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# Word-to-text integration: ERP evidence for semantic and orthographic effects in Chinese

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ABSTRACT

Although writing systems affect reading at the level of word identification, one expects writing system to have minimal effects on comprehension processes. We tested this assumption by recording ERPs while native Chinese speakers read short texts for comprehension in the word-to-text integration (WTI) paradigm to compare with studies of English using this paradigm. Of interest was the ERP on a 2-character word that began the second sentence of the text, with the first sentence varied to manipulate co-reference with the critical word in the second sentence. A paraphrase condition in which the critical word meaning was coreferential with a word in the first sentence showed a reduced N400 reduction. Consistent with results in English, this N400 effect suggests immediate integration of a Chinese 2-character word with the meaning of the text. Chinese allows an additional test of a morpheme effect when one character of a two-character word is repeated across the sentence boundary, thus having both orthographic and meaning overlap. This shared morpheme condition showed no effect during the timeframe when orthographic effects are observed (e.g. N200), nor did it show an N400 effect. However, character repetition did produce an N400 reduction on parietal sites regardless it represented the same morpheme or a different one. The results indicate that the WTI integration effect is general across writing systems at the meaning level, but that the orthographic form nonetheless has an effect, and is specifically functional in Chinese reading.



## 1. Introduction

Reading comprehension involves integrating a word, as it is read, with the meaning of the previous text and thus updating the mental representation of the text (Gernsbacher, 1990; Kintsch, 1988). Accordingly, the Reading Systems Framework (Perfetti & Stafura, 2014) places word meaning in a central role in comprehension: it is the output of word identification system and the input into the comprehension systems. In this framework the integration of a word's meaning into the reader's current understanding of the text is a key recurring process in reading. From these recurring processes, comprehension occurs incrementally, building a mental model of the text and using that model to continue the integration process. It is this process of word-to-text integration (WTI) that is our focus here. In particular, we examine how this process works in

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Chinese reading, given key differences between written Chinese and written English. Differences between reading Chinese and reading English appear at the word identification level because of writing-to-language mapping differences between alphabetic and Chinese writing (Perfetti, Liu, & Tan, 2005). At the level, of comprehension, after accounting for writing system influences on word identification, one expects more universal comprehension processes to prevail.

### 1.1. Word-to-text integration (WTI)

As a processing concept, word-to-text integration (WTI) is the set of meaning related processes that leads to the understanding of word—while it is read—in relation to the preceding text. While these integration processes occur continuously within a sentence, a particular focus of the WTI paradigm is the integration processes that occur *across a sentence boundary*. This boundary condition on WTI allows a clearer focus on incremental comprehension of text, as opposed to the comprehension of a sentence. The incremental updating processes across and within sentence boundaries may differ in the support they receive from memory-based integration processes as opposed to prediction. Specifically, predictive processes and memory-based integration processes both occur continuously to bring about WTI. But across a sentence boundary, predictive processes are weaker than they are within a sentence. Memory-based integration becomes the main mechanism for incremental updating (Stafura, Rickles, & Perfetti, 2015; Calloway & Perfetti, 2106, Submitted for publication).

Research on WTI in English has used ERPs, in particular the N400 and the late positivity response (LPR), as indicators of integration (Perfetti & Stafura, 2014; Stafura et al., 2015; Yang, Perfetti, & Schmalhofer, 2007). The N400, a negative component at centro-parietal sites that peaks around 400ms after the onset of a word, has been well established as a marker of meaning congruence between a stimulus and its preceding context (Kutas & Federmeier, 2011; Kutas & Hillyard, 1980). In a sentence, the predictability of a word has a strong influence on the N400, which becomes relatively more positive when the word is predictable.

In cross-sentence boundary text comprehension, the WTI paradigm has focused on the first content word across the boundary. Thus, the N400 amplitude is reduced on this cross-boundary word when readers are presented with short stretches of two-sentence texts (Yang, Perfetti, & Schmalhofer, 2005, 2007).

For example, Yang et al. (2007) presented texts such as the following:

a. Referentially explicit: After being dropped from the plane, the bomb hit the ground and **exploded**. The **explosion** was quickly reported to the commander.
b. Referentially paraphrased: After being dropped from the plane, the bomb hit the ground and **blew up**. The **explosion** was quickly reported by the commander.
c. Baseline: Once the bomb was stored safely on the ground, the plane dropped off its passengers and left. The **explosion** was quickly reported to the commander.

When the first sentence established an event (exploded/blow up) that could serve as an antecedent for the first content word of the second sentence (explosion), the N400 on the critical word "explosion" was more positive compared to the baseline (no referent for critical word "explosion"). Especially interesting for text comprehension is that N400 deflection was as great for the paraphrase effect, where there was no morpheme overlap across the sentence boundary ("blew up. The explosion") as when there was shared morpheme across the boundary ("exploded. The explosion"). This paraphrase effect suggests that the cross boundary reduction in the N400 reflects meaning integration, rather than word repetition. A study by Stafura and Perfetti (2014) found the strength of word association across the sentence boundary did not influence the paraphrase effect, further supporting the interpretation that the WTI paraphrase effect was about meaning integration.

### 1.2. Writing system influences

Writing systems influence word identification processes, as shown by comparisons of Chinese and English (Perfetti et al., 2005). Such influences, if full absorbed at the level of orthographically based word identification, should be absent in comprehension, which is dependent on linguistic and cognitive processes. The integration processes in WTI would then be general across different writing systems. However, it is possible that orthographic factors have a continued effect on "downstream" meaning processes when, as in Chinese, they directly express morpheme at the character level. The nonalphabetic Chinese character system allows a basic morphemic/orthographic unit—the character—to convey meaning information within a word in a very transparent way. The fact that each character is a morphemic orthographic unit allows us to observe transparent morpheme effects across a sentence boundary.

Although morphological processes play a role in visual word identification across languages, they are particularly important in Chinese as orthographic units. In alphabetic writing, the strategy for detecting morphology has been to try to separate morphology from orthography. Morphological decomposition occurs on frequently occurring morphemic units, producing morpho-orthographic segmentation at early stage (Lavric, Elchlepp, & Rastle, 2012; Morris, Grainger, & Holcomb, 2008; Rastle, Davis, & New, 2004).

The situation is different in Chinese, where the major orthographic unit is a meaning bearing morpheme. English spacing makes words easy to see but morphemes not so easy to see. Chinese spacing reverses this situation—difficult to see words, easy to see morphemes. Chinese words may have one, two, and three or more characters, with two-character words being the most frequent. For example, 花园 (garden) is composed of two morphemes: 花 (flower) and 园 (garden). The abundance of such compound words suggests an important role for morphological awareness in Chinese children's literacy development (Liu & McBride-Chang, 2014; Wu et al., 2009). Words that share morphemes are identified more readily and with reduced fixation time (Yen, Tsai, Tzeng, & Hung, 2008; Zhou, Marslen-Wilson, Taft, & Shu, 1999). Relevant for our ERP study is evidence that the N200 component in central and parietal regions reflects the early morphemic orthography overlap in Chinese compound word recognition (Du, Hu, Fang, & Zhang, 2013; Du, Zhang, & Zhang, 2014; Jia, Wang, Zhang, & Zhang, 2013; Zhang et al., 2012).

Important is this additional fact: In a Chinese two-character word, each character contributes a morpheme to the meaning of the word. A second word can share one of these characters while being either closely related in meaning to the first word or unrelated in meaning to the first word. For example,花销 ("expense") and花费 ("cost") are meaning related and share the character "花" (" spend"); 花园 (" garden") and花费 ("cost") have the same character "花" but their meanings are unrelated (This character means "flower" in the first word and "spend" in the second word). Thus this character represents different morphemes in the two words, a single orthography and pronunciation associated with different meanings. Thus, we can ask whether, in addition to a word-related effect across a sentence boundary, there is also a morphemic meaning effect that is independent of orthography. A shared morpheme may accelerate word identification and word meaning access, leading to rapid integration of word meaning with prior text. Alternatively, because reading comprehension and word identification have different processing demands, it is possible that only word identification is sensitive to an orthographic morpheme. Integration in reading comprehension may depend directly on word meaning rather than on both morpheme meaning and word meaning.

Thus, the goals of our study are, first and most generally, to determine whether cross boundary word-to text integration effects extend to Chinese, a language and writing system very different from English. Second and more specifically, to determine whether a distinctive property of Chinese writing—the orthographic conveyance of morpheme information through a character within a two-character word—has a role in mediating word-to-text integration. If the effects of orthographic mapping are limited to word identification without affecting integration processes, then the WTI results for Chinese should pattern with those of English: An effect of *word* meaning congruence across a sentence boundary with no additional effect of orthography. However, if an *orthographic morpheme* serves as a retrieval cue in meaning integration, then WTI in Chinese should be affected by whether an orthographic character repeated across a sentence boundary conveys related or unrelated meanings across the sentence boundary.

These alternatives lead to the following predictions. If the orthographic morpheme plays a role in WTI, then a character repeated across a sentence boundary conveys the same morpheme to the two words, we expect see an additional reduction of the N400 beyond that produced by the paraphrase condition, which allows integration at the word meaning level without character overlap. However, when the character does not have the same meaning across the boundary, we expect a more complex mix of facilitation (from orthographic form repletion) and inhibition effects (from incompatible meanings). Finally, if the orthographic morpheme is not functional in integration beyond its contribution to word identification, then there should be no additional effect of a repeated character with the same meaning beyond that of meaning related words.

### 1.3. *Overview of experiment*

The experiment measures WTI on the first word of a second sentence, while manipulating the availability of information in the first sentence. The first sentence varies the characteristics of its final two-character word as follows: In a paraphrase condition, the two words across the sentence boundary have related meanings but share no characters (and thus no morphemes). This corresponds to the paraphrase condition in the English language experiments. In a condition of morpheme repetition, the two words share a character that is the same morpheme (orthography +, morpheme +, O+M+). In a condition of character repetition without morpheme repetition (orthography +, morpheme-, O+M-), the two words across the boundary share the same character, but the character does not convey the same morpheme. In a baseline condition, the two words across the boundary share no characters and are unrelated in meaning. Table 1 shows examples.

**Table 1**
Sample of each experimental condition.

| Conditions | Sample |
|---|---|
| (a) Paraphrase condition | 王伟认为，去欧洲旅行是一笔很大的*开支*。**花费**对他来说太高了。<br>(Wangwei thinks that traveling to Europe is a big *expense*. **Costs** are too high for him.) |
| (b) O+M+ condition | 王伟认为，去欧洲旅行是一笔很大的***花销***。**花费**对他来说太高了。<br>(Wangwei thinks that traveling to Europe is a big *expense*. **Costs** are too high for him.) |
| (c) O+M-condition | 王伟从欧洲旅行回来后，也想在院子里建一个***花园***。**花费**对他来说不是问题。<br>(After traveling from Europe, Wangwei wants to build a *garden*. **Costs** are not problems for him.) |
| (d) Baseline condition | 王伟从来没想过去欧洲旅行。**花费**对他来说太高了。<br>(Wangwei never thinks to travel to Europe. **Costs** are too high for him.) |

The words in italics are antecedents of critical word. And words in bold are critical words.

Comparisons of the paraphrase and O+M+ conditions with the baseline condition test the paraphrase effect—that related meanings support integration and produce an N400 reduction. Comparisons of the paraphrase and O+M+ conditions test the orthographic morpheme effect. To verify that the any orthographic morpheme effect is due to meaning rather than form, we compare O+M+ with O+M-. The key measurements are ERP measures—especially the N400, but also the N200 and the late positive complex (LPC)—taken on a two-character word that begins a new sentence across a sentence boundary.

## 2. Method

### 2.1. Participants

Thirty-two Chinese native speakers (age range from 18 to 35 years) from the University of Pittsburgh and Carnegie Mellon University were paid for their participation in the experiment. Participants were all from mainland of China and proficient in English as a second language, they had TOEFL scores of at least 85 or IELTS scores of at least 7.0. All participants were right handed with normal or corrected-to-normal vision and without any history of head injury or neurological diseases. Each participant signed the consent form before the experiment.

### 2.2. Stimuli

A total of 120 sets of two-sentence passages (mean number of words = 16) were created for the experiment. For each set, there are four versions, one for each of four conditions. Across the four conditions of each set, the first word of the second sentence—the critical word—was the same.

The four conditions are presented in Table 1. The standard *paraphrase* condition paralleled to that defined in English, had no overlap between the two words across the boundary. But the words were co-referential in the context of the sentences. For example, the critical word "花费" ("costs") had an antecedent referent "开支" ("expense") in the first sentence. A second condition implements a paraphrase relation by repeating one of the character from the word across the sentence boundary. For example, both the critical word "花费"and its antecedent "花销" ("expense"), shared the first character and morpheme "花" ("spend"). This we refer to as the Orthography+, Morpheme+ condition (O+M+). The third condition exploits the fact that some characters map to more than one morpheme, thus separating orthography from morphology. For example 花maps to two morphemes, one meaning spending and another flower. Pronunciation of these two "花" (pronunciation: huā) were same. In the third condition, the last word of first sentence "花园" ("garden") shared the first character "花" with critical word"花费", but the character represented different morphemes in two words. "花" in "花园" refers to flower, while "花" in "花费" refers to spend. In this condition, the two words across the sentence boundary were meaning unrelated, so there was no antecedent referent for the critical word "花费". Because the critical word shared a character with the last word of first sentence, this condition was called as Orthography+, Morpheme- condition (O+M-). In the baseline condition, there was no antecedent referent for the critical word and no character overlap. Critical words and referents (in Orthography+, Morpheme- condition, it is preceding word of first sentence) across four conditions were matched on word frequency and strokes (see Table 2).

It is important that the degree to which semantic relations between the two words across the sentence boundary are the same across the two conditions that are to provide integration. We had a separate group of participants judge the semantic relatedness of the word pairs. On a scale with 5 as maximum semantic relatedness, the average relatedness was 3.99, 4.06, 1.57 in Paraphrase condition, O+M+ condition, O+M -condition, respectively. The judged similarity of the two conditions designed to allow WTI were not different ($p = 0.13$), and both were more similar than the O+M- condition, $ps < 0.001$.

As a further control, all passages in four conditions were evaluated for their ease of understanding. With 5 as the maximum, the four conditions were all rated easy to understand, 4.17, 4.13, 4.04, 4.06 in the Paraphrase condition, O+M+ condition, O+M- condition, and Baseline condition, respectively.

### 2.3. Procedure

Participants were seated in a soundproof booth. The stimuli were presented on a 15-in (38.1 cm) CRT monitor (60 Hz refresh rate) using E-Prime (Version 2.0.10, Psychology Software Tools, Inc., Pittsburgh, PA, USA). Participants read 120 two-sentence passages and answered comprehension questions by making a true or false judgment, while EEGs were

**Table 2**
Average word frequency and strokes of referent and critical word.

| | Word Frequency/million | Number of strokes |
|---|---|---|
| Referent of Paraphrase condition | 32 | 17 |
| Referent of O+M+ condition | 23 | 17 |
| Preceding word of O+M- condition | 37 | 16 |
| Referent of Baseline condition | N/A | N/A |
| Critical words | 27 | 17 |

continuously recorded. Passages were presented in 4 blocks of 30 texts each, with a rest after each block. A center fixation preceded each passage. Words from the passage appeared one at a time on the center of the screen in black font. The word font was 24 Chinese Kaiti. Each word was presented for 400ms with a SOA of 700ms and the punctuation was presented with the last word of each sentence. The inter stimulus interval (ISI) prior to the first word of second sentence was increased to 600ms to allow for a sentence wrap-up effects. There were 40 sentences followed by a question on a random basis. All questions were based on the passages comprehension, with half of the correct answers as True. The response was followed by immediate feedback.

### *2.4. ERP recordings and analysis*

EEGs were recorded from a 128-channel Geodesic sensor net (Tucker, 1993) with Ag/AgCI electrodes (Electrical Geodesics, Inc., Eugene, OR). EEG signals were recorded with a sampling rate of 1000 Hz and a hardware bandpass filter between 0.1 and 200 Hz. All electrode impedances were maintained less than 40 KΩ, which is an acceptable level for this system (Ferree, Luu, Russell, & Tucker, 2001). EEG data were processed and analyzed using Net Station Tools and EP toolkit. Data of each participant was filtered through a 0.1 Hz highpass and a 30 Hz lowpass and segmented into epochs, from 150ms before to 700ms after the critical word. A segment was rejected if it contained an eye blink (exceeding 140 μV), an eye movement (exceeding 55 μV), or extreme variance (larger than 200 μV) on more than 10 channels. Channels with extreme variance on more than 20% of segments were defined as bad channels, and data from surrounding channels were used for interpolation (Ferree, 2006). Data from five participants with more than 12 bad channels were excluded from further analysis. After artifact rejection, there were an average of 26 trials for each condition. Data were then re-referenced to the average of all electrodes and segments under each condition were averaged for each participant. A baseline correction was applied to the averaged waveforms by subtracting the mean amplitude of the baseline period (150ms before critical words).

ERPs on the critical word of the second sentence provide the key results. The ERP amplitude analyses focused on time windows centered on N200, N400 and LPC. The earliest time window is of interest for observing early word processing effects related to orthographic factors; the later time windows include the N400 component and late positive complex (LPC) reflective of semantic processes and memory operations indicative of WTI. The N200, N400 and LPC are typically observed in central-parietal regions. We examined central sites (C3 cluster, Cz cluster, and C4 cluster) and parietal sites (P3 cluster, Pz cluster, and P4 cluster) for each component (see Fig. 1 for included electrodes for each cluster). The time window for N200 is from 100 to 250ms after onset of critical word. Time window for N400 is from 250 to 450ms[1] and LPC is from 550 to 700ms, respectively. Grand average ERP waveforms were plotted in Fig. 2.

Two separate repeated-measures 4 (sentence condition) × 3 (cluster) ANOVAs were conducted on mean amplitude, one at central sites and one at parietal sites. Greenhouse-Geisser correction was applied to repeated measures when sphericity assumption was not met (Greenhouse & Geisser, 1959).

## 3. Results

### *3.1. Behavioral results*

Average comprehension accuracy of sentences was high across all four conditions at 95%, with no reliable condition differences, $F(3,93) = 1.34$, $p = 0.27$.

### *3.2. ERP results*

#### *3.2.1. N200 component*

Mean amplitudes in the N200 window were unaffected by the experimental condition. Thus the early phases of word identification, where sensitivity to orthographic factors might be expected, were not affected by the appearance of a character in the preceding sentence. At central sites, repeated measures ANOVA failed to show a main effect of Condition, $F(3,78) = 0.37$, $p = 0.78$, and Cluster $F(2,52) = 2.99$, $p = 0.059$. Interaction of Condition × Cluster did not reach significance either, $F(6,156) = 1.03$, $p = 0.41$. The result was the same at parietal sites: $F(3,78) = 0.17$, $p = 0.85$, $F(2,52) = 0.77$, $p = 0.47$, $F(6,156) = 0.51$, $p = 0.71$, for Condition, Cluster, and Condition × Cluster interaction, respectively.

#### *3.2.2. N400 component*

In the N400 time window, the paraphrase effect emerged in both Paraphrase condition and O+M+ condition, relative to baseline, at central electrode sites. Further, the two effects were similar in magnitude and not different from one another. These conclusions are confirmed by ANOVAs at the central sites: $F(3,78) = 3.28$, $p < 0.05$, $\eta_p^2 = 0.11$ for Condition and $F(2,52) = 15.75$, $p < 0.001$, $\eta_p^2 = 0.38$ for Cluster. Condition and Cluster did not interact, $F(6,156) = 1.77$, $p = 0.14$. Planned pairwise comparisons showed that both the Paraphrase condition ($t(26) = 2.40$, $p < 0.05$) and O+M+ condition ($t(26) = 2.66$,

[1] We chose the 250–450ms time window based on the waveforms. We replicated the analyses using a 300–500ms time window and found substantively similar results.

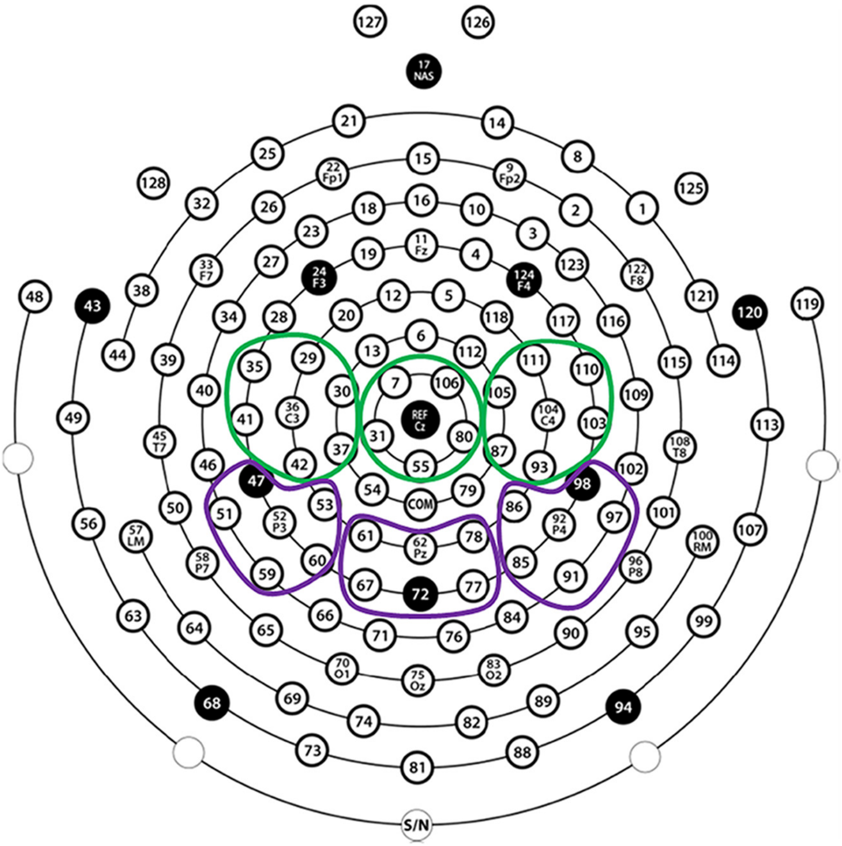

**Fig. 1.** Clusters in central and parietal sites. Central clusters (the top 3 clusters) from left to right: C3, Cz, and C4; Parietal clusters (the bottom 3 clusters) from left to right: P3, Pz, and P4.

$p < 0.05$) had a reduction of N400 amplitude compared with Baseline condition; the Paraphrase and O+M+ conditions did not differ: $t(26) = 0.98$, $p = 0.34$. The O+M-condition appears intermediate between the baseline and O+M+ conditions (Fig. 3), but it did not differ significantly from either baseline ($t(26) = 1.61$, $p = 0.12$) or O+M+ ($t(26) = 1.41$, $p = 0.17$.).

A somewhat different pattern emerged at parietal sites, which also showed main effects of Condition $F(3,78) = 3.19$, $p < 0.05$, $\eta_p^2 = 0.1$, and clusters $F(2,52) = 7.44$, $p < 0.005$, $\eta_p^2 = 0.22$ with no significant interaction, $F(6,156) = 1.07$, $p = 0.38$. However, the condition differences reflected orthographic effects more than meaning effects. Both O+M+ condition ($t(26) = 3.23$, $p < 0.005$) and O+M- condition ($t(26) = 3.45$, $p < 0.005$) showed a reduction of N400 compared with Baseline, and did not differ from each other ($t(26) = 0.42$, $p = 0.68$). Moreover, unlike at central sites, the Paraphrase condition did not show a reduced N400: $t(26) = 0.13$, $p = 0.9$. The O+M+ condition showed a nonsignificant difference from the paraphrase condition: $t(26) = 1.75$, $p = 0.09$. The mean amplitude of central site and parietal site clusters are plotted in Fig. 3.

### 3.2.3. Late Positive Complex (LPC)

In the LPC time window, mean LPC amplitude at both central sites and parietal sites did not vary significantly across experimental conditions. ANOVAs at central sites produced $F < 1$ for both Condition and Cluster. Condition and Cluster did not interact, $F(6,156) = 1.24$, $p = 0.3$. The results at parietal sites were: $F(3, 78) = 2.69$, $p = 0.067$ for Condition and $F(2,52) = 11.92$, $p < 0.001$, $\eta_p^2 = 0.31$ for Cluster. Condition and Cluster did not interact, $F(6,156) = 1.45$, $p = 0.2$. Planned pairwise comparisons showed that neither Paraphrase condition ($t(26) = 0.64$, $p = 0.53$) nor O+M- condition ($t(26) = 1.51$, $p = 0.14$) was different with Baseline condition. The O+M+ condition showed a greater positive-going deflection relative to Baseline condition near marginal difference ($t(26) = 2.01$, $p = 0.055$).

## 4. Discussion

The current study examined the influence of writing system on word-to-text integration processes in a study of Chinese reading that can be compared with results from English. A key result is that Chinese text comprehension employed

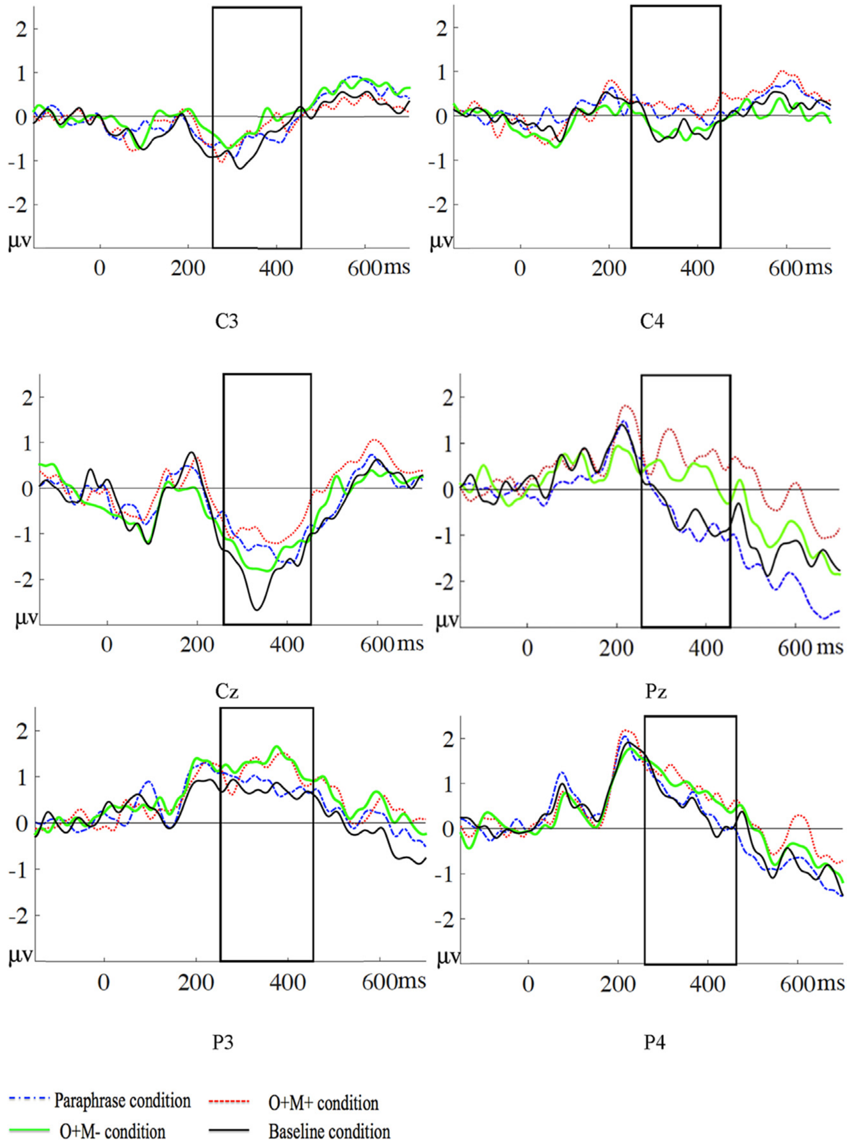


**Fig. 2.** ERP waveforms of 6 clusters.

immediate integration of word with the meaning of the text, as found in English. A second result was that a contribution of orthographic form emerged for Chinese reading.

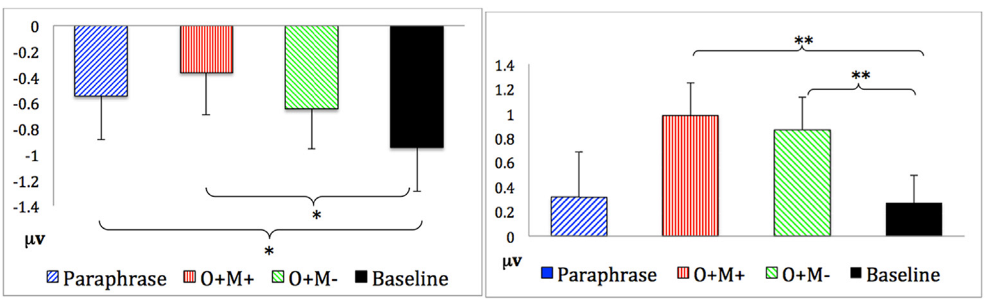


**Fig. 3.** Mean amplitude of N400 on central sites (left panel) and parietal sites (right panel). Error bars indicate 1 standard error, *: $p < 0.05$; **: $p < 0.01$.

### 4.1. Cross-sentence boundary WTI is general across writing systems

The results confirm WTI effects in reading Chinese that are similar to those found in English. Thus, to some extent, the integrative comprehension processes of WTI are indifferent to some of the linguistic and writing system factors that differ between Chinese and alphabetic writing. Across a sentence boundary, ERP results suggest that integration occurs between the word being read in the second sentence and an antecedent referent in the first sentence. As in the alphabetic research, the study cannot distinguish the nature of the memory representation of the antecedent. This representation can be conceptualized as lexically based (propositional) meaning or as referential information in a mental model. In either case, meaning connections produce the integration that is evidenced by the N400 effect.

The evidence for this cross-language similarity is the paraphrase effect at central sites, which is based not on word overlap but on contextually dependent meaning relations. Furthermore, the results find no additional boost to the paraphrase effect when the two words across a sentence boundary share a character that conveys the same meaning (O+M+). The central sites showed a tendency for a morpheme effect at the N400; a character repeated across the sentence boundary showed a reduced N400 when it was the same morpheme (O+M+), but not when it was a different morpheme (O+M-). (See Fig. 3). However, this difference was significant only relative to the baseline condition; O+M- and O+M+ did not differ reliably in a direct comparison. To the extent that a repeated morpheme did reduce the N400, this tendency may reflect the similarity of meaning at the word level, as in the paraphrase effect, and not the role of the morpheme only. However, the similar tendency for a pure orthographic effect—the nonsignificant difference between (O+M-) and baseline, may suggest that a repeated character itself, aside from its meaning, reduces the N400. This suggestion is consistent with the results for the parietal electrodes.

An orthographic effect emerged strongly in the parietal electrodes. In fact, at parietal electrodes, there was a reversal. Meaning overlap without character repetition (Paraphrase condition) was not sufficient to produce a reliable N400 reduction, but orthographic overlap was sufficient to produce such an effect. A character that was shared between the two words across the sentence boundary produced a reduced N400, whether it mapped to the same morpheme (O+M+) or not (O+M-). We expected that such an orthographic effect would emerge as an early effect within 200ms. Instead, it emerged in the N400 window and at electrode sites that typically show meaning related shifts within sentences, as well across sentences in the WTI paradigm. A divergence between N400 effects at parietal and central electrodes has been reported in studies using word processing paradigms (Dien, Franklin, & May, 2006; Franklin, Dien, Neely, Huber, & Waterson, 2007) and text comprehension paradigms (Dien, Michelson, & Franklin, 2010; Stafura et al., 2015). However, the nature of the divergence is different in each case, and there is no clear generalization to make at this point about these site-dependent factors.

An orthographically based N400 effect is consistent with research on word processing. For example, in an English language study, Deacon, Dynowska, Ritter, and Grose-Fifer (2004) reported an N400 effect to a repeated nonword. More directly related are results from a Chinese meaning-based task by Liu, Perfetti, and Hart (2003). Graphic similarity based on shared radicals reduced the amplitude of N400. Most closely related to our study in its character based orthographic effect, Zhang et al. (2012; Experiment 6) found a reduced N400 in lexical decisions when semantically unrelated primes and targets shared a character. However, in the WTI paradigm, where the goal is comprehension rather than lexical form or meaning judgments, semantic effects are expected to dominate over orthographic effects, as was found in Yang et al. (2007). The 1000ms SOA between words across the sentence boundary and the boundary itself should make lexical associations, meaning as well as form, less influential. Thus the discovery of a character form effect in the present study remains difficult to explain without appealing to the specific properties of Chinese characters.

The possibility that the N400 is more specifically related to lexical meaning associations, while text updating is reflected in the P600 or LPC has been raised in prior research by Burkhardt (2007). In a possibly related finding, Stafura et al. (2015) report a late positivity associated with the paraphrase effect. This effect was primarily in the left hemisphere when the two words across a sentence boundary had a backward associative relation; i.e. strong associative strength from the second word (rage) to the first (anger), but weak associative strength from the first (anger) to the second word (rage). The authors suggested this late positivity reflected a memory process that retrieved the contents of the text memory as part of the updating process. Consistent with the Burkhardt's (2007) conclusion, it is possible that this memory-based process is a key mechanism of word-to-text integration and that its typical indicator is a later positivity, not the N400. However, in our study, the experimental conditions did not show differences in the LPC. It is quite possible that the N400 itself, as suggested by Baggio and Hagoort (2011), may reflect two separate phases of meaning binding, semantic activation and integration (or unification). More research is needed to clarify the interpretation of updating effects in the N400 relative to the P600.

There remain critical questions in the interpretation of the N400 on a word immediately across a sentence boundary, where words are not very predictable. For now the simplest assumption is that the N400 reflects integration rather than mere lexical association (Stafura & Perfetti, 2014; Stafura et al., 2015). In that context, the results reported here for Chinese are compatible with the results for English (Stafura & Perfetti, 2014; Stafura et al., 2015; Yang et al., 2005, 2007). In reading comprehension, integrating words into a memory for the text is a universal process in incremental comprehension and this process can be indexed by the N400 across a sentence boundary. This incremental process serves the broader goals of text comprehension, for which a reader builds a mental representation of situation model and continuously updates it.

### 4.2. Interaction of message, word, morpheme and orthography in word-to-text integration

Finally, we reconsider orthographic and morphemic contributions to the WTI effects, in light of Chinese-English comparisons enabled by the current study. First, the failure to find a morphemic enhancement beyond that provided by the paraphrase condition tends to reinforce the interpretation of the WTI as a referential meaning effect, not a morpheme meaning effect. This result is parallel to the result of Yang et al. (2007) for English that for skilled readers, the explicit repetition of a morpheme or whole word did not produce a greater N400 reduction than a meaning paraphrase. Neither repeating an English word (or stem morpheme) nor repeating a Chinese character seems to add to the meaning effect produced by a paraphrase word. The reason, we suggest, is that reading comprehension depends on meaning unification that secures specific reference across meaning bearing units. Although both morphemes and multiple-morpheme words qualify as meaning bearing units, the word that combines the meanings of individual morphemes—here, two morphemes conveyed by two characters—is the output of the lexical system to the comprehension system. The N400 is an indicator of the congruence of the word meaning with the text. The sentence boundary also may reduce the priming role of the character morpheme, reflecting the importance of memory for message level semantics over specific subword units (Stafura & Perfetti, 2014).

Another consideration in explaining this effect, however, is the experimental paradigm. Our presentation was word by word, which certainly favors word level effects over individual character morpheme effects. Character by character presentation would force each morpheme to be processed and put a premium on the congruence provided by the next character. However, we note that this word-by-word presentation did not prevent character morpheme effects to emerge. They did so in the parietal electrodes. That they did not emerge with the paraphrase effect in central electrodes suggests that the semantic processes reflected in WTI are primarily at the word-to-text level.

Why character effects emerged in an N400 at parietal electrodes remains to be explained. These effects are strictly orthographic because whether the morpheme stayed the same across the sentence boundary did not matter. We have no comparable WTI English results for comparison, where the analogy might be to find an effect of "played baseball" at the end of a first sentence on a second sentence that begins with either "The ballgame" or "The ballroom". Our prediction would be that only "ballgame" would show an effect, based on the assumption that referential meaning overlap is necessary. But if so, why would Chinese be different? One possibility is that the convention of having a compound word in English without spaces between morphemes (e.g. "ballgame") makes the orthography less salient. By representing the morpheme as a character in its own defined space, a Chinese character morpheme is more salient as a unit of processing. The parietal effects may reflect a matching process based on form rather than meaning. In this, it would be parallel to experiments showing the sensitivity of the N400 to congruence of form as well as meaning (Liu et al., 2003). Thierry and Wu (2007) found Chinese-English bilinguals showed an implicit Chinese orthography repetition effect when they made meaning judgments on English words whose Chinese equivalents shared characters; e.g. in *train-ham, train* corresponds to Chinese word "火车", *ham* corresponds to Chinese word "火腿". Sharing a character in Chinese translation equivalents elicited a bigger N400 negativity.

The overall pattern of results suggests a tentative generalization: The WTI effect across a sentence boundary is driven by referential meaning relations as indexed by the N400 and sometimes by a late positivity (Burkhardt, 2007; Stafura et al., 2015). However, not all N400 effects are meaning based and in a writing system that expresses morphemes as distinct stand-alone orthographic units, as Chinese does, congruence occurs at this orthographic level as well as the meaning level, even across a sentence boundary. But why didn't form repetition show an effect earlier at 170 or 200ms when orthographic effects are often reported? That, we suggest, is again because of the sentence boundary and the reader's task to comprehend, which reduce the kind of form based priming reflected in the early orthographic effect.

Consistent with this assumption about sentence boundaries is evidence that punctuations affect sentence reading. For example, a comma within a Chinese sentence affects orthographic recognition (Liu, Wang, & Jin, 2010). The form effects reflected in the N400 are not form priming at the visual form level, or they would have been observed as N200 effects. Instead, they are memory-based recognition effects in which the reader recognizes the character form as having occurred recently. The N400 then reflects a passive form-memory response, just as the semantic N400 reflects a passive meaning-memory response. The results of Liu, Jin, Qing, and Wang (2011) support this interpretation. In a sentence reading task, they found that replacing a character with one orthographically similar because of a shared radical (e.g. "针"replaced by "汁") elicited a large positive amplitude. This was taken to indicate orthographical retrieval and reanalysis (Liu et al., 2011) prompted by a character that was similar to but not identical to the one required by the sentence. This situation is parallel to that of the present study. Here, the critical word in O+M+ condition and O+M- condition shared a character but the word was actually different. This may prompt a retrieval of the similar orthography and a reanalysis of the meaning, whether that meaning is close (M+) or not (M-).

## 5. Conclusion

Comprehending Chinese, as in comprehending an alphabetic language, requires the reader to integrate the meanings of words, as they are read, with the meaning of the preceding text held in memory. Although integration is not always triggered by the first word across a sentence boundary, when the meaning of that word activates memory for the recently read text, word-to-text integration occurs immediately. This integration is reflected in ERP components measured on the word across a sentence boundary from its antecedent. We found reduced N400 effects on this word when it had a meaning relation to a word at the end of the prior sentence, as is found in English. Unlike English results, this effect was restricted to central electrodes, and not found in parietal electrodes, where instead we found an effect of shared orthography, a repeated character across the sentence boundary. This was a pure orthographic effect, not dependent on the meaning of the character. While immediate integration occurs without respect to writing system, just as in word identification processes (Perfetti et al., 2005), the writing system does affect the details of this process.

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