Brain & Language 123 (2012) 164–173

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Orthographic facilitation in Chinese spoken word recognition: An ERP study

Lijuan Zou [a,b], Amy S. Desroches [c], Youyi Liu [a], Zhichao Xia [a], Hua Shu [a,*]

[a] State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China
[b] College of Psychology and Education, Zaozhuang University, Zaozhuang, China
[c] Department of Psychology, The University of Winnipeg, Winnipeg, Canada

ARTICLE INFO

Article history:
Accepted 18 September 2012
Available online 23 October 2012

Keywords:
Orthographic effects
Spoken word recognition
ERP
Chinese

ABSTRACT

Orthographic influences in spoken word recognition have been previously examined in alphabetic languages. However, it is unknown whether orthographic information affects spoken word recognition in Chinese, which has a clean dissociation between orthography (O) and phonology (P). The present study investigated orthographic effects using event related potentials (ERPs) and an auditory lexical decision task. We manipulated the relationship between the phonology and orthography of the first syllable in each prime-target pair using the following four conditions: P+O+, P+O−, P−O+, P−O−. Importantly, we found significantly reduced N400 amplitudes when an item was preceded by an orthographically similar prime. In addition, these reduced N400 amplitudes were positively correlated with participants' reading skill. The findings indicate that orthographic information is activated automatically during Chinese spoken word recognition, supporting the theory that there is a reciprocal connection between speech and print.

1. Introduction

Spoken word recognition is a continuous and dynamic process, with meaning being derived as an acoustic input unfolds. Over the past several decades, a number of models have been put forth to account for this complex cognitive process. For instance, the Cohort model suggests that phonology is perceived sequentially, with word-initial speech sounds simultaneously activating a cohort of lexical candidates (e.g., *cat*: car, cash, cabbage, catch; Marslen-Wilson & Tyler, 1980; Tyler, 1984). According to this account, as the acoustic signal unfolds and more information becomes available, initially activated alternatives are suppressed until only one candidate remains (Marslen-Wilson & Tyler, 1980). Alternatively, subsequent models have provided a different account of this process, suggesting that although bottom-up input is important, other factors also influence recognition (e.g., TRACE, McClelland & Elman, 1986; Shortlist, Norris, 1994; Norris & McQueen, 2008; Norris, McQueen, & Cutler, 2000; NAM, Luce & Pisoni, 1998). For example, the TRACE model proposes that feedback from higher-level representations influences processing, such that items sharing other types of similarity, like rhymes and other neighbors, compete for recognition as well (e.g., *cat*: hat, bat, kit). This account of spoken word recognition has been supported by behavioral and neuroimaging data (Allopenna, Magnuson, & Tanenhaus, 1998; Desroches, Newman, & Joanisse, 2009; Dufour & Peereman, 2003; Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Zwitserlood, 1989; McClelland & Elman, 1986; Norris et al., 2000; Prabhakaran, Blumstein, Myers, Hutchison, & Britton, 2006; Righi, Blumstein, Mertus, & Worden, 2010; Ziegler & Muneaux, 2007; Ziegler, Muneaux, & Grainger, 2003).

Influences of phonological similarity during spoken word recognition, such as phonological competition and phonological neighborhood effects, have been observed using a variety of measures. For instance, using an eyetracking paradigm (i.e., the visual world paradigm), Allopenna and colleagues found that individuals looked more to phonologically related competitor pictures vs. unrelated distractors when asked to respond to a target (Allopenna et al., 1998). This effect was not only observed for cohort competitors (e.g., carrot-carriage) but also rhymes (e.g., carrot-parrot), suggesting that the process of spoken word recognition is not sequential. Data from neuroimaging provides further specification of this account, supporting the notion that top-down feedback influences recognition (Desroches et al., 2009). For instance, event-related potentials (ERPs) revealed that auditory targets preceded by rhyming pictures were recognized more readily than those preceded by unrelated pictures (Desroches et al., 2009). Data from functional magnetic resonance imaging (fMRI) reveals similar findings, with competition effects being associated with greater activation in the left supramarginal gyrus and left inferior frontal gyrus (Righi et al., 2010).

Interestingly, recent studies have also revealed that orthographic similarity plays a role during auditory word processing

* Corresponding author. Address: State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing 100875, China. Fax: +86 10 58800567.
E-mail address: shuhua.bnu@gmail.com (H. Shu).

0093-934X/$ - see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.bandl.2012.09.006

(Chereau, Gaskell, & Dumay, 2007; Pattamadilok, Perre, Dufau, & Ziegler, 2009; Pattamadilok, Perre, & Ziegler, 2011; Perre, Midgley, & Ziegler, 2009; Perre & Ziegler, 2008; Ziegler & Muneaux, 2007; Ziegler, Petrova, & Ferrand, 2008; Ziegler et al., 2003). This suggestion is consistent with theories of language processing which suggest that phonology, semantics, and orthography are all interconnected component systems (Harm & Seidenberg, 1999, 2004; Seidenberg & McClelland, 1989). Both phonological–orthographic consistency effects and orthographic facilitation effects suggest a reciprocal connection between spoken and written language processing (Ziegler & Goswami, 2005; Ziegler et al., 2008; also see Morais, Cary, Alegria, & Bertelson, 1979 for a discussion of the reciprocal relationship between speech abilities and reading skill).

Indeed, there is ample evidence suggesting that orthography is activated automatically during spoken word recognition (Chereau et al., 2007; Cone, Burman, Bitan, Bolger, & Booth, 2008; Dehaene et al., 2010; Pattamadilok et al., 2009, 2011; Peereman, Dufour, & Burt, 2009; Perre, Midgley, et al., 2009; Seidenberg & Tanenhaus, 1979; Ziegler & Muneaux, 2007; Ziegler et al., 2003). For instance, rhyme judgments are facilitated by orthographic similarity, with faster responses to orthographically similar vs. dissimilar rhymes (e.g., pie-tie vs. pie-rye; shirt-dirt vs. hurt-dirt; Chereau et al., 2007; Seidenberg & Tanenhaus, 1979). As well, off-line factors of orthography have been observed, with orthographic neighborhood size impacting auditory lexical decision (Ziegler & Muneaux, 2007; Ziegler et al., 2003). Neuroimaging studies have also isolated orthographic effects during spoken word processing. For instance, ERPs have been used to demonstrate the time point at which orthographic inconsistency effects take place (Perre & Ziegler, 2008). For prime-target pairs sharing orthography, reduced N400 amplitudes were observed in comparison with unrelated pairs (Perre, Midgley, et al., 2009). fMRI studies have also revealed orthographic intrusion effects during spoken word processing, marked by the involvement of the left fusiform gyrus during auditory word tasks, despite the fact that this area typically associated with visual word processing (Booth et al., 2002, 2004; Cone et al., 2008; Dehaene et al., 2010). Moreover, the activation of the fusiform gyrus has been found to be related to reading skill or literacy experience, with greater activation in the fusiform gyrus being observed for better vs. poorer readers (Dehaene et al., 2010; Desroches et al., 2010).

To date, studies that have examined the role of orthography during spoken language processing have been limited to alphabetic languages. In such languages orthography and phonology cannot be separated completely, since they rely on systemic grapheme–phoneme-conversion rules. Therefore, in a phonologically similar but orthographically dissimilar condition, the prime and target still have some degree of orthographic overlap (e.g., beef-leaf, wall-doll). Examining the effects of orthography during spoken word recognition in non-alphabetic languages like Chinese may offer a unique insight into this relationship.

Languages differ in many ways including phonology, orthography, morphology, and syntax (Chen, Xue, Mei, Chen, & Dong, 2009), such that the relationship between these component systems might differ between languages. How these processes interact in non-alphabetic languages, like Chinese, remains unclear. Chinese is a nontransparent language with a deep orthography (i.e., there is no letter-phoneme mapping; Chen et al., 2009; Feng, Miller, Shu, & Zhang, 2001). The mapping between syllable and orthography is quite arbitrary, and Chinese is replete with homophonic characters. For example, each syllable (e.g., /shi4/) is associated with a set of Chinese characters that share no orthographic components (e.g., /shi4/: 是, 市, 室, 事, 试, 示, 士, 视). This one to many mapping results in ambiguity during spoken language processing. One way to resolve the ambiguity inherent in spoken language is to write out the character. Therefore, orthographic information is important in lexical access among syllables in the Chinese auditory modality.

Compared with alphabetic writing systems, in which similar pronunciations tend to have similar spellings, Chinese allows for a clean dissociation between orthographic and phonological codes. Thus, using Chinese we can investigate the nature of orthographic effects during spoken word recognition, independent of phonology. For example, in Chinese, one syllable can be associated with two (or more) unique characters, which share no orthography (P+O−; e.g., /shi4/ can be associated with '市' or '事'). Similarly, one character can be associated with two pronunciations (P−O+; e.g., '会' can be pronounced as /hui4/ and /kuai4/). These homophonic and homographic dilemmas in Chinese are well resolved in disyllabic words. Within the word context (e.g., /cheng2/-/shi4/), a syllable (e.g., /shi4/) usually corresponds to a specific character (e.g., 市), therefore the correspondence between phonology, orthography and semantics is clear. When a disyllabic word is presented aurally, multiple candidate representations (or characters) may be activated during the first syllable. However, as the acoustic signal unfolds and the second syllable is perceived, contextual information is provided that allows the correct word (and character for the first syllable) to be identified. Considering this, disyllabic words provide a unique way to investigate orthographic effects in Chinese spoken word recognition. We hypothesize that orthographic effects in Chinese might be much stronger than in alphabetic languages because of the very specific correspondence between phonology and orthography in Chinese disyllabic words.

In the present study we used ERPs to measure the degree to which individuals access orthography during an auditory priming paradigm in Chinese (adapted from Perre, Midgley, & Ziegler, 2009). Because of their high temporal resolution, ERPs are an ideal way to explore the time course of orthographic effects during spoken word recognition. Participants in our study were required to perform an auditory lexical decision task, responding to target words that were preceded by primes. Orthographic similarity was manipulated, and we hypothesized that similar and non-similar primes should produce different effects, marking automatic activation of orthography during the auditory word recognition. This is unlike many previous studies examining orthographic processing in Chinese, since these past studies have typically relied on auditory spelling judgment tasks, which require explicit orthographic computation (Booth, Mehdiratta, Burman, & Bitan, 2008; Booth et al., 2002, 2003, 2004; Cao et al., 2011). We manipulated four relations between the first syllable of prime and the target to investigate orthographic effects during auditory word processing: similar phonology–similar orthography (P+O+, e.g. 面包 /mian4/, 面孔 /mian4/), similar phonology–dissimilar orthography (P+O−, e.g. 灯光 /deng1/, 登门 /deng1/), dissimilar phonology–similar orthography (P−O+, e.g. 长城 /chang2/, 长官 /zhang3/), and dissimilar phonology–dissimilar orthography (P−O−, e.g. 海带 /hai3/, 电台 /dian4/). Although we use the terminologies 'similar' and 'dissimilar' to be consistent with alphabetic studies, in our experiment, 'similar' is actually the 'same', and 'dissimilar' is 'different'.

We were interested in examining whether orthography is activated during Chinese spoken word recognition, as has been previously observed in alphabetic languages. This would be revealed in the present study by differential modulations of the N400 component to orthographically similar vs. dissimilar pairs. Furthermore, in order to more fully explore the underlying mechanism of any observed orthographic effects, we were also interested in their relation to basic reading performance. We evaluated reading skills focusing on single word and sentence level reading, both were important aspects of automatic skilled reading. The single word reading tasks covered three aspects of reading: mapping from orthography to phonology (onset judgment), mapping from orthography to phonology and semantics (homophone discrimination), and mapping from orthography to semantics (animal word cross out). The sentence task (ambiguous sentence judgment) evaluated processing of syntax and meaning during reading. Since phonology, orthography and semantics are tightly interconnected in Chinese disyllabic words, we hypothesized that individuals' proficiency in processing orthography, phonology, and semantics may correlate with any observed orthographic effects.

2. Methods

2.1. Participants

Thirty-three college students (mean age: 23 years, 17 females) recruited from Beijing Normal University participated in a behavioral pilot experiment and another 23 college students (mean age: 21.2 years, 11 females) participated in the ERP study. All participants were right-handed native speakers of Chinese with normal hearing and no reports of neurological disorders. All participants gave written informed consent in accordance with the guidelines of the Human Subjects Committee of Beijing Normal University. As well, all participants were given a hearing test to make sure their hearing ability was balanced across both ears. Data from one participant in the behavioral experiment was not included in the final analyses due to a high error rate across all conditions. For this individual, his error rate was greater than three standard deviations (*SD*) from the group mean. Data from two ERP participants were excluded because of large EEG artifacts that made it impossible to analyze their data.

2.2. Materials and tests

Three-hundred-and-sixty disyllabic compound words were selected from a Chinese lexical database (Yu, Zhu, Wang, & Zhang, 1998). Pairs of items were created with each item occurring in only one of four conditions (P+O+, P+O−, P−O+, P−O−). In total, there were 45 pairs in each of the four conditions. All pairs were semantically unrelated. An additional group of 35 college students rated the semantic relatedness of each pair of disyllabic words on a 7-point scale (1 – 'not related at all', and 7 – 'highly related'). The final 180 pairs were selected from a pool of 623 pairs that were rated as not related (on the basis of having average ratings lower than 3). The average rating scores for the items in the four conditions were 1.22 ($SD = 0.29$) for P+O+, 1.26 ($SD = 0.29$) for P+O−, 1.3 ($SD = 0.23$) for P−O+ and 1.32 ($SD = 0.39$) for P−O−, with no significant difference across the four conditions (all $ps > 0.1$). Stimulus pairs in each of the four conditions were matched for prime-target/first character syllable frequency, prime-target/first character phonological family size, prime-target/whole word frequency, prime-target/first character whole word frequency, number of prime-target/first character strokes, and number of prime-target/second character strokes (all $ps > 0.2$, see Supplementary Table 1). The character/word/syllable frequency were taken from the Chinese lexical database (Yu et al., 1998).

For the purpose of the lexical decision task, 240 pseudoword targets were created. Pseudoword targets were created by changing the second syllable/character of the prime words (e.g., *zu3 zhuang1* (组装, prime) vs. *zu3 mei3* (组美, target)) or non-prime words (e.g., *ni2sha1* (泥沙, prime) vs. *hua1wei1* (花薇, target)). On both real word and pseudoword trials, primes were always real words. Some of the word-pseudoword pairs shared phonology, and some did not, with the ratio being 1:2 for similar vs. dissimilar phonology (PseudoP+: PseudoP− = 1:2). Thus, participants could not perform the lexical decision task by phonological similarity alone. The two pseudoword conditions (PseudoP+ and PseudoP−) that were also matched for prime-target/first character syllable frequency, prime-target/first character phonological family size, prime/whole word frequency, prime/first character frequency, prime/first character number of strokes, and prime/second character number of strokes (all $ps > 0.05$, see Supplementary Table 2).

All stimuli were recorded by a native Mandarin female speaker (with a standard Beijing accent) in a soundproof room on a digital audio recorder (Yamaha MG124C) using a CME MG-900 microphone at a sampling rate of 48 kHz with a 16-bit resolution. The mean duration of primes in each condition was 709 ms ($SD = 42$ ms) for P+O+, 704 ms ($SD = 39$ ms) for P+O−, 719 ms ($SD = 50$ ms) for P−O+, 715 ms ($SD = 40$ ms) for P−O−, 713 ms ($SD = 47$ ms) for PseudoP+, and 716 ms ($SD = 48$ ms) for PseudoP−. The mean duration of targets in each condition was 704 ms ($SD = 40$ ms) for P + O+, 705 ms ($SD = 53$ ms) for P + O-, 712 ms ($SD = 42$ ms) for P−O+, 704 ms ($SD = 32$ ms) for P−O−, 716 ms ($SD = 46$ ms) for PseudoP+, and 712 ms ($SD = 48$ ms) for PseudoP−. There was no significant difference in stimulus duration across conditions for either primes ($p = 0.53$ for words, $p = 0.59$ for pseudowords) or targets ($p = 0.63$ for words, $p = 0.54$ for pseudowords).

2.2.1. Basic reading tests

After finishing the EEG session, participants were administered a battery of reading tests to provide information about their reading skill. Three subskills of reading tests were developed at the word level – onset judgment (orthography to phonology), homophone discrimination (orthography to phonology and semantics), and animal word cross-out (orthography to semantics). In addition, a sentence level task (i.e., ambiguous sentence judgment) was administered to evaluate the processing of syntax and meaning during reading. One more task, figure-cross-out was added as baseline to assess general cognitive processing. Each of the tests had time limits (see below), such that no participant could finish all the items on any task. Several practice items were provided before the formal test. The reading scores were adjusted by subtracting the number of false-alarm items from the number of hit items.

2.2.2. Figure-cross-out

This task consisted of 162 figures (e.g., §⊙〒♀), including 100 § symbols. All the figures were sequenced in a random order. Participants were asked to mark all the § with a slash "\". The time limit was 30 seconds.

2.2.3. Onset judgment

This task consisted of 308 high frequency single-character words, with an average word frequency that was approximately 125 times per million. The pronunciation of 100 of the items began with /b/ (e.g., '北, /bei3/'), while the remaining items did not (e.g., '回, /hui2/'). All the words were sequenced in a random order. Participants were asked to mark all the words with pronunciation onset "b" with a slash "\". The time limit was 80 seconds.

2.2.4. Homophone discrimination

Two-hundred-and-twenty two-character words, with an average word frequency that was approximately 27 times per million, were first selected (e.g., '荷花', /he2hua1/, lotus). Seventy-two of them had one character replaced with another that was pronounced same, producing a pseudo-homophone word that did not really exist in Chinese (e.g., '何花', /he2hua1/). The types of misspellings in pseudo-homophone words mainly consisted of a missing, additional, or changed component of a given character (e.g., missing a component: 荷/he2/→何/he2/; adding a component: 然/ran2/→燃/ran2/; changing a component: 垃/la1/→拉/la1/). The pseudo-homophones and the correct words were sequenced in a random order. Participants were asked to mark all the pseudohomophones with a slash "\". The time limit was 70 seconds.

2.2.5. Animal-word cross-out

This task consisted 220 two- or three-character words, including 74 animal words, such as "青蛙" (/qing1wa1/, frog). They were familiar words with an average word frequency that was approximately 16 times per million. Animal and non-animal words were sequenced in a random order. Participants were asked to mark all the animal words with a slash "\". The time limit was 50 s.

2.2.6. Ambiguous Sentence Judgment

This task consisted 69 sentences, in which 35 were ambiguous ones like "吉姆发现约翰和他的朋友仍然在屋里聊天" (*Jim found that John and his friend were still chatting in the room*) and 34 were unambiguous sentences like "他大学毕业后去清华大学读研究生" (*He entered Tsinghua University as a graduate student after graduated from college*). There were 18 or 19 characters in each sentence. Subjects were required to indicate whether a sentence was ambiguous or not with a slash "\" on "Yes" or "No". The time limit was 3 min.

2.3. Procedures

2.3.1. Behavior

Participants were tested individually in a quite room. A trial consisted of the following sequence of events: a fixation point (+) was presented for 500 ms in the center of the screen, the spoken stimuli were presented binaurally through earphones while the fixation cross remained on the screen, with an interstimulus interval (ISI) of 150 ms between the prime and target. Participants were asked to respond as quickly and as accurately as possible after hearing the target word. They indicated their response by pressing a button with their right hand if the target was a real word or with their left hand if it was a pseudoword while ignoring the first word that they heard. Participants were allowed 2500 ms to indicate their response, with longer latencies being excluded. Between trials a blank screen was presented for 1000 ms. Reaction time was measured from the onset of the target stimulus until the participant pressed the response key. Items across different conditions were presented in a random order. Prior to completing the experimental trials, the participants were given 24 practice trials to familiarize them with the task. Practice stimuli were items not included in the formal tests, and feedback was provided during the practice session.

2.3.2. EEG

The ERP task was identical to the behavioral one with the exception of the inclusion of a response-delay after the target item. This response-delay was used to eliminate the influence of decision and motion from waveforms associated with lexical processing. For the ERP experiment, each trial began with the presentation of a fixation cross (+) for 500 ms in the center of the screen, following which a spoken stimulus was presented while the fixation cross remained on the screen. A 150 ms ISI was included between the prime and target. After the target word was presented, the fixation cross continued to remain on the screen for 1000 ms, following which an question mark ('?') appeared. Participants were told to indicate their response when the "?" appeared on the screen. This cue would disappear after participant pressed the button, and the time limit for a response was 2000 ms. To minimize artifacts due to eye blinks, participants were told not to blink their eyes while the fixation cross was present. The intertrial interval included a blank screen presented for 1000 ms. As with the behavioral experiment, a practice condition consisting of 24 pairs of items not included in the experimental stimuli was administered before the ERP experiment. Feedback was given during practice.

2.4. Data recording and analysis

2.4.1. Behavioral data

Mean reaction times (RTs) and error rates for words and pseudowords were calculated separately for each condition (P+O+, P+O−, P−O+, P−O−, PseudoP+, PseudoP−). RTs greater than two *SD*s beyond the global mean were discarded (4.5%). Items with an error rate above 50% across all subjects were excluded from the analysis (2.9%). This resulted in the exclusion of 12 items from the experiment (total number of items for both words and pseudowords is 420).

2.4.2. EEG data

Continuous electroencephalogram (EEG) was recorded using a NeuroScan system at a sampling rate of 500 Hz using 64 Ag/AgCl electrodes, placed according to the extended 10–20 system. All scalp electrodes were referenced online to the left mastoid and were re-referenced offline to the average mastoid reference by subtracting one half the activity recorded at the right mastoid. Vertical electrooculogram (VEOG) was recorded from electrodes above and below the left eye, and horizontal electrooculogram (HEOG) was recorded from electrodes placed at the outer canthi of both eyes. Impedances were kept below 5 kΩ. Data was filtered online using a band pass filter of 0.05–100 Hz, and off-line using a zero phase shift digital filter (24 dB, band-pass frequency: 0.05–30 Hz). Each trial was baseline corrected to the average voltage of the 200 ms prestimulus interval. Trials containing eye blinks and other artifacts were removed (determined by a maximum voltage criterion of ±70 μV on all scalp electrodes). Analyses were performed on the remaining trials (average nonrejected trials: 40/45 for P+O+, 39/45 for P+O−, 40/45 for P−O+, 40/45 for P−O−, 73/89 for PseudoP+, and 145/151 for PseudoP−). ERPs were calculated from −200 to 1000 ms, timelocked to the onset of the target words.

Analyses focused on a negative-going component commonly associated with spoken word recognition: the N400 (Desroches et al., 2009; Kutas & Hillyard, 1984; Lavric, Clapp, & Rastle, 2007; Perre, Midgley, et al., 2009; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002). The time intervals of the N400 was determined by visual inspection of the waveforms: 250–800 ms. We focused on the mean amplitude and peak latency of this component. The N400 was analyzed separately at the mid-line electrodes (FZ, CZ, PZ) and lateral electrodes (F3, F4, C3, C4, P3, P4). For the mid-line analysis, a three-factorial repeated measures ANOVA was conducted using phonology (P+, P−), orthography (O+, O−), and anterior-posterior extent (anterior, middle, posterior) as factors. For the lateral analysis, a four-factorial repeated measures ANOVA was conducted using phonology (P+, P−), orthography (O+, O−), laterality (left, right), and anterior-posterior extent (anterior, middle, posterior) as factors. Since the N400 component was largest over central and parietal sites, we focused the peak latency of N400 on the PZ electrode. The latency of this component can provide insight into when congruent vs. incongruent information is being processed (Liu, Shu, & Wei, 2006; Van Petten & Kutas, 1990). For the ERP data, we were particularly interested in the main effects of P and O, and the interaction of P by O by other factors (e.g., laterality, and anterior–posterior extent). Other effects (e.g., main effects of laterality and anterior–posterior extent) which we were not concerned with are reported in the Section 3, but they are not addressed further in Section 4. Greenhouse-Geisser corrections (1959) were applied when appropriate (corrected *p* values and original degree of freedom were reported). Finally, although some condition-wise differences may be apparent in the waveforms of an earlier component, the N100, we do not feel that our manipulations could have had an impact on this early component that is typically sensitive to subtle acoustic variations (e.g., Bonte & Blomert, 2004; Näätänen & Picton, 1987). Any differences between conditions that are apparent in the N100 component might reflect acoustic differences between the stimuli that were not explicitly manipulated. Further studies should follow-up with a directed manipulation in this regard; however, they are not of interest in the present study.

3. Results

3.1. Behavioral data

The reaction times and error rates across the P+O+, P+O−, P−O+, and P−O− were shown in Table 1. For RTs, a repeated-measures ANOVA showed a main effect of phonology ($F_1(1,31) = 41.25$, $p < 0.001$; $F_2(1,166) = 5.43$, $p = 0.021$) and orthography ($F_1(1,31) = 24.99$, $p < 0.005$; $F_2(1,166) = 11.38$, $p = 0.001$) that were significant by both subjects and items. The phonology by orthography interaction was significant by subjects but not by items ($F_1(1,31) = 8.24$, $p = 0.007$; $F_2(1,166) = 1.14$, $p = 0.29$, respectively). Participants took longer to judge that an item was a word when preceeded by a phonologically similar (P+) prime. In contrast, participants were faster to respond that an item was a word when it was preceeded by an orthographically similarly (O+) prime.

The analysis of error rate showed significant main effects of phonology ($F_1(1,31) = 17.84$, $p < 0.005$; $F_2(1,166) = 11.15$, $p = 0.001$) and orthography ($F_1(1,31) = 43.62$, $p < 0.005$; $F_2(1,166) = 9.22$, $p = 0.003$) in both the subject and items analysis. The phonology by orthography interaction was not significant for either analysis ($F_1(1,31) = 0.07$, $p = 0.8$; $F_2(1,166) = 0.06$, $p = 0.81$, respectively). Similar to the RT results, the main effect of phonology was inhibitory with a greater number of errors for words preceeded by phonologically similar vs. dissimilar primes. The main effect of orthography was facilitatory, with fewer errors for words that were preceeded by orthographically similar vs. dissimilar primes.

For pseudoword pairs, RT analysis showed no significant difference between the PseudoP+ and PseudoP− conditions ($t_{31} = 0.49$, $p > 0.05$). The error rate analysis showed a marginally significant difference, with more errors for PseudoP+ than PseudoP− ($t_{31} = -1.76$, $p = 0.09$).

Because a response-delay paradigm was applied during the ERP data collection, reaction time and error rates reported above came from the separate behavioral experiment. In the ERP experiment, the response accuracy was very high, with 95.16% ($SD = 1.02$) for words and 96.59% ($SD = 0.42$) for pseudowords, and there was no significant difference between either any condition of words nor pseudowords. Likewise, there was no significant difference between any condition on RTs. These results indicated that participants displayed adequate performance and there were no condition-wise differences on task difficulty in the ERP experiment.

3.2. ERP data

3.2.1. N400 amplitude

Larger N400 amplitudes were associated with orthographically dissimilar (O−) pairs (Fig. 1). In order to show more details about how ERPs were modulated by orthography, the four conditions (P+O+, P+O−, P−O+, P−O−) were presented in a single graph (Fig. 2). The ANOVA at the mid-line showed significant main effects of orthography ($F(1,20) = 31.46$, $p < 0.0005$) and anterior-posterior extent ($F(2,40) = 14.49$, $p < 0.0005$). Post hoc analyses revealed that the N400 amplitude was significantly reduced in O+ relative to O− conditions (O+: −2.34 μV; O−: −3.88 μV, $p < .05$). Neither the main effect of P ($F(1,20) = 0.134$, $p = 0.718$) nor the interaction of phonology by orthography by anterior-posterior extent ($F(2,40) = 0.026$, $p = 0.975$) was significant.

The results of the lateral ANOVA were similar to what we observed at the mid-line ANOVA. We observed significant main effects of orthography ($F(1,20) = 36.86$, $p < 0.0005$) and anterior - posterior extent ($F(2,40) = 5.39$, $p = 0.022$). The N400 amplitude was significantly reduced in O + relative to O- conditions (O+: −2.164 μV; O−: −3.46 μV, $p < .05$). Neither the main effect of phonology ($F(1,20) = 0.901$, $p = 0.3574$) nor the four-way interaction of phonology-by-orthography-by-laterality-by-anterior-posterior extent ($F(2,40) = 1.099$, $p = 0.308$) was significant.

3.2.2. N400 peak latency

The peak latency analysis revealed a significant effect of phonology on the N400 ($F(1,20) = 10.09$, $p = 0.005$, Table. 2, Fig. 3). That is, N400 component was delayed in the P+ conditions, marked by longer peak latencies for the P+ vs. P− conditions (P+ = 529.43 ms, P− = 475.86 ms, Fig. 2, PZ electrode)). The main effect of orthography ($F(1,20) = 0.001$, $p = 0.977$) and interaction of orthography by phonology ($F(1,20) = 0.594$, $p = 0.45$) were not significant.

3.2.3. Correlation between orthographic facilitation effect and basic reading performance

We transformed the reading scores into the number items correctly read in one minute. The average score for figure-cross-out was 88.76 ($SD = 14.48$), for onset judgment was 27.18 ($SD = 6.31$), for homophone discrimination was 20.78 ($SD = 4.07$), for animal-word cross-out was 43.20 ($SD = 6.85$), and for ambiguous sentence judgment was 8.87 ($SD = 3.07$; see Table 3). The figure-cross-out was used as a proxy for general cognitive ability such that performance on it was factored out of the other reading tests in order to better isolate for the variance in the orthographic effect unique to reading. Therefore, during the liner regression analysis, the other basic tests (i.e., onset judgment, homophone discrimination, animal-word cross-out, and ambiguous sentence judgment) were entered as dependent factors and figure-cross-out was entered as independent factor. The standardized residuals were saved and in the correlation analyses. The orthographic facilitation (N400 tuning) was defined as the difference of the mean N400 amplitude between the O− and O+ conditions (at PZ). A Pearson correlation analysis was conducted between the orthographic facilitation effect (N400 tuning) and the behavioral performance on the four reading tasks (based on the residuals after controlling for the figure-cross-out). The results are reported in Tables 3 and Fig. 4. We found a significant positive correlation between the orthographic facilitation effect and reading measures: animal word cross out ($r = 0.47$, $p < 0.05$), homophone discrimination ($r = 0.62$, $p < 0.01$), and ambiguous sentence judgment ($r = 0.53$, $p < 0.005$). The correlation coefficient between the orthographic facilitation effect and the onset judgment did not reach significance ($r = 0.26$, $p > 0.05$).

However, the reading tests might correlate with each other, making it difficult to access precisely what ability best accounted for the variance of N400. Therefore, an additional Pearson correlation analysis was conducted between each pair of behavioral tests (see Table 4). The results showed that figure-cross-out and onset judgment did not correlate with other tests. In contrast, animal

Table 1
Mean reaction time (RTs) and Error Rates (Err) in various priming conditions.

	Word				Pseudoword	
	P+O+	P+O−	P−O+	P−O−	P+	P−
RTs (ms)	939	962	902	944	1038	1036
SDs	82	93	101	95	136	134
Err (%)	12.4	17.4	7.5	12.2	6.1	4.9
SDs	7.0	9.5	4.2	5.8	4.9	3.9

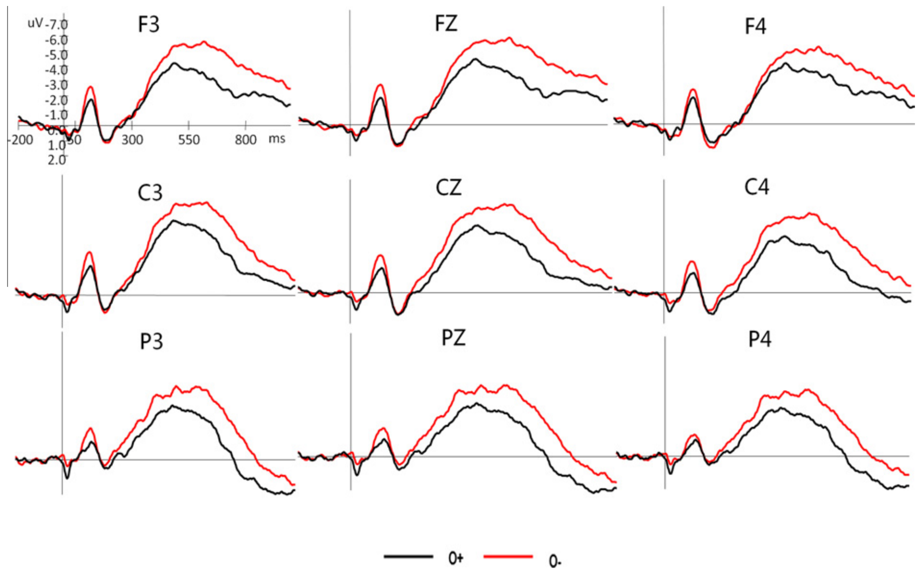

Fig. 1. Event related potentials on the main effect of orthography from nine representative electrodes. The black line stands for the prime-target pairs sharing the same orthography (O+) on the first character. The red line stands for the prime-target pairs with dissimilar orthography (O−). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

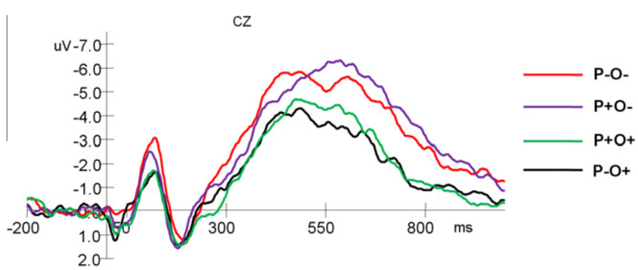

Fig. 2. Detailed pattern of ERPs elicited by the four conditions on CZ electrode. The red line stands for P−O−, the purple line stands for P+O−, the green line stands for P +O+, and the black line stands for P−O+.

Table 2
The peak latency (ms) of N400 at PZ electrode site.

P+O+	P+O−	P−O+	P−O−
523	536	482	496

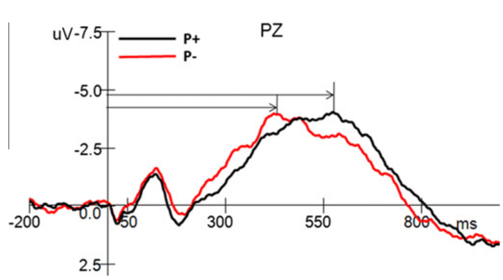

Fig. 3. The peak latency of N400 based on the phonological relationship between the prime and target words on the PZ electrode. The black line stands for phonologically similar prime-target pairs (P+). The red line stands for prime-target pairs sharing with dissimilar phonology (P−) on the first syllable. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

word cross-out, homophone discrimination, and sentence judgment were all significantly correlated with each other, indicating these three tests relied common cognitive processes in reading Chinese: namely, the integration of orthography, phonology and semantics.

In order to evaluate how much each measure accounted for unique variance to the N400, a regression model was applied between the behavioral tests and the orthographic N400 effect. Since animal word cross-out, homophone discrimination and sentence judgment were significantly interconnected, they were composited into O–P–S composite reading score (Orthography–Phonology–Semantics) using standard mean Z-scores. A three-step liner regression model was built with the figure-cross-out entered in the first step, the onset judgment entered in the second step and the O–P–S composite reading score entered in the third step. The regression model showed that only the O–P–S composite reading score significantly predicted the orthographic N400 effect (R^2 Change = 0.366, Table 5).

4. Discussion

The aim of the present study was to investigate whether individuals access orthography automatically during Chinese spoken word recognition, and whether this effect related to reading ability. To evaluate this we monitored ERPs during a spoken language task in which we manipulated the phonological and orthographic relationships of the initial syllable of sequentially presented pairs of disyllabic words: P+O+, P+O−, P−O+, and P−O−. Both behavioral and ERP data indicated that orthographic information was indeed automatically activated during Chinese spoken word recognition. In fact, orthographic similarity facilitated spoken word recognition in the absence of any kind of visual-orthographic information. Furthermore, we found that the orthographic facilitation effect correlated with subjects' basic reading performance, suggesting that this effect relates to skilled reading development. Overall, our results are consistent with what has been observed in previous studies conducted in alphabetic languages, supporting the hypothesis that orthography plays a critical role during spoken word recognition (Chereau et al., 2007; Cone et al., 2008; Dehaene et al., 2010; Desroches et al., 2010; Perre, Midgley, et al., 2009; Seidenberg & Tanenhaus, 1979; Ziegler & Muneaux, 2007; Ziegler et al., 2003, 2008).

Table 3
Correlations between reading tests and N400 tuning of orthography.

Indices	Correlation coefficient with N400 tuning	*p* Value
Onset judgment	0.26	ns
Animal word cross out	0.47	0.034
Homophone discrimination	0.62	0.003
Ambiguous sentence	0.53	0.013

Two-tailed test for Pearson correlation analysis. ns, $p > 0.02$.

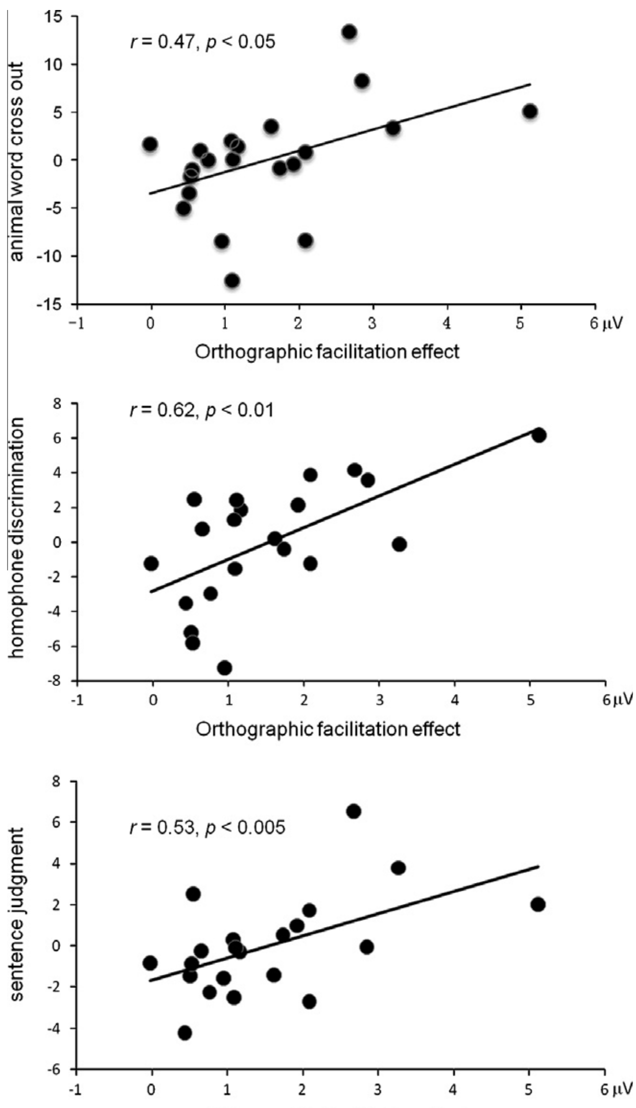

Fig. 4. Correlations between the orthographic facilitation effect on N400 and reading performance (residuals). Orthographic facilitation is calculated as the difference of the mean N400 amplitude between the O− and O+ conditions (on PZ electrode). The *r* stands the Pearson correlation coefficient.

The behavioral data suggests that orthographic overlap between prime-target pairs facilitates lexical access. That is, responses were faster and more accurate to targets preceded by orthographically similar primes, indexed by reaction time and error data. This finding is consistent with previous studies examining neighborhood effects, which reveal that larger orthographic neighborhoods facilitate spoken word recognition (Ziegler & Muneaux, 2007; Ziegler et al., 2003). Our results are also in line with evidence from rhyme judgment tasks, which indicate that individuals respond more quickly to orthographically similar pairs with overlapping phonology (Seidenberg & Tanenhaus, 1979). To our knowledge, this is the first study to reveal orthographic effects during spoken word recognition in Chinese even when the task requires no orthographic access for correct performance.

Similarly, results from ERPs indicate that orthography plays an important role during spoken word recognition in Chinese. However, ERPs provides insight beyond what behavioral measures can reveal. That is, sensitivity to orthographic similarity during Chinese spoken word recognition was marked by modulations of the N400 component. We observed reduced N400 amplitudes for orthographically similar vs. dissimilar (O+ vs. O−) pairs (over the 250–800 ms interval). Indeed, the amplitude of the N400 has been previously associated with lexical processing (Connolly, Phillips, & Forbes, 1995; Hagoort & Brown, 2000; Holcomb, Grainger, & O'Rourke, 2002; Kutas & Hillyard, 1984; Van Petten & Kutas, 1990). Various lexical factors including word frequency, morphological structure, phonology, and orthography have all been shown to influence the amplitude or latency of the N400 (Chereau et al., 2007; Desroches et al., 2009; Kutas & Hillyard, 1984; Pattamadilok et al., 2009, 2011; Perre, Midgley, et al., 2009; Perre & Ziegler, 2008; van den Brink, Brown, & Hagoort, 2001; Van Petten & Kutas, 1990). For example, Perre, Midgley, et al. (2009) investigated the influence of orthography in the spoken word recognition using a lexical decision paradigm similar to that used in the present study. They found significantly reduced N400 amplitudes to pairs of words with overlapping orthography (e.g., 'beef-reef [P+O+]), relative to those with non-overlapping orthography (e.g., 'leaf-reef [P+O−]). Furthermore, ERP differences were time-locked to the 'arrival' of the orthographic inconsistency, which provided strong evidence about the on-line activation of orthography during spoken word recognition (Pattamadilok et al., 2009; Perre & Ziegler, 2008). Thus, the orthographic effect found in our experiment is highly consistent with studies carried out in alphabetic languages, suggesting that despite drastically different writing systems, similar factors drive activation of orthographic information during spoken word recognition.

Both the behavioral and ERP data indicated the automatic activation of orthography during Chinese spoken word processing. We attribute the observed orthographic effects to the top-down connections of orthographic representations driven by the disyllabic word context during spoken word processing. According to the TRACE Model, feedback from higher-level representations will influence processing. For example, items sharing other types of word similarity, like rhymes and other neighbors, compete for recognition (McClelland & Elman, 1986). Here we provided evidence that feedback from another type of representation – orthography – could affect the spoken word processing as well.

4.1. Orthographic effects across languages

There appear to be differences between languages in terms of how orthographic information is accessed during spoken word recognition. In Chinese, orthographic similarity effects on the N400 started early with coverage across the scalp, and were sustained over the duration of the ERP (from 250 to 800 ms). In contrast, Perre, Midgley, et al. (2009) revealed significant orthographic effects at three different time windows in different brain locations. They found reduced N400 at 400–450 ms in anterior and middle electrodes, 450–500 ms in posterior electrodes, and 650–700 ms in anterior electrodes. We hypothesize that the difference between our result and Perre's is accounted for by key differences between the languages. Chinese is replete with a large number of

Table 4
Correlations between each two of the reading tests and reading performance.

	Figure cross out	Onset judgment	Animal word	Homophone	Sentence
Figure cross out	1				
Onset judgment	0	1			
Animal word	0	0.289	1		
Homophone	0	0.144	.646**	1	
Sentence	0	−0.013	.568**	.497*	1
Scores	88.76	27.18	43.20	20.78	8.87
SDs	14.48	6.13	6.85	6.13	3.07
Max	200	75	87.6	75	23

* $p < 0.05$.
** $p < 0.01$ (2-tailed).

Table 5
Unique variance (R^2) in Orthographic facilitation on N400 explained by individual difference in reading tests.

Predicting variables	R^2 change	*p* Value
Step 1: figure cross out	0	0.936
Step 2: onset judgment	0.065	0.277
Step 3: O–P–S composite reading score	0.366	0.004
Total R^2	0.431	

Step 1 = figure cross out; step 2 = figure cross out + onset judgment; step 3 = figure cross out + onset judgment + O–P–S composite reading score; O–P–S composite reading score: composite reading scores of animal word, homophone discrimination and sentence judgment using standard mean *Z* scores.

homophones relative to alphabetic languages (e.g., English), such that each homophone corresponds to several characters with similar or distinct meanings. However, disyllabic words provide top-down contextual information, such that the correspondence between phonology, orthography and semantics is extremely tight and unique. The two syllables in disyllabic words correspond to specific characters. Once a character is accessed in the prime, it is much easier for the subsequent character to be accessed. Therefore, on our task, shared orthography between the prime and target facilitated the access of the target word, resulting in the robust reduced N400s that were elicited in O+ conditions.

4.2. Orthographic effects and their relation to reading skill

Previous studies have suggested that reading skill modulates the way that the brain processes spoken language (Booth et al., 2004; Chereau et al., 2007; Cone et al., 2008; Dehaene et al., 2010; Seidenberg & Tanenhaus, 1979; Ziegler & Muneaux, 2007). More specifically, it has been suggested that the presence of orthographic effects during spoken word recognition emerge as a function of learning to read and write (also see Morais et al., 1979). For example, orthographic effects differ based on reading ability, such they are attenuated or absent in poor vs. good readers (Desroches et al., 2010; Ziegler & Muneaux, 2007). Here too we showed a relationship between activation of orthography during spoken word processing and reading skill. That is, the orthographic facilitation effect on the N400 was significantly correlated with a number of reading skill measures (the animal word cross out, homophone discrimination, and ambiguous sentence judgment). In addition, the regression analysis consistently showed that only the integration of animal word, homophone discrimination and sentence judgment uniquely predicated the variance of N400. These three behavioral tests mainly reflected three different aspects of skilled reading (semantic processing, orthographic-phonological-semantic mapping, and syntactic processing in sentence comprehension, respectively). Thus, individuals with higher reading proficiency have greater orthographic facilitation effects during spoken word recognition. Alternatively, a task mainly reflecting mapping from orthography to phonology (onset judgment), did not show any correlation with orthographic effect. Taken together, these effects suggest that the resolution of the ambiguity inherent in spoken Chinese (due to the large numbers of homophones) depends on orthography, which is accessed top-down via semantics. The brain-behavior correlation (between the N400 tuning of orthography and reading scores) provides strong evidence for the hypothesis that there is a reciprocal connection between speech and print (Morais et al., 1979; Ziegler & Goswami, 2005; Ziegler et al., 2008).

4.3. Phonological similarity effects during spoken word recognition

Besides orthographic effects, we also found significant phonological effects during Chinese spoken word recognition. That is, different responses were elicited to phonologically similar vs. dissimilar pairs. Behaviorally, longer response times were observed for phonologically related pairs during our lexical decision task. This inhibitory effect is consistent with previous studies examining phonological neighborhood effects, which have revealed that items with more phonological neighbors had longer response latencies (Ziegler et al., 2003, 2008). The ERP data also showed phonological similarity effects, with prime-target phonological similarity impacting the latency of the N400 (Table 2 and Fig. 2). The N400 effect in the P+ condition was delayed by some 40 ms as compared with the P− condition. Our finding is consistent with what others have observed: word initial overlap results in later N400 responses (Connolly et al., 1995; Desroches et al., 2009; Holcomb, Grainger, & O'Rourke, 2002; Liu et al., 2006; Van Petten & Kutas, 1990). For example, a delayed N400 was observed during sentence listening when the initial phonemes of a semantically incongruous word matched the expected word (e.g., "The gambler had a streak of bad *luggage*", since *luggage* was similar to the expected word *luck* responses were delayed; Connolly et al., 1995). Similarly, Liu et al. (2006) showed a delayed N400 effect in the cohort incongruous condition as compared with a rhyme incongruous and a plain incongruous condition in Chinese sentence listening (e.g., "The sound in the radio became weaker and weaker. It seems that I must buy several new sets of xxx" [cohort congruous: *dianchi*; cohort incongruous: *dianlu*; rhyme incongruous: *shuichi*; plain incongruous: *bingtai*). One explanation for this effect is that the later N400 reflects the later point of uniqueness between word pairs (i.e., the words do not differ until the second syllable). The outcome suggests that ERPs are sensitive to a sequential property of the auditory signal (Desroches et al., 2009; Liu et al., 2006).

The phonological similarity effect was consistent with what has been proposed by models of spoken word recognition like Cohort and TRACE. As the acoustic signal unfolds, information is accessed continuously and dynamically such that words are partially activated prior to the point of recognition (Marslen-Wilson & Tyler, 1980). In other words, large numbers of candidates are activated by the initial phonemes. Because of the existence of homophones in Chinese, when the first syllable of the target was the same as the prime, the bottom-up inputs would initially confirm subjects' expectation of a word consistent with the prime. However, as the second syllable of the target unfolded, subjects recognized that the correct target word was not what they expected based on the prime. Therefore, participants had to reject the expectation and accept the competitor (or the phonologically similar target). This process is reflected by later peak latencies in the N400 for phonologically similar vs. dissimilar pairs (P+ vs. P−).

5. Conclusion

In the current study we presented evidence that the orthographic information is automatically activated during Chinese spoken word recognition, and that it helps to facilitate the auditory word processing. This was marked by shorter behavioral reaction times and reduced N400 amplitudes for target words sharing orthography with preceding primes. The automatic activation of the orthography should be attributed to the top-down connections between lexical-semantic and orthographic representations during spoken word processing. Our work supports cognitive and neural models of spoken word recognition that include both bottom-up and top-down mechanisms. Moreover, the observed orthographic effects were positively correlated with basic reading performance, providing direct empirical evidence for the hypothesis that there is a reciprocal relationship between learning to read and write and spoken word processing.

Acknowledgments

This work was supported by grants from the National Natural Science Foundation of China (31271082, 30900392) to HS and YL, and from Fundamental Research Fund for the Central Universities to HS. We wish to thank Dr. Guosheng Ding, Ping Li for previous advice and suggestions. We thank Jie Yuan, Xiaojuan Wang, Guangzhen Jia, Xiaoping Fang and Jiuju Wang for help on experimental preparation and running. Special thanks to Dr. Jia Liu for providing the task-ambiguous sentence judgment.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandl.2012.09.006.

References

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*(4), 419–439.

Bonte, M. L., & Blomert, L. (2004). Developmental dyslexia: ERP correlates of anomalous phonological processing during spoken word recognition. *Cognitive Brain Research, 21*(3), 360–376.

Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (2002). Modality independence of word comprehension. *Human Brain Mapping, 16*(4), 251–261.

Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (2003). Relation between brain activation and lexical performance. *Human Brain Mapping, 19*(3), 155–169.

Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (2004). Development of brain mechanisms for processing orthographic and phonologic representations. *Journal of Cognitive Neuroscience, 16*(7), 1234–1249.

Booth, J. R., Mehdiratta, N., Burman, D. D., & Bitan, T. (2008). Developmental increases in effective connectivity to brain regions involved in phonological processing during tasks with orthographic demands. *Brain Research, 1189*, 78–89.

Cao, F., Khalid, K., Lee, R., Brennan, C., Yang, Y., Li, K., et al. (2011). Development of brain networks involved in spoken word processing of Mandarin Chinese. *Neuroimage, 57*(3), 750–759.

Chen, C., Xue, G., Mei, L., Chen, C., & Dong, Q. (2009). Cultural neurolinguistics. *Progress in Brain Research, 178*, 159–171.

Chereau, C., Gaskell, M. G., & Dumay, N. (2007). Reading spoken words: orthographic effects in auditory priming. *Cognition, 102*(3), 341–360.

Cone, N. E., Burman, D. D., Bitan, T., Bolger, D. J., & Booth, J. R. (2008). Developmental changes in brain regions involved in phonological and orthographic processing during spoken language processing. *Neuroimage, 41*(2), 623–635.

Connolly, J. F., Phillips, N. A., & Forbes, K. A. (1995). The effects of phonological and semantic features of sentence-ending words on visual event-related brain potentials. *Electroencephalography and Clinical Neurophysiology, 94*(4), 276–287.

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes, F. G., Jobert, A., et al. (2010). How learning to read changes the cortical networks for vision and language. *Science, 330*(6009), 1359–1364.

Desroches, A. S., Cone, N. E., Bolger, D. J., Bitan, T., Burman, D. D., & Booth, J. R. (2010). Children with reading difficulties show differences in brain regions associated with orthographic processing during spoken language processing. *Brain Research, 1356*, 73–84.

Desroches, A. S., Newman, R. L., & Joanisse, M. F. (2009). Investigating the time course of spoken word recognition: Electrophysiological evidence for the influences of phonological similarity. *Journal of Cognitive Neuroscience, 21*(10), 1893–1906.

Dufour, S., & Peereman, R. (2003). Inhibitory priming effects in auditory word recognition: when the target's competitors conflict with the prime word. *Cognition, 88*(3), 33–44.

Feng, G., Miller, K., Shu, H., & Zhang, H. C. (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(4), 1079–1100.

Geisser, S., & Greenhouse, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95–112.

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech: Semantic ERP effects. *Neuropsychologia, 38*(11), 1518–1530.

Harm, M. W., & Seidenberg, M. S. (1999). Phonology, reading acquisition, and dyslexia: insights from connectionist models. *Psychological Review, 106*(3), 491–528.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111*(3), 662–720.

Holcomb, P. J., Grainger, J., & O'Rourke, T. (2002). An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. *Journal of Cognitive Neuroscience, 14*(6), 938–950.

Kutas, M., & Hillyard, S. A. (1984). Event-related brain potentials (ERPs) elicited by novel stimuli during sentence processing. *Annals of the New York Academy of Sciences, 425*, 236–241.

Lavric, A., Clapp, A., & Rastle, K. (2007). ERP evidence of morphological analysis from orthography: A masked priming study. *Journal of Cognitive Neuroscience, 19*(5), 866–877.

Liu, Y., Shu, H., & Wei, J. (2006). Spoken word recognition in context: Evidence from Chinese ERP analyses. *Brain and Language, 96*(1), 37–48.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: the neighborhood activation model. *Ear and Hearing, 19*(1), 1–36.

Marslen-Wilson, W., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. *Cognition, 8*(1), 1–71.

Marslen-Wilson, W., & Zwitserlood, P. (1989). Accessing spoken words – The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance, 15*(3), 576–585.

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18*(1), 1–86.

Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously? *Cognition, 4*(7), 323–331.

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375–425.

Norris, D. (1994). Shortlist: A connectionist model of continuous speech recognition. *Cognition, 52*, 189–234.

Norris, D., & McQueen, J. M. (2008). Shortlist B: A Bayesian model of continuous speech recognition. *Psychological Review, 115*(2), 357–395.

Norris, D., McQueen, J. M., & Cutler, A. (2000). Merging information in speech recognition: feedback is never necessary. *Behavioral and Brain Sciences, 23*(3), 299–325. 325–370.

Pattamadilok, C., Perre, L., Dufau, S., & Ziegler, J. C. (2009). On-line orthographic influences on spoken language in a semantic task. *Journal of Cognitive Neuroscience, 21*(1), 169–179.

Pattamadilok, C., Perre, L., & Ziegler, J. C. (2011). Beyond rhyme or reason: ERPs reveal task-specific activation of orthography on spoken language. *Brain and Language, 116*(3), 116–124.

Peereman, R., Dufour, S., & Burt, J. S. (2009). Orthographic influences in spoken word recognition: The consistency effect in semantic and gender categorization tasks. *Psychonomic Bulletin and Review, 16*(2), 363–368.

Perre, L., Midgley, K., & Ziegler, J. C. (2009). When beef primes reef more than leaf: Orthographic information affects phonological priming in spoken word recognition. *Psychophysiology, 46*(4), 739–746.

Perre, L., & Ziegler, J. C. (2008). On-line activation of orthography in spoken word recognition. *Brain Research, 1188*, 132–138.

Prabhakaran, R., Blumstein, S. E., Myers, E. B., Hutchison, E., & Britton, B. (2006). An event-related fMRI investigation of phonological-lexical competition. *Neuropsychologia, 44*(12), 2209–2221.

Righi, G., Blumstein, S. E., Mertus, J., & Worden, M. S. (2010). Neural systems underlying lexical competition: An eye tracking and fMRI study. *Journal of Cognitive Neuroscience, 22*(2), 213–224.

Rodriguez-Fornells, A., Rotte, M., Heinze, H. J., Nosselt, T., & Munte, T. F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature, 415*(6875), 1026–1029.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*(4), 523–568.

Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory, 5*(6), 546–554.

Tyler, L. K. (1984). The structure of the initial cohort: Evidence from gating. *Perception and Psychophysics, 36*(5), 417–427.

van den Brink, D., Brown, C. M., & Hagoort, P. (2001). Electrophysiological evidence for early contextual influences during spoken-word recognition: N200 versus N400 effects. *Journal of Cognitive Neuroscience, 13*(7), 967–985.

Van Petten, C., & Kutas, M. (1990). Interactions between sentence context and word frequency in event-related brain potentials. *Memory and Cognition, 18*(4), 380–393.

Yu, S. W., Zhu, X. F., Wang, H., & Zhang, Y. Y. (1998). 现代汉语语法信息词典详解 (Detailed annotation of the dictionary of grammatical information in modern Chinese). Beijing: Tsinghua University Press. in Chinese.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological bulletin, 131*(1), 3–29.

Ziegler, J. C., & Muneaux, M. (2007). Orthographic facilitation and phonological inhibition in spoken word recognition: A developmental study. *Psychonomic Bulletin and Review, 14*(1), 75–80.

Ziegler, J. C., Muneaux, M., & Grainger, J. (2003). Neighborhood effects in auditory word recognition: Phonological competition and orthographic facilitation. *Journal of Memory and Language, 48*(4), 779–793.

Ziegler, J. C., Petrova, A., & Ferrand, L. (2008). Feedback consistency effects in visual and auditory word recognition: Where do we stand after more than a decade? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(3), 643–661.