Neuroscience Letters 473 (2010) 37–41

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

# P200 and phonological processing in Chinese word recognition

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ARTICLE INFO

*Article history:*
Received 27 October 2009
Received in revised form 2 February 2010
Accepted 8 February 2010

*Keywords:*
Chinese word recognition
Phonological similarity
Phonological processing
Event-related potential
P200

ABSTRACT

The present study examined the relationship between P200 and phonological processing in Chinese word recognition. Participants did a semantic judgment task on pairs of words. The critical pairs were all semantically unrelated in one of three conditions: homophonic, rhyme, or phonologically unrelated. Noting the possibility that P200 may be affected by phonological similarity and orthographic similarity and that literature studies may not have assessed such effects separately, the present study used visually dissimilar word pairs sharing no phonetic radicals. Relative to the control pairs, both the homophonic and rhyme pairs elicited a significantly larger P200 with a scalp distribution centering at the centro-parietal areas. The results present strong evidence that P200 can be modulated by lexical phonology alone, independent of sub-lexical phonology, or lexical or sub-lexical orthography. P200 effects were comparable in amplitude and topography between the homophonic and the rhyme conditions, suggesting that P200 is sensitive to phonology at both the syllabic and the sub-syllabic levels.


Visual word recognition is a complex process where multiple levels of lexical information including orthography, phonology and semantics unfold in time. It is crucial to understand the time courses of such lexical activations [2,4,7,9,19,21]. The temporal profile of phonological processing is considered a central issue in several major word recognition models, and has therefore provoked extensive research in many different languages [2,4,7,9,11,17]. Behavioral studies, for example, generally demonstrate rapid and early phonological access in reading English words, despite some controversies [1,4,6,7,9,11,17,21]. With excellent temporal resolution, event-related potentials (ERPs) have also informed much about online processing during word recognition and identified several components related to phonological processing, including the early positive component P200, and the late negative component N400 [1,2,7,11,18,19,20,24].

The present study examined phonological processing in Chinese word recognition focusing on the P200 component occurring around 200 ms post-stimulus. In the literature, P200 has been associated with early phonological and orthographic activation in visual word recognition. For example, in a same-different rhyme judgment task, Kramer and Donchin [11] found that P200 effect was the largest when two words in a pair mismatched in both orthography and phonology, intermediate when they mismatched in one but matched in the other, and the smallest when they matched in both. Their results suggest that P200 indexes early activation of orthography, phonology, and their interaction. Barnea and Breznitz [1] reported similar findings of enhanced P200 to homophones with a rhyme judgment task in Hebrew. There was also partial evidence that P200 was modulated by spelling-to-sound regularity in English [19]. However, Ziegler et al. [24] failed to find any differences in ERPs before the N400 time window between homophones and non-homophones in a semantic judgment task. Kutas and Van Petten failed to find reliable P200 reduction for word repetition [12], as one would expect if P200 is sensitive to phonological and orthographic processing. Bentin et al. [2] failed to find ERP differences between pronounceable and non-pronounceable letter strings until around 270 ms. Based on the topography results, the differences around 270 ms were unlikely to be a P200 effect delayed in time.

Briefly, more evidence is needed to better understand the functional significance of P200 with regard to phonological processing in alphabetic languages. For the non-alphabetic Chinese, there have been only a few ERP studies directly examining phonological processing and the results are so far not very consistent. Using the priming paradigm in a semantic-relatedness judgment task, Liu et al. [14] found a reduced P200 effect for visually similar word pairs sharing a common phonetic radical, but no P200 effect for visually dissimilar homophonic pairs. In the same study, with a phonological relatedness judgment task, they failed to find any P200 difference between matched and non-matched pairs, same as in Valdes-Sosa et al. [20]. A follow-up study of Liu et al. [14]

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doi:10.1016/j.neulet.2010.02.014

replicated the finding of P200 reduction for visually similar word pairs, but reported an enhanced P200 for low frequency homophonic word pairs [5]. This P200 enhancement is later replicated in Zhang et al. [23], also with a semantic-relatedness task.

With non-priming paradigms, two ERP studies reported a consistency effect on P200 where low consistency Chinese characters elicited significantly larger P200 than high consistency characters [10,13]. In Chinese, consistency is defined by how frequent characters containing the same phonetic radical share the same pronunciation. It indicates statistical mappings between orthography and phonology, or how orthographic similarity affects a word's phonological representations. While these results suggest that P200 may be associated with phonology–orthography interaction involving sub-lexical units, it remains unclear how such interaction has produced the observed P200 effect.

Although the evidence in Chinese is limited, together with that from studies in alphabetic languages, they point to a direction of research to first assess the extent to which P200 is modulated by phonological similarity, independent of orthographic similarity, and vice versa. Further research can then address how P200 is modulated in the presence of both phonological and orthographic similarities. Explicit dissociation between the two kinds of similarities is known to be difficult in alphabetic languages as visually similar words are often also similar phonologically. Confounds between the two also exist in non-alphabetic Chinese that may not have been fully taken into account in previous research. For example, P200 effects for visually similar words reported in Ref. [14] could have resulted from phonological processing of the pronounceable sub-lexical phonetic radicals shared by these words.

From this perspective, the finding from Refs. [5,23] that P200 is affected by phonological priming between two visually dissimilar Chinese words would be of particular importance. This is because it presents a clear case where P200 indexes lexical phonology, not confounded by sub-lexical phonology, or lexical or sub-lexical orthography.

To establish this critical finding more firmly, the present study was intended to first replicate it on homophonic pairs. Further and more importantly, we would examine another case of phonological similarity where two words share the same rhyme. Should enhanced P200 effects be found for rhyme pairs, relative to phonologically unrelated control pairs, it would greatly strengthen the conclusion that P200 can be modulated by phonological processing alone. Also, inclusion of both homophonic and rhyme conditions in the same study, which has never been done before in Chinese, would allow a comparison of P200 effects under two types of phonological relatedness. Given homophonic pairs share both onset and rhyme but rhyme pairs share just the latter, there seems to be a difference in degree of phonological similarity between the two. One may, for example, expect a graded P200 effect to be larger for homophonic pairs than for rhyme pairs. Apparently, such comparison should inform about the specific cognitive processes underlying P200 and help to reveal its characteristics.

Seventeen undergraduate students (mean age = 22.6 years, 9 females) from South China Normal University participated in the experiment. They were all right-handed native Chinese speakers with normal or corrected-to-normal vision. Written informed consent was obtained from each participant in accordance with a research protocol approved by the University IRB Committee.

For easy description, the first word in each pair was called the prime and the second the target, and the two were always visually dissimilar. Half of the word pairs used was the critical test pairs in which the prime and the target were semantically unrelated. The other halves were the filler pairs in which the prime and the target were semantically related.

Selected from a pool of the most commonly used 4, 574 one-character words according to the *Modern Chinese Frequency Dictionary* [22], a set of 70 different words served as the target words for the test pairs. For each of these target words, three prime words were selected from the same pool, one homophonic to the target (same sound and tone), one rhyming with the target, and one unrelated to the target in either semantics, phonology, or orthography. This formed a total of 210 test pairs. The three sets of prime words were matched in stroke number and word frequency. Filler pairs were selected from the same pool, matching the test pairs as much as possible (e.g., some of them were phonologically related and others were unrelated). Sample stimuli are provided in Table 1. Each participant completed a total of 420 trials in 5 blocks, each with 42 test trials and 42 filler trials, randomly intermixed. Block order was counter-balanced across-subjects. Latin square was used to assign stimulus items to different conditions.

**Table 1**
Sample stimuli and mean stimulus characteristics for each condition, and mean reaction times (RT) and error rates for the three prime conditions.

| | Prime | | | |
|---|---|---|---|---|
| | Homophone | Rhymed | Control | Target |
| Word | 梏 | 恤 | 甥 | 雇 |
| Pronunciation in Pinyin | /gu4/ | /xu4/ | /sheng1/ | /gu4/ |
| Meaning | Imprison | Compensate | Nephew | Hire |
| Frequency | 9 | 11 | 8 | 9 |
| Stroke number | 10 | 11 | 10 | 10 |
| RT (ms) | 665 (102) | 646 (103) | 644 (113) | |
| Error rate (%) | 3.9 (3.4) | 3.9 (3.5) | 1.8 (2.6) | |

*Note:* The bottom two rows show mean reaction times (RT) and error rates for the three prime conditions; numbers in brackets show standard deviations.

For maximal match of target stimulus properties across conditions, a within-subject design was used. For each participant, every test pair target would be presented three times, preceded by one of its three associated primes, respectively. Similar designs involving target repetitions have been adopted in related literature studies [5,14,23]. As in these studies, we distributed these target items to the 5 experimental blocks in such a way that each would appear only once within each block.

Participants sat in front of a computer monitor in a quiet room. In each trial (see Fig. 1), a fixation cross was presented at the center of the screen for 300 ms, followed by a prime word for 140 ms. There was a 360 ms blank screen after the prime. The target word

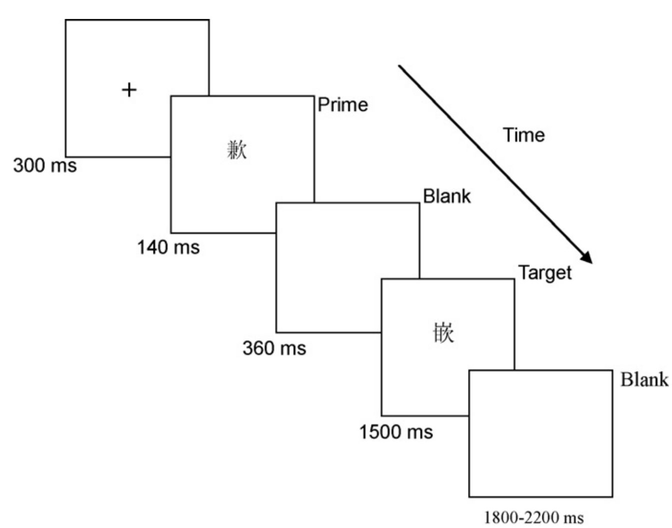


**Fig. 1.** A schematic illustration of the trial structure. Each trial displayed a warning screen and then showed a prime word for 140 ms. Following a blank screen, the target was shown for 1500 ms. Participants responded to the target by judging whether it was semantically related to the prime or not. The next trial started after a variable inter-trial-interval.

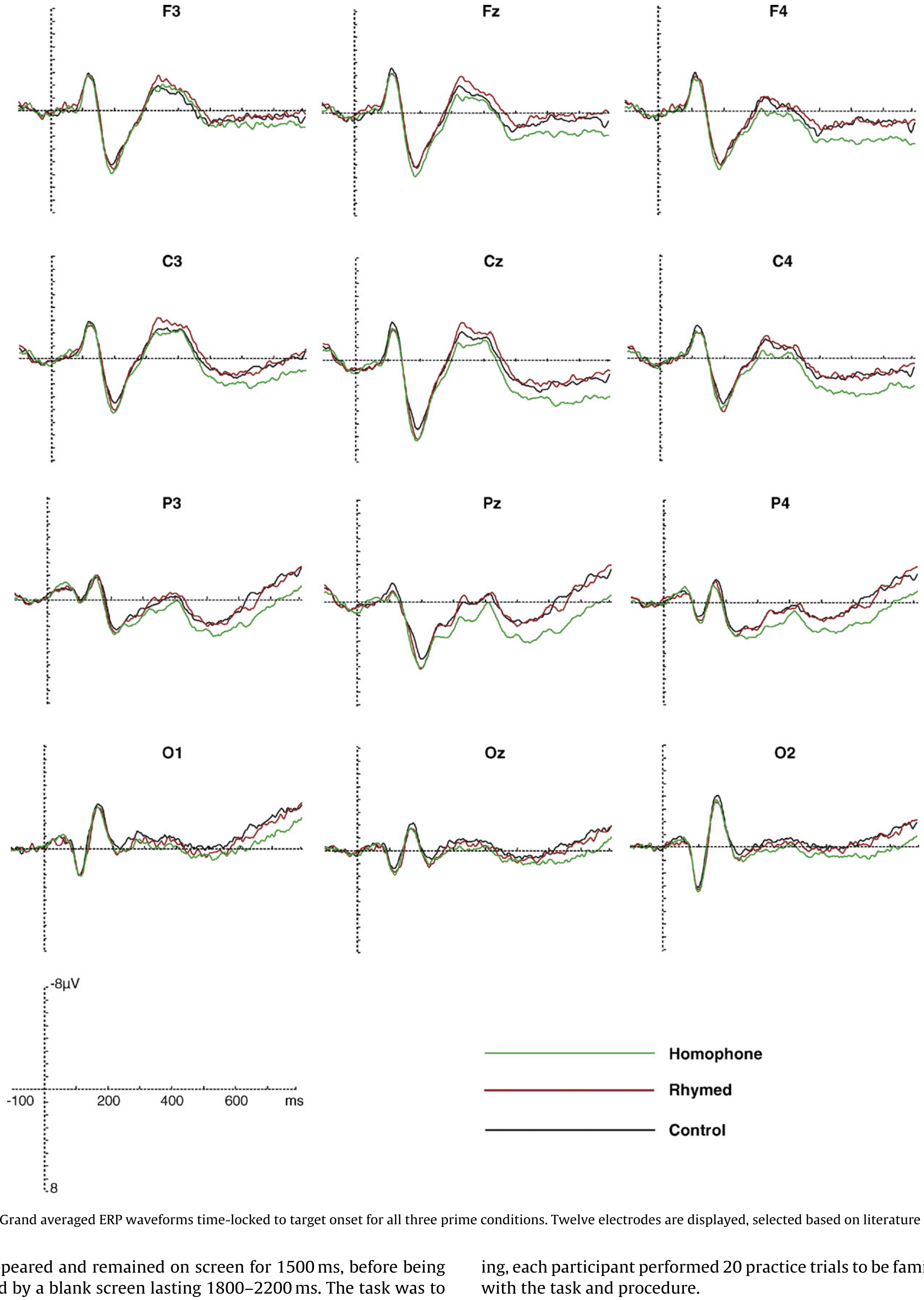


**Fig. 2.** Grand averaged ERP waveforms time-locked to target onset for all three prime conditions. Twelve electrodes are displayed, selected based on literature studies.

then appeared and remained on screen for 1500 ms, before being replaced by a blank screen lasting 1800–2200 ms. The task was to judge whether or not the two words in each pair were semantically related. Participants were asked to respond as quickly and accurately as possible with a button press. They were instructed to refrain from head movements and eye blinking. Prior to testing, each participant performed 20 practice trials to be familiarized with the task and procedure.

Electroencephalogram (EEG) was recorded from 63 scalp electrodes in an electrode cap (10/20 system) with BrainAmp DC amplifiers, all referred online to the left mastoid and re-referenced offline to the average of the left and right mastoids. Vertical

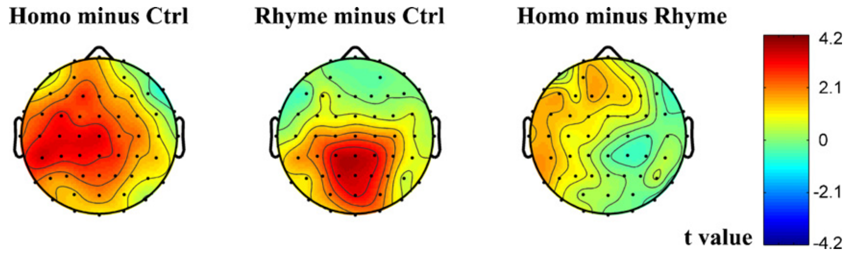


**Fig. 3.** Topographies showing scalp distributions of across-condition ERP differences. *t*-Statistic values from one-sample *t*-tests against zero (df = 17-1) are plotted for each pair-wise comparisons. Left: homophone vs. control; middle: rhyme vs. control; right: homophone vs. rhyme. *t*-Tests were conducted on mean amplitude differences from the 180–210 ms time window. Color bar shows *t*-values. At df = 16, a *t*-value of 2.1 corresponds to a significance level of $p = 0.05$.

electro-oculogram (VEOG) was recorded with a pair of electrodes placed above and below the left eye. EEG signals acquired with a 500 Hz sampling rate were band-pass filtered (range = 0.1–70 Hz). Electrode impedances were kept below 5 kΩ. Average ERPs were computed offline for correct trials free of ocular and movement artifacts (>±75 μV). Filler trials were excluded from analysis. Each averaging epoch was 900 ms long, including a 100 ms interval prior to target onset for baseline correction.

As shown in Fig. 2, inspection of the grand mean ERPs elicited by target presentation revealed a negative peak in the 100–140 ms post-stimulus time window, a positive peak in the 180–300 ms window, and a negative peak in the 300–450 ms time window. They were identified as N1, P200, and N400, respectively. The P200 component was focused in the following analysis. A 30 ms time window (180–210 ms) was selected centering the P200 peak. Mean ERP amplitudes from this time window were computed for each participant for all three prime conditions and submitted to a two-way repeated-measure ANOVA. The two factors were prime condition (homophonic, rhyme, unrelated), and electrode site (Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, Oz, O1, O2). These 12 electrodes were considered representative for examining phonological processing and commonly used in relevant ERP studies [5,10,13,14,23]. To be consistent with the literature to facilitate cross-study comparisons, we did not include other electrodes. Greenhouse-Geisser corrections were conducted for all effects having two or more degrees of freedom in the numerator.

Table 1 shows mean response times (RT) and error rates for the three prime conditions. For the RT data, one-way repeated-measure ANOVA revealed a significant main effect for prime condition [$F(2, 32) = 6.22$, $p < 0.01$]. Pair-wise comparisons showed significantly slower response to the homophonic pairs than the controls (665 ms vs. 644 ms, $p < 0.01$), but no difference between the rhyme pairs and the controls (646 ms vs. 644 ms, $p = 0.8$). Errors were minimal and not analyzed further.

The analysis showed a main effect for both prime condition [$F(2, 32) = 4.1$, $p < 0.05$] and electrode site [$F(11, 176) = 24.74$, $p < 0.001$], with no interaction between the two [$p = 0.46$]. Relative to the control condition, P200 amplitude was significantly larger for both the homophonic condition [1.97 vs. 2.57, $p < 0.01$] and the rhyme condition [1.97 vs. 2.39, $p < 0.05$], but the latter two did not differ from each other [2.57 vs. 2.39, $p = 0.47$].

Scalp distributions for these across-condition differences are shown in Fig. 3. Plotted in the topographies are *t*-statistic values from one-sample *t*-tests against zero (df = 16) for the three pair-wise comparisons. The *t*-tests were conducted on the mean amplitude differences from the 180–210 ms time window. The computed *t*-values, one for each recording electrode, were interpolated to cover the whole scalp.

With the control condition as the reference, both the homophonic condition and the rhyme condition showed comparable central/parietal locus (left and middle panels in Fig. 3). With the rhyme condition as the reference, the homophonic condition tended to show more left temporal and frontal distribution, which did not reach statistical significance, as seen from the direct contrast between the two in the right panel of Fig. 3 (at df = 16, the *t*-value of 2.1 on the color bar corresponds to a significance level of $p = 0.05$).

The results showed that when participants were asked to make semantic judgments between visually dissimilar pairs of Chinese words, homophonic but semantically unrelated elicited a larger P200 relative to phonologically unrelated control pairs. Replicating the Chen et al. [5] and the Zhang et al. [23] studies, this finding corroborates the conclusion that P200 can be modulated by phonological similarity independent of orthographic similarity. By the RT data, the homophonic pairs were also judged as semantically non-related more slowly than the control pairs, demonstrating a behavioral interference effect.

However, the larger P200 effect for homophones may not directly correspond to the interference effect. In our view, P200 enhancement in the homophonic condition reflects facilitated phonological processing of the target word by its homophonic prime [1,23]. This pre-activation of a target's phonology would then prime its semantic representation, as evidenced by N400 reduction for the homophonic condition, relative to the control condition. The presence of semantic priming may bias the participants to erroneously judge the two as semantically related. In addition, that the prime and the target match in the phonological dimension, though task-irrelevant, has been known to produce a similar response bias. We believe that the overcome of such response bias produced the behavioral interference effects in the RT results [23].

An enhanced P200 effect was also found for the visually dissimilar rhyme pairs that were semantically unrelated. This presents another piece of evidence for the conclusion that P200 is sensitive to phonological similarity independent of orthographic similarity. Just as for the homophonic condition, we interpret the P200 effect for the rhyme condition to indicate facilitated phonological processing due to partial match in phonology between the prime and the target.

Such partial phonological similarity, however, may not be strong enough to activate the target's semantic activation, given many Chinese words share the same rhyme. That is, unlike the homophonic condition, the target in the rhyme condition would not be semantically primed, as evidenced by the lack of N400 difference between the rhyme condition and the control condition. Further, as the prime and the target differ in whole syllable phonology, we suspect that phonology at the syllable level may suppress sub-syllable phonology as times went on so that later semantic judgment was not affected by the latter. This explains why there was no behavioral interference effect for the rhyme condition, i.e., its RT was not different from the control condition.

Although P200 effect sizes were slightly larger for the homophonic condition than the rhyme condition, the difference was not statistically significant. Similarly, although the homophone condition showed slightly more activity in left temporal and frontal areas than the rhyme condition, direct contrasts between the two conditions did not reveal any significant differences at the conventional $p = 0.05$ level. P200 effects in both conditions showed a scalp distribution with centro-parietal locus, consistent with previous functional MRI studies demonstrating inferior parietal activations during phonological tasks including rhyme judgment [3,8,15,16].

The finding that the homophonic and the rhyme conditions showed comparable P200 effects is somewhat surprising as the two seem to differ in degree of phonological similarity and one would expect a graded P200 effect to be larger for the homophonic pairs than for the rhyme pairs. However, this expectation was disconfirmed by the results. This may be due to characteristics of the Chinese word phonology which has no systematic rules of orthography-to-phonology mapping. The syllable phonology of a Chinese word is directly retrieved from lexical representations without going through any assembled process as in English. Therefore, rhyme phonology, though linguistically being part of syllable phonology, may be available at the same time syllable phonology is available. In other words, rhymes seem to be phonologically processed in the same way as syllables but do not subsume under them.

As described above, future studies need to see whether P200 can be modulated by orthographic similarity alone, in the absence of phonological similarity. Beside phonological similarity, there is some evidence that orthographic similarity may cause P200 reduction [5]. If this is truly the case, their joint effects may account for some of the conflicting results in the literature where P200 reduction was found in some studies [5] but P200 enhancement was found in others [23]. A then challenging issue would be to understand why one type of similarity enhances P200 but the other reduces it.

Further, although the present study adopted visually dissimilar words sharing no phonetic radicals and focused on lexical phonology, it does not exclude the possibility that P200 may also be sensitive to sub-lexical phonology associated with the phonetic radicals. Future studies can be designed to separate P200 effects from lexical and sub-lexical phonology by comparing regular and irregular Chinese characters where the two levels of phonology can be dissociated.

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