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# P200 can be modulated by orthography alone in reading Chinese words

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## HIGHLIGHTS

- Prime–probe Chinese character pairs were presented in sequence for meaning decision.
- Primes visually similar to the probe led to reduced P200 response to the probe than control primes.
- P200 effect was more salient for visually similar composite characters than integrated characters.
- P200 can be modulated by orthographic processing alone.

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## ABSTRACT

The present study examined the relation between the event-related potential component P200 and orthographic processing in reading Chinese words. Participants performed a semantic judgment task on pairs of words (prime–target pairs) presented sequentially and the P200 elicited by the second target word was examined and compared across different prime conditions. The critical pairs were single characters similar in orthography but unrelated in phonology or semantics. Results showed that for both integrated and composite characters, visually similar primes led to reduced P200 than control primes and the effect was larger for composite characters than integrated characters. The study presented clear evidence that P200 is sensitive to orthographic similarity and can be modulated by orthography alone in reading Chinese word.



## 1. Introduction

The neural mechanism for early orthographic and phonological processing in word recognition is a critical issue that draws increasing attention in studies of different languages [1–3,6,8–11,14,18]. Related research may help to understand the role of orthographic and phonological information in word recognition beyond what has been offered by behavioral studies [5,7,12,13,15,16,18]. One specific question under debate is how the event-related potential (ERP) component P200 is related to such lexical processing [2,9]. Kong et al. [9] identified a connection between P200 and phonological processing in Chinese word recognition. As a follow-up, the present study was intended to examine whether P200 can be modulated by orthographic processing.

Early studies on English word recognition found that P200 was an index to the interaction of orthographic and phonological processing [10], also supported by studies on Hebrew words [1]. However, there were also many inconsistent findings [2,19]. For example, Ziegler et al. [19] found no P200 difference between homophonic (with different meanings, i.e., *two* and *too*) and non-homophonic words in a semantic judgment task. Similarly, Bentin et al. [2] found no ERP differences between pronounceable and unpronounceable letter strings before 270 ms. In addition, visually similar English words are often phonologically similar, making it difficult to distinguish visual and phonological similarity and to examine the modulation of P200 by visual or phonological similarity alone.

In Chinese word recognition, it had been shown that P200 can be modulated by phonological processing alone. For example, Kong et al. [9] found that homophonic pairs and rhyming pairs produced P200 effect compared with controls. Several studies found that visually similar character pairs caused reduced P200 (and N400) [4]. In these studies, two characters were presented in sequence and the P200 elicited by the second word was analyzed. For example, Chen et al. [4] found that both high and low frequency visually similar character pairs elicited reduced P200. However, these studies showing reduced P200 effects for visually similar character pairs used composite character pairs sharing the common

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phonetic radical and the orthographic P200 may be confounded by sub-lexical processing of the phonetic radical (here "sub-lexical" refers to the semantic and phonetic radicals embodied in a whole character. Phonetic radical is a sub-lexical unit, relative to the lexical-level whole character). It is thus unclear whether or not P200 can be modulated by orthographic processing alone in Chinese word recognition.

The present study addressed this issue by using visually similar integrated character pairs, in addition to the composite character pairs. An integrated character is a character that cannot be divided into meaningfully sub-lexical units (e.g., 大 /da4/, big). A composite character is a character that contains two or more radical components which often give clues to the pronunciation and meaning of the whole character (e.g., 秒 /miao3/, consisting of two radicals and meaning second as a whole). Unlike composite characters, integrated characters do not have phonetic radicals that may be themselves characters with pronunciation and meanings. There are many integrated Chinese characters with visual similarity but no phonological similarity at the sub-lexical or lexical level (e.g., 未 /wei4/, not; 末 /mo4/, end).

Such pairs of integrated characters can be used to examine whether P200 can be modulated by orthographic processing alone. Several studies had shown reliable P200 reduction for visually similar composite character pairs that cannot be attributed solely to sub-lexical (phonetic radial) phonological similarity [4]. If visually similar integrated pairs also lead to P200 reduction, relative to the control pairs, it would provide evidence that P200 can be modulated by orthographic processing alone. Furthermore, the present study also for the first time directly compared integrated and composite characters to assess the potential contribution of both lexical and sub-lexical processing to P200.

## 2. Methods

### 2.1. Participants

Eighteen undergraduate students (mean age = 22.9 years, 11 females) from South China Normal University (Guangzhou, China) participated in the experiment. All were right-handed native Chinese speakers with normal or corrected-to-normal vision. None took any medication or had any history of neurological disease. Written informed consent was obtained from each participant in accordance with a research protocol approved by the university's IRB Committee.

### 2.2. Materials

All experimental materials were chosen from the 4574 characters that make up a 1,810,000-character Chinese corpus used in Modern Chinese Frequency Dictionary [17]. The materials included nonhomophonic pairs of integrated, composite and filler characters. The first character in each pair was referred to as the prime and the second the target. Only the filler pairs were semantically related. Integrated characters included visually similar pairs and controls with no visual similarity, each of 35 pairs. Composite characters included visually similar pairs and visually dissimilar controls, each of 35 pairs. The two characters in a visually similar composite pair shared one phonetic radical. There were in total 140 pairs, 35 pairs in each of the four conditions.

The prime and target in each pair were matched in mean stroke number and character frequency and the two measures were also matched across all conditions. The fillers included semantically related characters with and without visual similarity, each of 18 pairs. Sample stimuli are provided in Table 1. Each participant completed judging a total of 176 character pairs, divided into two blocks. Each block included 35 integrated pairs, 35 composite pairs, and 18 filler pairs, randomly intermixed. Block order was counterbalanced across subjects. Latin square was used to assign character pairs to different conditions.

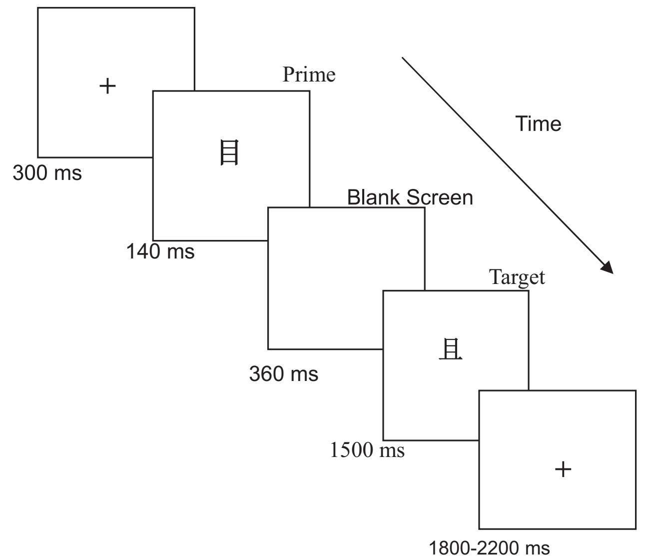


**Fig. 1.** A schematic illustration of the trial structure. Each trial displayed a warning screen and then showed a prime word for 140 ms. Following a blank screen, the target was shown for 1500 ms. Participants judged whether or not the target was semantically related to the prime by pressing a button to related pairs but withholding their response to unrelated pairs. The next trial started after a variable inter-trial-interval.

### 2.3. Procedure

Participants sat in front of a computer monitor in a quiet room. In each trial (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 then appeared on screen and remained for 1500 ms before being replaced by a blank screen lasting 1800–2200 ms. The task was to

**Table 1**
Sample stimuli and mean stimulus characteristics for each condition.

| | Integrated | InteCtrl | Composite | ComCtrl |
|---|---|---|---|---|
| Character pair | 目-且 | 片-八 | 读-续 | 料-神 |
| Pronunciation in Pinyin | /mu4-qie4/ | /pian4-ba1/ | /du3-xu4/ | /liao4-shen2/ |
| Meaning | Eye-Just | Slice-Eight | Read-Continue | Expect-Mind |
| Frequency | 737–726 | 732–726 | 707–695 | 717–718 |
| Stroke number | 4.5–4.4 | 4.4–4.6 | 8.1–8.2 | 8.8–8.4 |

*Note.* Integrated: integrated character pairs; InteCtrl: control character pairs matched with Integrate; Composite: composite character pairs; ComCtrl: control character pairs matched with Composite. One pair of character is used for each condition for illustration purpose. Frequency and stroke number show mean frequency and stroke for all characters in each condition.

judge whether or not the two characters in each pair were semantically related. Participants were asked to respond as quickly and accurately as possible with a button press only when the two characters were semantically related. Otherwise they need not make any response. 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. As the filler trials were not the focus of the study, only data from the non-motor trials were entered into the statistical analyses. This way, motor artifacts on the P200 response can be minimized.

### *2.4. ERP recordings*

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 two mastoids. Vertical electro-oculogram (VEOG) was recorded with a pair of electrodes placed above and below the left eye. EEG signals were acquired with a 500 Hz sampling rate and band-pass filtered (range = 0.1–70 Hz). Electrode impedances were kept below 5 kΩ. Average ERPs were computed offline for non-motor 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.

## 3. ERP results

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 the focus in the following analysis. A 50 ms time window (180–230 ms) was selected centering around the P200 peak. Mean ERP amplitudes from this time window were computed for each participant for all four conditions and submitted to a three-way repeated-measure ANOVA with three factors, character type (integrated vs. composite characters), the type of character pair (visually similar pair vs. visually dissimilar pair) and electrode site (Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, Oz, O1, O2). These 12 electrodes were considered representative for examining orthographic or phonological processing in related ERP studies [9,18]. Greenhouse–Geisser corrections were conducted for all effects with two or more degrees of freedom in the numerator.

The three-way analyses showed a main effect for electrode site ($F$ (11, 187) = 17.05, $p$ < .001). The main effect of character pair type was also significant ($F$ (1, 17) = 8.62, $p$ < .01), indicating that P200 for visually similar character pairs was smaller than for the visually dissimilar controls. There was also a significant interaction between electrode site and character type ($F$ (11, 187) = 4.17, $p$ < .001), between electrode site and character pair type ($F$ (11, 187) = 1.86, $p$ < .05), and across the three factors ($F$(11, 187) = 10.55, $p$ < .001). The interaction between character type and character pair type was marginally significant ($F$ (1, 17) = 3.67, $p$ = .07). Pairwise comparisons with Bonferroni correction showed that P200 amplitude for the integrated character pairs was significantly smaller than for the integrated controls at central, occipital and parietal electrodes (C3, C4, $P$s < .05; O1, O2, Oz, P3, P4, Pz, $P$ < .01; Cz, $P$ = .05). For composite characters, a similar pattern was found at frontal and central electrodes (F3, F4, $P$s < .01; Fz, C3, C4, $P$s < .05; Cz = .08). Critically, the P200 effect (reduction in visually similar pairs compared

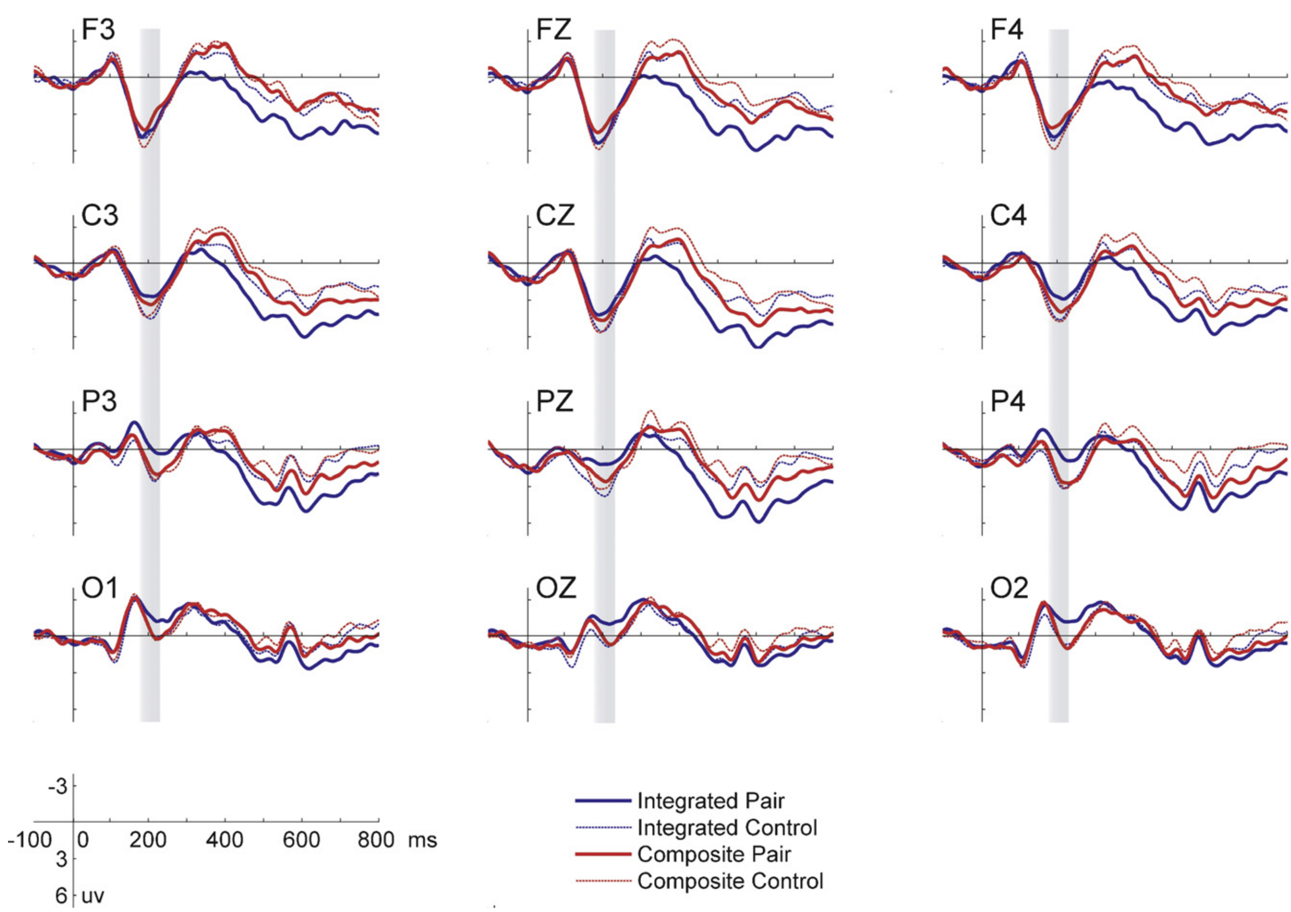


**Fig. 2.** Grand averaged ERP waveforms time-locked to target onset for all four conditions in twelve representative electrodes.

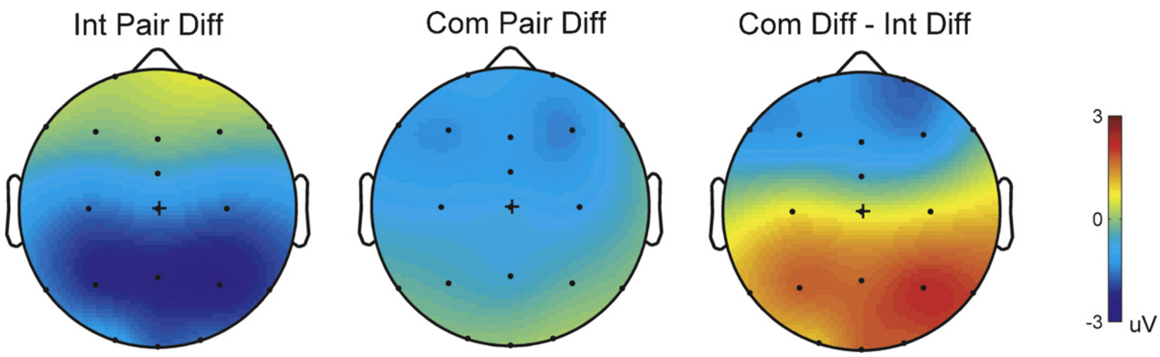


**Fig. 3.** Topographies showing scalp distributions of ERP differences across conditions in the 180–230 ms time window. Left: integrated character pairs vs. integrated character controls; middle: composite character pairs vs. composite character controls; right: visually similar integrated character pairs vs. visually similar composite character pairs.

with dissimilar pairs) was significantly smaller for the integrated characters than for the composite pairs at frontal, occipital and parietal electrodes (F3, F4, Fz, C4, Oz, Pz, *P*s < .05; O1, O2, P3, P4, *P*s < .01).

Fig. 3 shows the scalp distributions for the across-condition differences within the 180–230 ms time window (left: integrated character pairs vs. integrated character controls; middle: composite character pairs vs. composite character controls, right: visually similar integrated character pairs vs. visually similar composite character).

## 4. General discussion

How is the P200 response related to orthographic and phonological processing remains controversial in visual word recognition. Although P200 was found to be modulated by phonological processing alone in our previous study [9], it is unclear whether P200 can also be modulated by orthographic processing alone.

Here we found that both integrated and composite characters elicited smaller P200 when they were primed with visually similar characters and the effect was significantly larger for the latter than for the former. These findings suggest that P200 effect can be modulated by orthographic processing alone and sensitive to visual similarity in Chinese word recognition.

Larger P200 effect for composite than integrated characters may be due to the involvement of the cognitive processing in sub-lexical (phonetic radical) phonology. Another possibility is that that the visually similar composite pairs were more visually complex than the integrated character pairs. Composite characters are composed of more strokes, (semantic and phonetic) radicals and patterns than integrated characters. Perhaps visual similar composite pairs need more visual analyses and consequently cause larger P200 effect.

Previous studies showed that homophones alone often caused enhanced P200 effect than non-homophonic controls [9,18]. The present study found that visually similar characters always produced smaller P200 effects than controls. When sub-lexical phonological similarity was involved, the P200 effect was increased, as showed by the larger P200 effect for the composite characters than the integrated characters. These results indicate that orthographic and phonological processing have different effects on P200, i.e., while the former leads to reduced P200, the latter leads to enhanced P200. P200 may be the smallest for visually similar character pairs, the largest for phonological similar character pairs, and intermediate for characters with both visual and phonological similarity.

This inference was inconsistent with previous findings in alphabetical scripts such as English [1,10]. Kramer and Donchin [10] 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. More studies are needed to understand such differences across different scripts.

Briefly, there are intrinsic connections between orthography and phonology for words in alphabetical languages, making it difficult to distinguish visual and phonological similarity an to reveal the relation between P200 and orthographic and phonological processing. In contrast, it is possible to distinguish visual similarity from phonological similarity in Chinese, allowing the assessment of the relation between P200 and character orthographic and phonological processing separately. The present results suggest that P200 is sensitive to visual similarity and can be modulated by orthographical processing alone. Further studies can be carried out to explore the relation between P200 and sub-lexical phonological processing.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2012.09.028.

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