are some contradictory findings (Daneman and Reingold, 1993; Daneman et al., 1995); a considerable amount of evidence indicates that phonological codes are accessed rapidly and play an early important role in English reading (Rayner et al., 1998; Sparrow and Miellet, 2002; Jared et al., 1999). For the logographic Chinese, however, there is still no consensus on whether phonology plays an important role in word identification, especially in sentence context. The basic writing unit in Chinese is a character, with mapping onto a single syllable and usually a morpheme. The Chinese characters do not associate with phonemes but with meaning instead. Chinese provides an interesting case for the ideas about writing systems and the role of phonology in reading.

Much of studies on the role of phonology in word recognition frequently make use of homophones (Perfetti and Zhang, 1995; Jared and Seidenberg, 1991; Pexman et al., 2001). Typically, stimuli were created such that one member of the homophone pair is correct in a context, and then the correct homophone is replaced by its homophone mate. Performance on the incorrect homophones is compared with the performance on correct homophones and on non-homophone spelling control words that do not fit in the context. Investigations using the homophone paradigm have involved a variety of tasks including category decision, eye movements monitoring, and event-related potential (ERP) recording (Van Orden et al., 1988; Jared and Seidenberg, 1991; Daneman et al., 1995; Rayner et al., 1998; Connolly et al., 1995).

In a semantic category task, Van Orden (1987) found that participants made more errors on homophones and pseudo-homophones than controls, but there were no any frequency effects of incorrect homophones. By varying the frequency of homophone pairs and increasing the breadth of semantic categories used, Jared and Seidenberg (1991) demonstrated that only low frequency words yield the homophone effects when broader categories were used. In subsequent experiments, Jared et al. (1999) manipulated the frequency of correct homophones, the frequency of incorrect homophones, and the predictability of correct homophones. They found that the predictability of correct target words inflates the differences in performance on homophone errors and spelling controls, particularly for high-frequency words.

The homophone effects were also observed when using Chinese words as stimuli. Manipulating the orthographic and phonemic resemblance of targets to the correct words, Chua (1999) observed the homophone effects of Chinese words in both accuracy and response time data. In a semantic related judgment task, Xu et al. (1999) also observed the homophone effects for Chinese words in silent reading, and the effects were not modulated by either target or distractor frequency. Using priming paradigm, Tan et al. (1996) addressed the phonological processing of Chinese words and demonstrated the crucial role of phonological codes in accessing to meaning. The prominent role of phonology was not only for the high frequency Chinese single-character words, but also for the

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Abbreviations: ANOVA, analysis of variance; EEG, electroencephalogram; ERP, event-related potential; LORETA, low-resolution electromagnetic tomography; MSE, mean square error; SD, standard deviation.

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commonly used double-character words (Perfetti and Tan, 1998; Tan and Perfetti, 1999).

However, some other studies did not obtain the homophone effects as mentioned above in Chinese reading (Chen et al., 1995; Zhou et al., 1999; Zhou and Marslen-Wilson, 2000; Wong and Chen, 1999; Feng et al., 2001). In a category decision task, Chen et al. (1995) found that the interference effects including both the error rates and the correct "no" reaction times from orthographic similarity, but not from homophones. They concluded that phonological information may not be activated automatically during accessing the meaning of Chinese characters.

Taken together, there is a lack of consensus as to the contribution of phonology in Chinese word recognition. Despite of the existing evidence on the relative roles of orthographic and phonological processing during Chinese reading (Meng et al., 2007; Meng et al., 2008; Xu et al., 1999; Feng et al., 2001), how the phonology of Chinese character plays a role in sentence reading still remained unclear. This study focused on the issues that whether phonological activation of Chinese character is automatically even when the task in not focus on pronunciation, and when and where the activation of phonology takes place during Chinese reading.

ERPs can illuminate the temporal dynamics of cognitive processes related to orthography, phonology and semantics. Researchers have found several ERP components to be relevant to reading, such as early components (100–250 ms), somewhat later component (300–500 ms), and later component (later 600 ms) (Kramer and Donchin, 1987; Niznikiewicz and Squires, 1996; Kutas and Hillyard, 1984; Osterhout and Holcomb, 1993). Moreover, the cortical generators of each ERP component can be localized with low-resolution electromagnetic tomography (LORETA). An ERP study using LORETA by He et al. (2006) showed that the wide area of frontal cortex bilaterally including Broca's areas (BA 46, 45, 44, 9, and 10) were involved at 375 ms (the peak of N400) when participants performed a homophone judgments task on Chinese homophone pairs. Liu et al. (2003) observed a reduced P200 elicited by orthographically similar Chinese characters and a less negative N400 by homophone pairs. They traced the cortical sources of each component and found that the sources of the P200 were located at BA 6 and BA 8, and the N400 were located at the areas of left BA 6, BA 3/4, right BA 22 (superior temporal) and BA 44.

The P200 is an early component relevant to the current study. Although less robust than the N400, the P200 has also been associated with general "mismatch" detection (Liu et al., 2003; Meyler and Breznitz, 2005; Barnea and Breznitz, 1998; Landi and Perfetti, 2007; Meng et al., 2007; Meng et al., 2008). Liu et al. (2003) found that the P200 component scores were reduced when the second character was preceded by a graphically similar character in a pronunciation task. Meng et al. (2007) observed a smaller P200 for the Chinese characters in homophonic condition than in congruent condition. In subsequent study, Meng et al. (2008) obtained a smaller P200 for the homophonic and orthographical than congruent Chinese characters. Furthermore, the P200 was also found to be modulated by semantic associates (Coulson et al., 2005), and be sensitive to semantic incongruity (Landi and Perfetti, 2007). A larger P200 was observed by Landi and Perfetti (2007) for semantically related pairs relative to semantically unrelated pairs.

Another component, the N400, is of particular relevance for the present study. The N400 can be generated and influenced by words, as well as by other types of meaningful stimulus such as faces (Barrett and Rugg, 1989) and environmental sounds (Van Petten and Rheinfelder, 1995) and so on. Besides the relatedness of the N400 with semantics (Kutas and Hillyard, 1984; Kutas and Federmeier, 2000; Kutas and Hillyard, 1980), this component is also sensitive to phonological relations as well (Kramer and Donchin, 1987; Liu et al., 2003; Meng et al., 2007; Meng et al., 2008). Using a sentence verification task, Newman and Connolly (2004) found a reduced N400 when phonological expectations were met regardless of the orthographically appropriateness of the sentence-ending words. Furthermore, even in a meaning-decision task, the N400 for Chinese homophone pairs was significantly smaller than for control pairs (Liu et al., 2003). When taking the congruent condition as baseline, Meng et al. (2007, 2008) found that the N400s for homophonic and orthographic conditions were more negative than baseline. The N400 effects for homophones suggest the activation of phonological information in word identification. However, some other studies did not observe the attenuation of N400 to homophones (Connolly et al., 1995; Niznikiewicz and Squires, 1996; Ziegler et al., 1999).

The aim of the present study was to examine when and where the activation of phonology takes place during Chinese reading. All the target words were single-character words and were embedded in the end of high cloze sentences. We manipulated the target words, such that the correct target words were replaced by their homophonic mates which were phonologically congruent but orthographically incongruent to the correct words (homophone condition), or by unrelated control words which were both phonologically and orthographically incongruent to the correct words (unrelated control condition). In addition, the frequency of the target words was also manipulated. These manipulations enabled us to examine whether the N400 effects for homophones can be obtained in sentence context during Chinese reading, and whether the role of phonology is restricted to low frequency word as indicated by previous studies (Jared and Seidenberg, 1991; Jared et al., 1999).

By comparing the early (P200) and the somewhat late (N400) component between conditions, we are able to examine the potential differences underlying phonological processing in Chinese reading. If phonology plays an early role in Chinese reading, we would observe the homophone effects on the P200. However, if the phonological information contributes to the integration of meaning and context, then a reduced N400 would be elicited by the homophone condition. The frequency effects could be observed either on the P200 or the N400 if phonological effect only occurs to the low frequency words. Furthermore, the cortical sources of the P200 and the N400 should be related to their cognitive functions reflected in word identification.

EXPERIMENTAL PROCEDURES

Participants

Twenty undergraduate and graduate students (9 males, 11 females) between the ages of 21 and 26 (mean=24.1) participated in this study as paid volunteers. The number of participants was minimized. All participants were native Mandarin Chinese speakers and right-handed, with normal or correct-to-normal vision and no history of neurological or psychiatric impairment. Informed consent was obtained from all the participants.

Stimuli

Six experimental conditions were defined by frequency and type of target words which were embedded in the end of sentences. Three versions of a sentence were created, such that a correct target word was replaced either by its homophonic mate or by an unrelated control word. Thus, high and low frequency target words were divided into the three types of ending: (1) the congruent targets, the correct homophones which were highly predictable from a sentence (e.g., 燕子飞到南方过冬 [Swallow fly to the south to live through winter.]); (2) the homophonic targets, the homophone mates which were phonologically congruent to the correct target words whereas orthographically and semantically incongruent to the expectation of the sentence endings (e.g., 燕子飞到南方过东 [Swallow fly to the south to live through east.]); and (3) the unrelated control targets, which were orthographically, phonologically, and semantically incongruent to the expectation of the sentence endings (e.g., 燕子飞到南方过布 [Swallow fly to the south to live through cloth.]).

All the target words were Chinese single character words and were matched for their stroke numbers across conditions. In addition, the homophone density (the number of homophones of a character has) was matched between the high- and low-frequency homophone pairs since it may exert an influence on the phonological activation in Chinese word identification (Tan and Perfetti, 1997). The homophone pairs shared the same tone and pronunciation (such as 冬 [pronounced "dong1," meaning winter] and 东 [pronounced "dong1," meaning east]). Thus they were full homophones that share the same tone, vowel, and consonant information. Sixty homophone pairs were selected according to Xiandai Hanyu Pinlü Cidian (1986). Half of the pairs were high-frequency words, with both words occurring more than 55 times per million words (M=204.98, standard deviation (SD)=118.96), and the other half had word frequency lower than 20 occurrences per million (M=5.36, SD=2.26). For each homophone pair, an unrelated control word was selected and its frequency was matched to the homophone pair.

Stimuli consisted of 180 high cloze Chinese sentences that varied in length from six to 11 Chinese characters (mean=8). To ensure the sentences highly constrained the congruent targets, a cloze probability test was used in which other 25 undergraduate students were presented the sentences with the final target words deleted and required to guess what the last words of the sentences would be. Sentences in which targets words were judged to be the best completion over 75% of the time were retained and the mean predictability was 89.9%. Sentences were divided into three blocks according to Latin square design. Each block included all conditions, and no sentence was presented to the participants more than once.

Procedure

Participants sat approximately 1 m from a computer monitor upon which sentences were presented word-by-word. Word duration was 500 ms and then followed by a 500 ms blank. Each trial began with a waiting signal (~***~) that remained in the center of the screen until the participant initiated the trail. The waiting signal allowed participants to pace themselves and blink between trials. The participants were instructed to read sentences silently for comprehension. They were also told that some of the sentences may contain wrong words, but they should not worry about that and should focus on understanding the sentences. On approximately one-third of the trials, the participants were asked to answer a yes-no question by pressing a button and they had no difficulty to answer those questions.

EEG acquisition

Electroencephalogram (EEG) was recorded using a 128-channel geodesic sensor net (Electrical Geodesics Inc., EGI net station, Eugene, OR, USA) with a sampling rate of 250 Hz, and a band-pass of 0.1–100 Hz. A vertex reference was used in the recording and six eye channels were recorded to allow the rejection of trials with eye movements and blinks. All impedances were kept below 40 kΩ (Ferree et al., 2001). Data were further filtered with a 30 Hz low pass filter and referenced to an average reference off-line. Epochs were 1200 ms including a 200 ms pre-stimulus baseline. ERPs were averaged off-line across the experimental trials in each condition after eliminating eye movements and other artifacts. After a baseline correction, the grand mean ERPs over participants were calculated.

ERP analysis

Two time windows and nine electrodes were selected for further statistical analysis based on previous research and confirmed with a visual inspection of the grand-averaged waveform plots. The first time window of 150–260 ms covered the P200 component, and the second time window of 390–500 ms covered the N400 component. For statistical testing of the ERP effects, nine electrodes of the international 10–20 system (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4) were analyzed. A four-way repeated measures analysis of variance (ANOVA) was conducted on the mean amplitudes and peak latencies for each component, with frequency (high- and low-frequency), type (congruent, homophone, and unrelated control), lobe (frontal, central, parietal), and hemisphere (left, middle, and right) as within subjects variables. The Greenhouse–Geisser adjustment was applied when the variance sphericity assumption was not satisfied.

Source analysis

LORETA was used to estimate the sources of the significant ERP components for each condition. LORETA is a tomographic technique that can help find the best possible solution of all possible solutions consistent with the scalp distribution (Pascual-Marqui et al., 1994). The LORETA-key software (Pascual-Marqui et al., 2002, online at http://www.unizh.ch/keyinst/NewLORETA/LORETA01.htm) was used in the analysis and the spatial reference used for this procedure is the Talairach brain atlas (Talairach and Tournoux, 1988). The solution space of LORETA consists of 2394 pixels with 7 mm resolution. Although this is a coarse analysis compared with functional magnetic resonance imaging (fMRI), it is informative when used together with the temporal information provided by ERP.

The input for LORETA was the grand averaged ERP, sampled cover the P200 time points from 150 to 260 ms and the N400 time points from 390 to 500 ms after the stimulus onset. The outputs were 3D maps of activity value for each of 2394 cortex

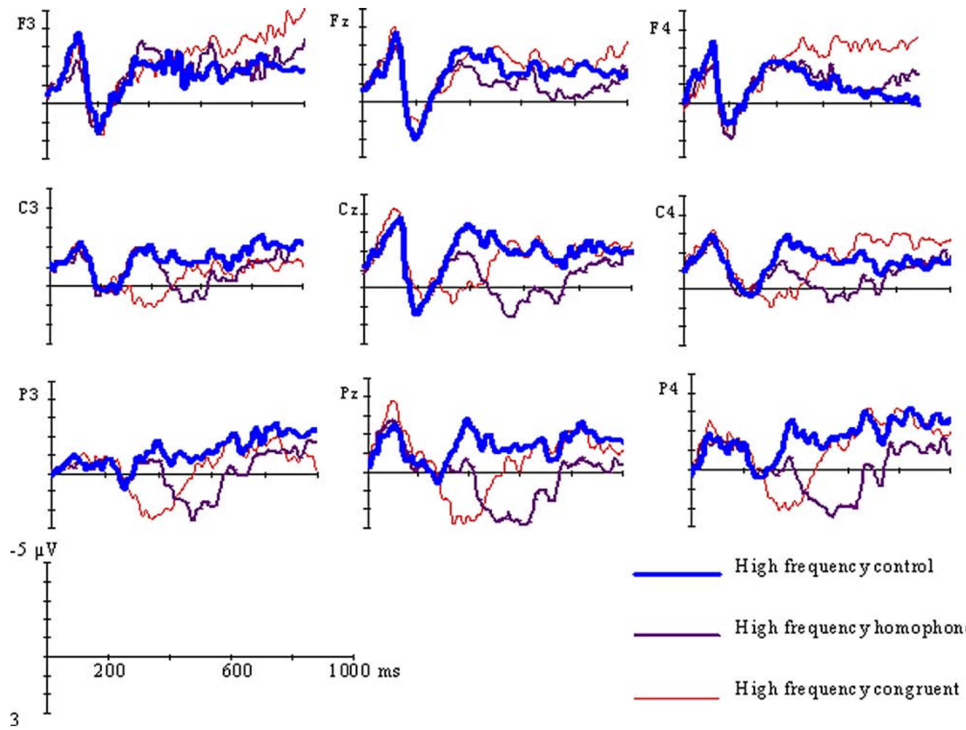

Fig. 1. Grand average ERP waveforms at nine electrodes for the high frequency targets presented in the congruent, homophone, and unrelated control conditions. For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.

pixels, based on the scalp distribution of each time point, with a subtraction of the averaged scalp distribution during the 200 ms prior to stimulus onset which corresponding to the baseline. Those pixels among the top 5% in activation value of each 3D map were treated as "active" pixels and shown in red in LORETA maps (Fig. 3) to allow focusing on a reduced set of highly activated brain regions.

RESULTS

The grand average waveforms for the high and low frequency targets are presented in Fig. 1, 2 respectively, illustrating the effects for the three types of target ending. To assess the homophone effects on the P200 and the N400, we took the unrelated control condition as baseline and compared the congruent and homophone condition against this baseline. Fig. 3 shows the P200 and N400 effects at Cz electrode.

A four-way repeated measures ANOVA on the P200 mean amplitudes showed a significant main effect of ending type, $F(2,38)=3.828$, mean square error (MSE)$=3.978$, $P<.05$, with the overall mean amplitudes most positive for the unrelated control condition, less so for the homophonic condition and even less so for the congruent condition. Further tests showed a smaller P200 for the congruent condition than for the unrelated control condition, $P<.01$, while the differences between the homophonic and unrelated control condition were not significant, $P=.881$. No significant main effect of frequency was observed, $F(1,19)=1.626$, $MSE=2.741$, $P>.1$. The main effect of lobe was significant, $F(2,38)=33.542$, $MSE=11.554$, $P<.001$, indicating a larger P200 in frontal than in central ($P<.001$) and parietal sites ($P<.001$). The interaction between lobe and hemisphere reached significance, $F(4,76)=10.829$, $MSE=0.652$, $P<.001$. Further tests revealed the larger P200 at C3 ($P<.01$) and Cz ($P<.01$) than C4, and at P3 ($P<.01$) and Pz ($P<.01$) than P4. No significant effects were observed for the P200 latency.

A four-way repeated measures ANOVA on the N400 mean amplitudes showed a significant main effect of the ending type, $F(2,38)=12.013$, $MSE=16.578$, $P<.001$, with less negative N400 amplitudes for the homophonic than the unrelated control condition ($P<.001$). The main effect of frequency did not reach significance, $F(1,19)=.978$, $MSE=5.645$, $P>0.1$. The main effect of lobe was significant, $F(2,38)=29.560$, $MSE=46.307$, $P<.001$, indicating that the N400 amplitudes were more negative at frontal and central than parietal ($P<.001$). Furthermore, there was a significant interaction between type and hemisphere, $F(4,76)=4.867$, $MSE=3.101$, $P<.01$. Further tests revealed that the N400 amplitudes were less negative at left than central and right sites for the congruent endings ($P<.01$). No significant effects were observed for the N400 latency.

Fig. 4 shows the maximum intensity projection images of grand mean current density (LORETA) averages for the P200 and the N400 across experimental conditions. For the P200, the highest level of activation was located in left superior frontal (BA 6), right superior frontal (BA 6), and left occipital (BA 17 and BA 18) areas for the high-frequency targets. Whereas the highest level of activation of the P200 to the low-frequency targets was located in left medial

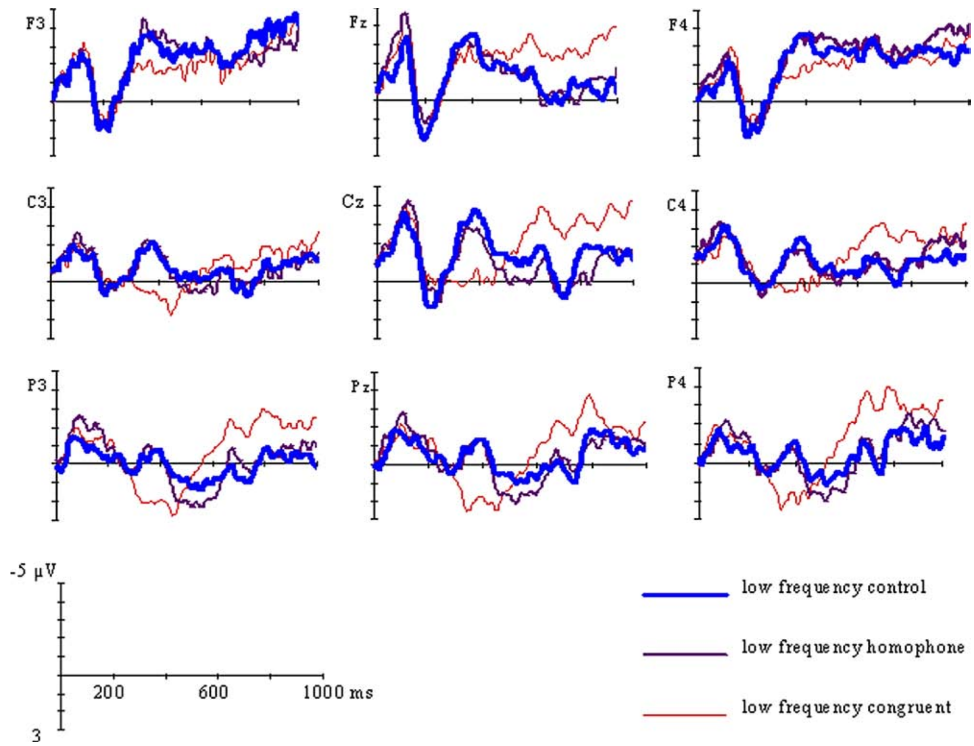

Fig. 2. Grand average ERP waveforms at nine electrodes for the low frequency targets presented in the congruent, homophone, and unrelated control conditions. For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.

frontal (BA 6), left occipital (BA 17 and BA 18), and right occipital (BA 18 and BA 19) areas. For the N400, the highest level of activation was located in left medial frontal (BA 6) for both the high- and low-frequency targets.

DISCUSSION

The present study addressed the issue of phonological activation for Chinese words in sentence context by combining the data of ERP and LORETA. The results showed that the P200 was smaller for the congruent than the unrelated control condition, and there was no significant difference between the homophonic and unrelated control condition. No frequency effect on the P200 was observed. More importantly, a reduced N400 for the homophonic targets relative to the unrelated control targets was observed independent of word frequency. These results suggest that phonology is activated automatically for both high-frequency and low-frequency Chinese characters presented in highly constrained sentences, and contributed to the integration of semantic information and sentence context.

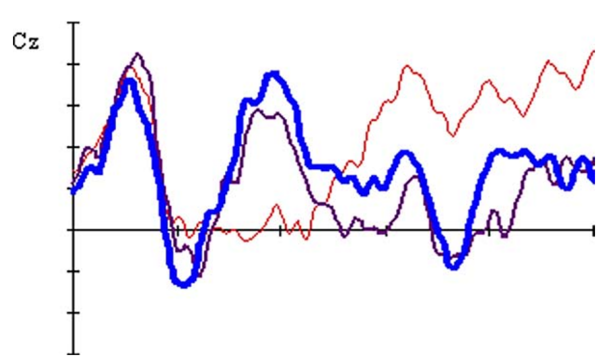

Fig. 3. Grand average ERP waveforms for the low frequency targets presented in the congruent, homophone, and unrelated control conditions at Cz electrode. For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.

The absence of homophonic effect on the P200 may indicate that phonology plays a limited role in the early stage of Chinese reading (Feng et al., 2001). Nevertheless, the failure of finding phonology effects on the P200 cannot rule out the early activation of phonology. There exist two possible interpretations for the P200 differences. The first possibility is that the P200 differences might reflect an early semantic effects (Landi and Perfetti, 2007; Coulson et al., 2005). Landi and Perfetti (2007) found a larger P200 for semantically related pairs relative to semantically unrelated pairs. The fact that both the homophonic and unrelated control conditions in this study were semantically incongruent may result in the little difference between the two conditions. The second possibility is that the P200 may be associated with mismatch detection of orthography and phonology (Liu et al., 2003; Meyler and Breznitz, 2005). Kramer and Donchin (1987) found that the amplitudes of N200 varied with the mismatch degree of orthography and phonology between targets. Although with inversed direction of polarity, the P200 observed in

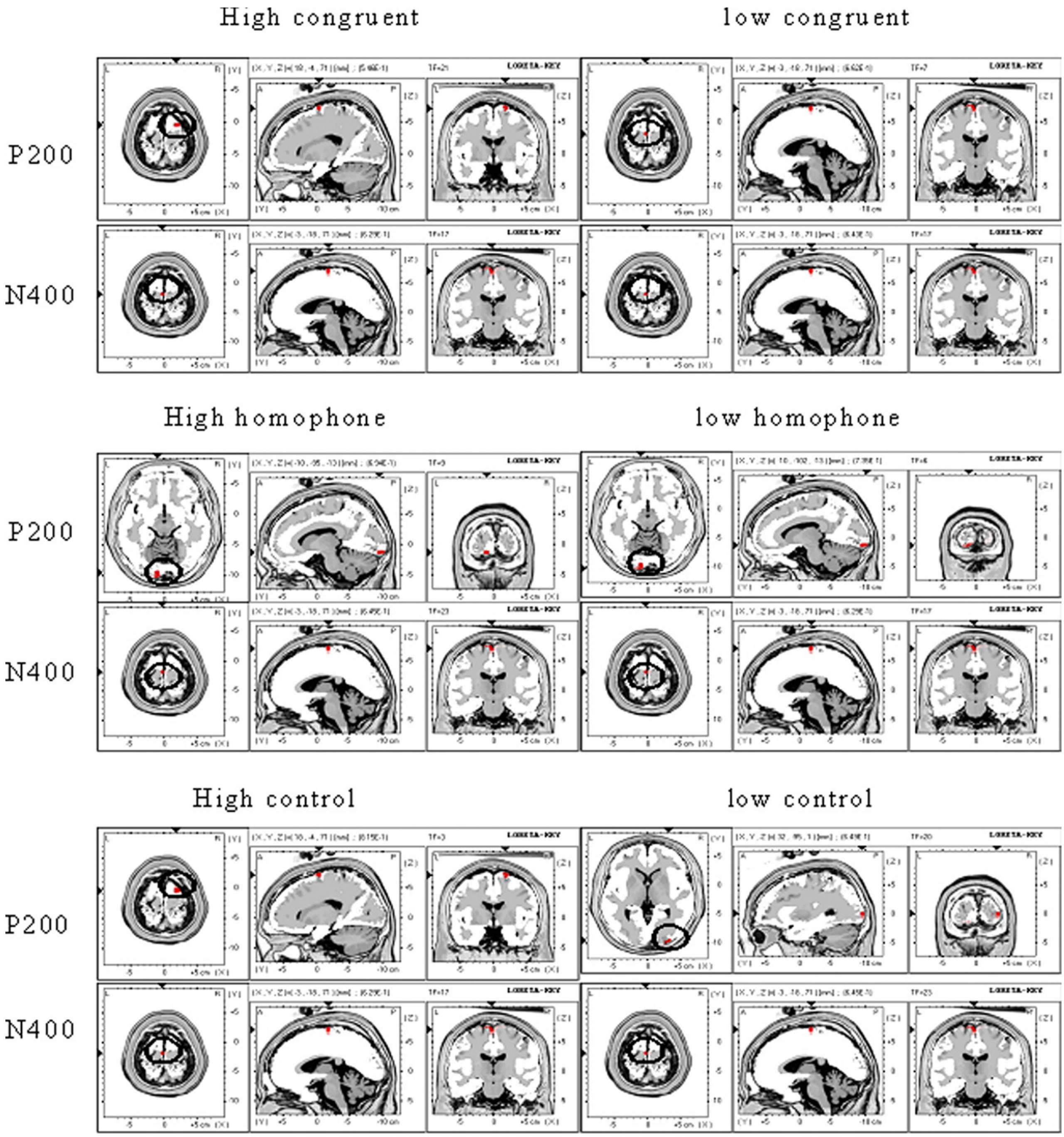

Fig. 4. Maximum intensity projection images of grand mean current density (LORETA) averages for the P200 and the N400 across experimental conditions. Each map consists of axial, sagittal, and coronal planes showing the same activation area (circled for easy identification). For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.

this study may be related to the N200 reported in that study.

The N400 amplitudes were significantly attenuated for the homophonic targets than for the unrelated control targets. The attenuation of the N400 to homophonic targets is independent of the mechanism related to orthographic and semantic mismatch, since both the orthography and meaning in the homophonic and unrelated control conditions were incongruity to the expectations and there was no orthographic similarity between the homophonic and unrelated control targets. The reason for the reduced N400 to the homophonic targets may be that readers expect a certain ending word in the high cloze sentence. Although what they encounter fail to match that word on orthography and meaning, yet not on phonology. Thus, this pattern of the N400 suggests that phonological information is activated and contributes to the integration of meaning and context. The finding of the reduced N400 for homophonic targets confirmed previous studies on phonological processing both in English (Newman and Connolly, 2004) and in Chinese (Liu et al., 2003; Meng et al., 2007, 2008).

However, phonological information of Chinese words might not mediate access to meaning, as evidenced by the larger N400 for homophonic targets than congruent targets. This result is somewhat different from that of Newman and Connolly (2004), who observed a reduced N400 to congruent words (CW) and congruent non-words (CN) which were pseudo-homophones of the real words congruent with the context, and that the reduction was the same for both. They took the reduction of N400 in CN condition as evidence supporting the activation of correct orthographic form by phonological mediation and subsequent semantic integration. However, it should be cautious when explaining the findings from pseudo-word data, since pseudo-words neither are familiar to subjects nor have meaning in lexicon. Just as acknowledged by the authors, the presence of pseudo-homophones may have enhanced the processing of phonology despite they attempted to discourage its use by keeping the proportion of nonwords to words low.

The homophonic effects on the N400 in this study are in contrast to previous studies (Niznikiewicz and Squires, 1996; Ziegler et al., 1999), which failed to find the reduced N400 to homophones. These discrepancies may be attributed to experimental materials. In the studies by Niznikiewicz and Squires (1996) and by Ziegler et al. (1999), orthographically similar homophone pairs were presented to participants, which may influenced the extent to which participants relied on orthographic knowledge in making their decisions. By varying the orthographic similarity of homophonic pairs, Rayner et al. (1998) found a different pattern in gaze duration for orthographically similar and orthographically dissimilar homophone pairs, which suggest that the orthographical similarity between homophonic pairs influences the detection of phonology in word identification. Given that the homophones presented in our study were orthographically dissimilar to each other, it is unlikely for participants to emphasize orthographical information of the homophones in integrating meaning with sentence context.

As discussed above, the homophonic effects were absent on the P200 but present on the N400. However, word frequency effect was not observed either on the P200 or the N400. These results indicate that the later activation of phonology contributes to the integration of meaning and context. Moreover, the phonological effects are independent of word frequency for Chinese words in highly constrained sentence context. These results were compatible with the findings that phonological effects exist for high- and low-frequency words in English (Van Orden, 1987; Daneman et al., 1995; Rayner et al., 1998; Folk, 1999) and in Chinese (Feng et al., 2001; Zhang et al., 1999). Nevertheless, when presenting a broader category preceded the targets, Jared and Seidenberg (1991) found homophone benefits for low-frequency words but not for high-frequency ones. This discrepancy in findings supports the view that the contextual predictability can exert an influence on the activation of phonology in word identification.

This study failed to find the word frequency effect on the P200. However, Dambacher et al. (2006) found that the P200 was smaller for high frequency than for low frequency words, and the first occurrence of the word frequency effect was taken as an upper limit for lexical access during reading. The data pattern for the P200 across conditions in this study indicate that the P200 may be associated with the mismatch detection, that is, the early semantic effect or the mismatch degree of orthography and phonology between targets. The absence of word frequency on the P200 may result from the influence of the highly constrained context, since context can facilitate word-processing (Van Petten, 1993; Feng et al., 2001; Rayner et al., 1998) and the effect of context is larger for low frequency than high frequency words (Dambacher et al., 2006).

As for the cortical responses to the targets out beyond 600 ms after stimulus onset, it appears that there are differences between the three types of ending seen from the grand-averaged waveform plots. Besides the early component (P200) and the somewhat late component (N400), the late components (approximately 600 ms from stimulus onset) also associate with language processing. Furthermore, the late components have been found to be elicited primarily by sentence or syntactic level processing (Osterhout and Holcomb, 1992, 1993; Hagoort et al., 2003; Hoeks et al., 2004; Ye et al., 2006). The ERP components of most interest for the present purposes are the P200 and N400. However, in the further studies on Chinese comprehension, we would take an overall analysis for the sentence processing during reading.

The analysis of LORETA provides complementary information on the cortical sources of the P200 and the N400. In general, the results of LORETA showed that the P200 was mainly localized at cortical areas involved in visual analysis or graphic processing, while the N400 was localized at supplementary motor or preparation of pronunciation area. The source analysis revealed that the stronger activated areas for the N400 were mainly located at bilateral superior frontal (BA 6) and occipital (BA 17, 18 and 19) areas at the early stage of Chinese word identification. These findings are compatible with the results of previous studies (Liu et al., 2003; Tan et al., 2001). The right BA 6 was found to be active in an fMRI study during Chinese reading (Tan et al., 2001), and the left BA 6 was involved in Chinese character identification (Liu et al., 2003).

CONCLUSION

In conclusion, along with previous studies (Chua, 1999; Xu et al., 1999; Perfetti and Zhang, 1995; Peng et al., 2004), the current study provides evidence that phonological processing is a compulsory mechanism involving in Chinese reading. Our findings support the lexical constituency model by Perfetti et al. (2005), in which a phonological form is an indispensable constituent of word identity, since a word representation consists of three interlinked constituents: orthography, phonology and semantics. Our data showed that phonological information is activated automatically both for high- and low-frequency words and contributes to the integration of meaning and context during Chinese sentence reading, even when the task is focused on semantic processing.

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