# ERP Evidence for Chinese Compound Word Recognition: Does Morpheme Work all the Time?

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**ABSTRACT**

By holding the homophonic morpheme constants, the present study examined the effects of word frequency and morpheme frequency on the recognition of Chinese compound word using event-related potential (ERP) measurements and a delay response lexical decision task (LDT). The results revealed that low frequency word elicited less positivity when its initial morpheme with high-frequency in the time windows of 150-250ms,but a reverse ERPs pattern was elicited in time windows of 250-400ms; Different from Vergara-Martínez et al.'s (2009) results, the morpheme frequency effect of final morpheme showed a robust inhibitory frequency effect as words with high frequency morpheme elicited larger negativity in both 250-400ms and 400-500ms time windows for both high and low frequency compound words. Additionally, whole word frequency showed consistent facilitative effects ranged from 150 to 400 ms windows for initial morpheme word conditions, and from 250 to 500 ms windows for final morpheme word conditions. Our results suggested that morpheme frequency affects the processing of Chinese compound word, which depends on the whole word frequency and the position of a morpheme in a compound word, providing evidence for the sub-lexical representations in Chinese compound word, and the different role of constituents in compound word comprehension.



**Key Words:** Chinese Compound Word, Word Processing, Morpheme Frequency, Whole Word Frequency, N400.

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## Introduction

The representation of mental lexicon has been extensively examined in the past several decades for psycholinguistic research. One of the central questions in these studies is whether multi-morphemic words (or called compound words) are represented as a whole or by their constituent morphemes cross the languages (e.g., Caramazza, Laudanna, & Romani, 1988; Miwa, Libben, & Baayen; 2012; Miwa & Dijkstra, 2017; Williams & Bever, 2010; Zhou & Marslen-Wilson, 2009). As a special existence, Chinese is unique in that 74% of its vocabulary is disyllable compound words, allowing ample opportunity to study compound word recognition (Liu, 1990). A basic rationale that has been often adopted in the literature is as follows, if a word is represented as a whole unit in the mental lexicon, its processing should be affected by whole word frequency but not frequency of its constituent morphemes, and if a word is represented by its constituent morpheme, its processing should be influenced by morpheme frequency only but not whole word frequency, and if both a word and its morphemes are represented, its processing should be affected by both word and morpheme frequencies.

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Up to now, there are two main conclusions for the above issue. One has found evidence that both whole words and its morphemes were represented in the mental lexicon (e.g., Zhang & Peng, 1992). In series of experiments, Zhang and his colleagues systemically varied whole word frequency and frequency of both constituents of compound words and showed that high whole word frequency and high morpheme frequency both facilitated the recognition of the compound words. This was consistent with other reports of effects of both whole word frequency and morpheme frequency on recognition time of Chinese compound words (Taft, Huang, & Zhu, 1994). Such findings replicated similar results in alphabetic languages (e.g., Hyönä & Pollatsek, 1998; Fiorentino & Poeppel, 2007; Juhasz, Starr, Inhoff, & Placke, 2003; Shoolman & Andrews, 2003; Pollatsek, Hyönä, & Bertram, 2000). Furthermore, Yan, Tian, Bai, and Rayner (2006) have found that compound words' word frequency modulated the morpheme frequency as the difficult recognition was raised for words with low-frequency initial morpheme than those with high-frequency initial morpheme when the whole word frequency was low. Specially, they found that the initial morpheme play a pronounced role in the processing of Chinese compound words while the second morpheme had no such significant effect. However, the other addressed that Chinese compound word existed as whole word representation in the mental lexicon, regardless of the relative frequency of the individual constituents (Janssen, Bi, & Caramazza, 2008).

Besides, it has been argued that these frequency effects may be confounded by other properties of compound words, such as semantic transparency, headedness, and concreteness (Myers, 2006). There is evidence that words with transparent semantic meanings were recognized more quickly than words with opaque meaning (e.g., Myers, Derwing, & Libben, 2004). A complex pattern was found in another study by Peng, Liu, and Wang (1999). In a lexical decision task holding semantic transparency constant, they found a positive morpheme frequency effect (faster response to high frequency than low frequency morphemes) when word frequency was high relative to when it was low. Further, when word frequency was controlled, they found a positive morpheme frequency effect for transparent words but a reversed effect for opaque words.

It is well-established that words referring to concrete concepts (e.g., apple) are processed more quickly and accurately than those referring to abstract concepts (e.g., honest) (Zhang, Han, & Bi, 2013). Such concreteness effect was more often found in low frequency words in alphabetic language studies (Kroll & Merves,1986). However, the effect was less consistent in Chinese compound word recognition (Zhang, Guo, Ding, & Wang, 2006). For example, Zhang and Zhang (1997) found that this effect only existed for low frequency words while Chen and Peng (1998) found the effect only for high frequency words. Later on, Zhang et al. (2006) reported main effects of both frequency and concreteness but no interaction between them.

In studies of complex word recognition in Dutch and English, it was found that, possibly due to left-to-right processing, word stem in suffixed words was accessed first than the whole word and stem frequency affected word recognition. However, word stem in prefixed words was not accessed prior to whole word processing and stem frequency did not affect word recognition (Gary, Gibson, Yoon, & Sandra, 2003). For Chinese compound words, there is evidence that frequency of both the first and second morphemes was equally important in bi-headed coordinative words and right-headed modifier words (Zhang & Peng, 1992). Wang (2001) further showed different pattern of results for different kinds of coordinative words. The recognition time for bi-headed words consisting of two synonymous morphemes (e.g., 危险 /danger-risk/, whole word meaning *dangerous*) was faster than that for non-headed words (e.g. 矛盾 /spear-shield/, whole word meaning *conflict*).

The brief review indicates that there are many factors that may potentially affect compound word recognition. To assess the genuine effects of whole word frequency and morpheme frequency, it is essential to control for confound factors such as semantic transparency, concreteness, and headedness. Vergara-Martínez, Duñabeitia, Laka, and Carreiras (2009) was to our knowledge the only one that focused on investigating the effects of constituent frequency in Basque compound word reading after controlling semantic transparency, headedness and concreteness. Based on the results that high-frequency first constituents elicited more negativity in the time window of 100-300 ms, while high-frequency second constituents elicited smaller N400 amplitudes than low-frequency second constituents, they argued for the inhibitory and facilitative effects of constituent frequency in compound word processing.

However, Vergara-Martínez et al. (2009) failed to reveal whether these effects of constituent frequency in compound word processing varied across different word frequency as they ensured the word frequency constant across different conditions.

As the first study towards this end, the present study also utilized the event-related potential (ERP) techniques by taking word frequency and morpheme frequency into consideration simultaneously. Brain responses as revealed with ERP are often considered superior in providing more specific information about the temporal dynamics of word recognition than response time measures. Additionally, there has recently been only one ERP study examining English compound word recognition but no similar studies for Chinese (Vergara-Martínez et al., 2009). The Chinese language possesses linguistic properties that are distinct from those of the most widely studied European languages. Given such uniqueness, research on the neurocognitive processing of Chinese not only contributes to our understanding of language-specific cognitive processes but also sheds light on the universality of psycholinguistic models developed on the basis of these European languages.

## Experiment Section

## Method

### Participants

Sixteen (9 female, mean age = 21.1 yrs, SD = 2.1) college students from the Chinese University of Hong Kong participated in this study. All were right-handed native Mandarin Chinese speakers with normal or corrected-to-normal vision, and no history of neurological or psychiatric impairments. Written informed consent was obtained from each participant in accordance with a research protocol approved by the Institutional Review Board of the Chinese University of Hong Kong.

### Materials

For morpheme-initial condition, the stimuli included 40 sets of two-character Chinese compound words, with both characters being free morphemes. Each set consisting of 4 words the first character (morpheme) of which was manipulated holding their second character (morpheme) constant, e.g., 热爱 (love), 恋爱 (amativeness), 偏爱(favoritism), 宠爱(dote on). The four words in each set fell into a 2 × 2 design crossing over the frequency of the first morpheme (high vs. low) and the frequency of the whole word (high vs. low), producing words with high frequency for both the whole word and the first character (referred as HH-1 words), words with high frequency for the whole word but low frequency for the first character (referred as HL-1 words), words with low frequency for both the whole word and the first character (referred as LL-1 words), and words with low frequency for the whole word but high frequency for the first character (referred as LH-1 words). By using the same second morpheme, irrelevant stimulus characteristics can be nicely controlled across the four conditions, which has never be done in previous studies. According to a word frequency dictionary (Liu, 1990), for the whole words, high or low frequency was defined as above 10 or below 4 occurrences per million; for the morphemes, high or low frequency was defined as above 100 or below 40 occurrences per million. It is typical in Chinese that character (morpheme) frequency is much higher than word frequency. No character in any of the words was associated with more than one pronunciation.

The stimuli in morpheme-final condition were constructed in a similar way except the second morpheme was manipulated holding the first morpheme constant, e.g., 指标 (index), 指挥 (compere), 指派 (assign), 指控 (indict), thus, producing four types of words: words with high frequency for both the whole word and the second morpheme (referred as HH-2 words), words with high frequency for the whole word but low frequency for the second morpheme (referred as HL-2 words), words with low frequency for both the whole word and the second morpheme (referred as LL-2 words), and words with low frequency for the whole word but high frequency for the second morpheme (referred as LH-2 words). Besides, 320 two-character non-words were composed as the fillers. No component character of the filler non-words appeared in the real words.

All target words were pretested to ensure that their comprehension would not be affected by semantic transparency, concreteness, or headedness. Twenty-eight college students from the same subject pool of formal experiment who did not contribute to the test data, were asked to rate the semantic transparency, concreteness, and headedness of each word. For the semantic transparency rating, college students rated semantic relatedness between a word and its two constituent morphemes in a 5-point scale (1 for not related at all, 5 for highly related). Ratings for the two constituents of a word were averaged to obtain the word's semantic transparency measure. Additionally, they rated the concreteness of each word in a 5-point scale (1 for highly abstract, 5 for highly concrete), and headedness in a 3-ponit scale (1 for left-headedness if the word's meaning is biased to the first morpheme, 3 for right-headedness if the word's meaning is biased to the second morpheme, and 2 for words not biased to either morpheme). Table 1 showed the balanced information across the eight types of word conditions in subjective semantic transparency rating, subjective word concreteness, subjective headedness rating, visual complexity (stroke number), word frequency and morpheme frequency. According to the word frequency corpus (Liu,1990), the mean word frequencies for HH-1, HL-1, LH-1, LL-1, HH-2, HL-2, LH-2, and LL-2 were22.75, 22.82, 1.81, 1.82, 23.36, 23.54, 1.73, and 1.56 per million, respectively.

## Procedure

In each trial, a fixation cross was presented at the center of the screen for 500 ms, followed by a mean 500 ms blank screen. A compound word was then displayed for 500 ms. After a 100 ms bank screen, a "?" appeared in the central screen to cue participants to make responses. Participants were asked to press a button if the word was a real word or non-word. The cue "?" was disappeared once participants press response keys. The inter-trial interval was 1500 ms. There were 24 practice trials with feedback. No feedback was provided during the testing trials.

## EEG recording and analyses

Scalp voltages were collected from 58 Ag/AgCl electrodes mounted in an elastic cap (ElectroCap International, Eaton, USA, 10-10 system).

The left mastoid was used as recording reference. Eye movements and blinks were monitored with two electrodes providing bipolar recordings of the horizontal and vertical electro-oculogram (EOG). Inter-electrode impedances were kept below 5 kΩ. EEG was filtered with an analogue bandpass filter of 0.01-250 Hz with 1000 Hz sampling rate. The signals were digitally re-referenced to the linked mastoids, and refiltered offline with a 0.05-40 Hz band-pass. Continuous EEG data were divided off-line into epochs beginning 100 ms prior to and 800 ms following the word onset. The first 100 ms was used for baseline correction.

Average ERPs were based on trials with a correct response only. The rejection rate was below 1%, including rejections due to ocular and muscular artifacts. ERP analysis was performed on time windows of interest (i.e., 150-250 ms, 250-400 ms, and 400-500 ms) using 4-way repeated-measures ANOVAs. The factors were whole word frequency (high vs. low), and morpheme frequency (high vs. low), hemisphere (left vs. right hemisphere), brain regions (anterior, medial-central and posterior regions) were selected based on prior researches, The six regions of interest were left-anterior (F5, F3, F1, FC5, FC3, FC1), left-medial (C5, C3, C1, CP5, CP3, CP1), left-posterior (P5, P3, P1, PO5, PO3,PO1), right-anterior (F2, F4, F6, FC2, FC4, FC6), right-medial (C2, C4, C6, CP2, CP4, CP6) right-posterior (P2, P4, P6, PO2, PO4,PO6),

## Results

## Behavioral results

RTs (response time) were measured from target onset to response. Data was discarded that was due to excessive EEG artifacts. These cutoffs led to the rejection of less than 1% of the observations. RTs to stimuli and ACC of performance were both analyzed in a 2×2 two-way repeated-measures analyses of variance (ANOVAs).

**Table 1**. mean balance information for eight types of stimulus

| word types | word frequecy | morpheme frequency | semantic transparency | word concreteness | headedness | stroke number of 1st morpheme | stroke number of 2nd morpheme |
|---|---|---|---|---|---|---|---|
| HH1 | 22.75 | 216.47 | 3.13 | 3.29 | 1.95 | 8.48 | 7.70 |
| HL1 | 22.82 | 18.82 | 3.13 | 3.26 | 1.93 | 9.90 | 7.70 |
| LH1 | 1.81 | 214.93 | 3.01 | 3.28 | 2.00 | 7.98 | 7.70 |
| LL1 | 1.80 | 18.68 | 3.18 | 3.14 | 1.93 | 9.35 | 7.70 |
| HH2 | 23.36 | 212.47 | 2.96 | 3.16 | 2.03 | 8.00 | 7.87 |
| HL2 | 23.54 | 20.30 | 3.06 | 3.25 | 2.10 | 8.03 | 9.93 |
| LH2 | 1.73 | 211.29 | 2.88 | 3.27 | 2.10 | 8.03 | 7.78 |
| LL2 | 1.56 | 20.01 | 3.05 | 3.24 | 2.10 | 8.03 | 9.78 |

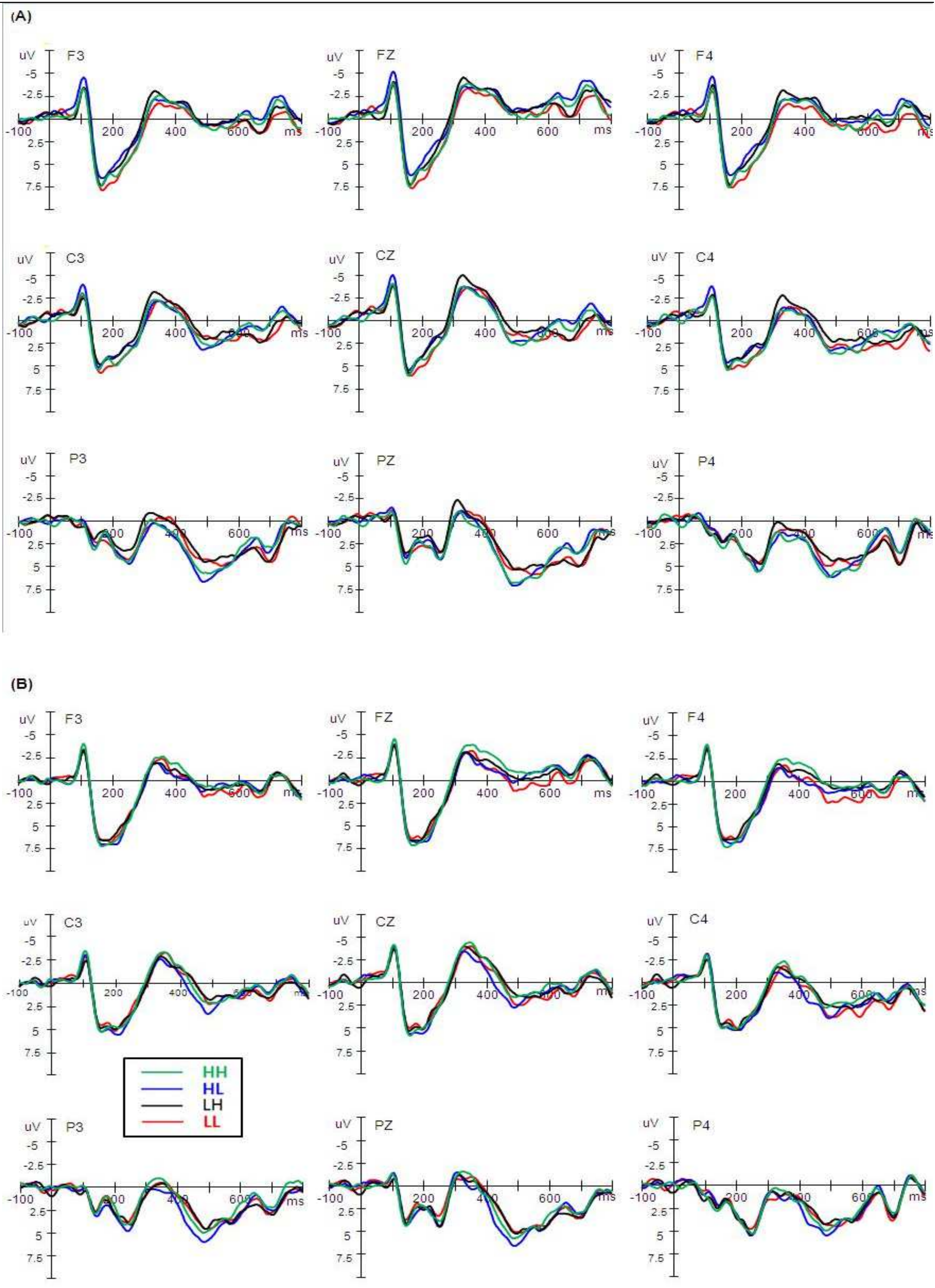




**Figure 1.** Grand average event-related potentials for the (A) words in morpheme-initial condition and (B) words in morpheme-final condition in response to each stimulus type (i.e., HH, HL, LH, and LL). Data were recorded at the 9 representative sites.

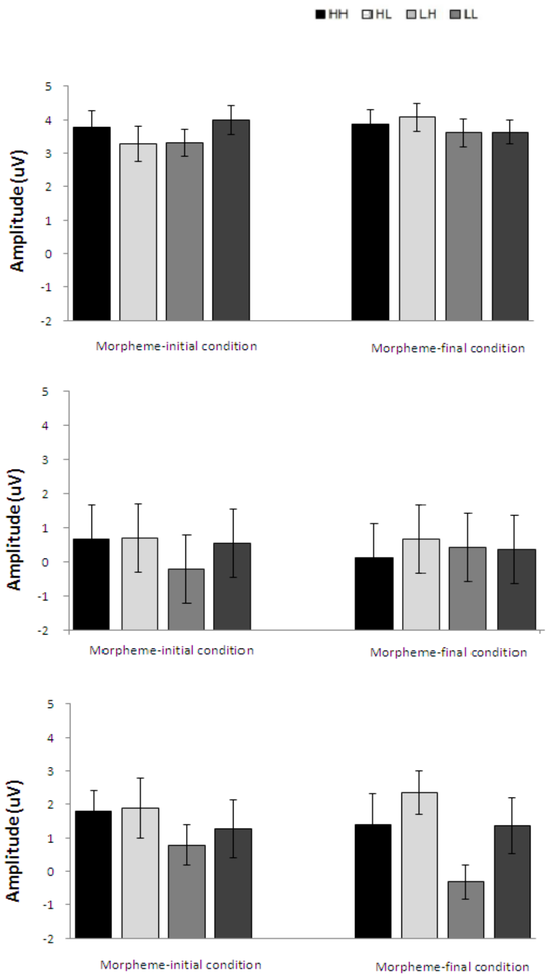


**Figure 2.** Mean amplitudes in the time windows of 150-250 ms (A), 250-400 ms (B), and 400-500 ms (C).

The mean accuracies were 98.8%, 97.4%, 95.7% and 97.2% for HH-1, HL-1, LH-1 and LL-1 words (morpheme-initial condition), and 98.9%, 97.7%, 95.6% and 97.3% for HH-2, HL-2 , LH-2, and LL-2 words (morpheme-final condition), indicating participants were highly attentive to the task as they performed at ceiling level for lexical decision. Mean RTs were 885, 870, 883 and 873 ms for HH-1, HL-1, LH-1 and LL-1 words, respectively, and 872, 870, 868 and 882 ms for HH-2, HL-2, LH-2 and LL-2 words, respectively. As applying the delay response lexical decision task, the RT results showed no significant main effects of Morpheme Position, Word Frequency, Morpheme Frequency, or their interaction effect (*ps* > .05).

## ERP results

Figure 1 shows the grand-averaged ERP responses time-locked to the target word onset in all conditions. Figure 2 shows a summary of the results.

## Results for word-initial conditions

### *150-250 ms time window*

ANOVA results showed no significant main effects of Morpheme Frequency and Word Frequency; however, their two-way interaction effect was significant ($F$ (1, 15) = 10.15, $p$ = 0.006). The further simple comparisons showed significant morpheme frequency effect only for low-word-frequency words ($F$(1,15) = 5.52, $p$ = .03), with less positivity in LH-1 words (3.33 μV) than in LL-1 words (4.03 μV); meanwhile, a significant word frequency effect was also found restrict for low-morpheme-frequency words ($F$(1,15) = 4.91, $p$ < .05), with less positivity in HL-1 words (3.30 μV) than in LL-1 words (4.03 μV). More importantly, there was a significant three-way interaction between Word Frequency, Morpheme Frequency and Region ($F$(2,30) = 5.61, $p$ < .01). To follow up on this three-way interaction, the further simple comparisons shown significant morpheme frequency effect for high frequency word in anterior region, the HH-1 words elicited significantly more positivity than the HL-1 words (5.58 μV vs. 4.62 μV; $F$ (1, 15) = 6.20, $p$ = 0.025); and a (marginal) significant morpheme frequency effect for low frequency word in anterior region ($F$ (1, 15) = 4.26, $p$ = 0.057) and medial-central region ($F$ (1, 15) = 6.25, $p$ = 0.026), while the LH-1 words elicited less positivity than the LL-1 words (5.15 μV vs. 6.06 μV, *in* anterior region; 3.35 μV vs. 4.17 μV *in* medial-central region) . Furthermore, a word frequency effect also was found for low frequency word in anterior region ($F$ (1, 15) = 9.74, $p$ = 0.007), with the HL-1 word elicited less positivity amplitude than that for the LL-1 word (4.62 μV vs. 6.06 μV).but there were no significant main effect of Morpheme Frequency, neither their interaction (*ps* > .1).

### 250-400 ms *time window*

ANOVA results showed no significant main effects of Morpheme Frequency or Word Frequency, nor their two-way interaction effects (*ps* > .05). More importantly, there was a significant two-way interaction between Word frequency and Region ($F$ (2, 30) = 5.01, $p$ = .013). For word frequency, the high frequency words elicited significantly less negative ERPs than the low words restrict in posterior brain regions ($F$ (1, 15) = 15.09, $p$ = 0.001; 1.96μV vs. 1.09 μV). More importantly, a marginally significant three-way interaction between Word Frequency, Morpheme Frequency and Region ($F$(2,30) = 3.15, $p$ = .057) was found. To follow up on this three-way interaction, the further simple comparisons shown significant

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morpheme frequency effects for low frequency word in anterior region ($F$ (1, 15) = 11.49, $p$ = 0.004) and medial-central region ($F$ (1, 15) = 6.69, $p$ = 0.02); In contrast to the 150-250ms time window, the LH-1 words elicited larger negative than the LL-1 words (-1.13 μV vs. 0.06 μV, *in* anterior region; -0.44 μV vs. 0.39 μV *in* medial-central region). Similar, a word frequency effect also was found for high morpheme frequency word in medial-central ($F$ (1, 15) = 4.67, $p$ = 0.047; -0.35μV vs. -1.13 μV) and posterior regions ($F$ (1, 15) = 5.30, $p$ = 0.036; 0.48μV vs. -0.44 μV), with the HH-1 word elicited less positivity amplitude than that for the LH-1 word (4.62 μV vs. 6.06 μV).

### *400-500* ms *time window*

ANOVA results showed that the main effect of Word Frequency was significant ($F$ (1, 15) = 7.17, $p$ = .017), with the high frequency words (1.84 μV) elicited significantly less negative ERPs than the low frequency words (1.03μV). Furthermore, the Region × Word Frequency interaction was also significant ($F$ (2,30) = 8.31, $p$ =.001). In order to specifically reveal the word frequency effect, the further comparisons shown that high frequency word elicited less negative ERPs than the low frequency word in both medial-central ($F$ (1, 15) = 5.427, $p$ = 0.03; 2.23μV vs. 1.38μV) and posterior brain regions ($F$ (1, 15) = 28.18, $p$ < 0.001; 3.78μV vs. 2.34μV).However, there was no significant main effect of Morpheme Frequency, neither other interactions ($ps$ > .1).

## Results for word-finial conditions

### *150-250 ms time window*

ANOVA results showed significant main effect of Word Frequency ($F$(1,15) = 7.58, $p$ = .015), with more positivity in high-word-frequency words (4.1 μV) than in low-word-frequency words (3.6 μV), but there were no significant main effect of Morpheme Frequency, neither their interaction (ps > .1).

### *N250-400 ms time window*

ANOVA results showed that the main effect of Morpheme Frequency was significant ($F$ (1, 15) =4.80, $p$ = .045), but no significant Word Frequency main effect was found ($p$ > .5). The data showed that the high morpheme frequency words (-0.76 μV) elicited significantly more negative ERPs than the low morpheme frequency words (-0.38μV). Moreover, there was a significant three-way interaction between Hemisphere, Region, and Morpheme Frequency ($F$ (2, 30) = 5.26, $p$ = .01). Further comparisons showed that high morpheme frequency words elicited significant larger negative component than that in low morpheme frequency words only restrict in right-medial region ($F$ (1, 15) = 4.86, $p$ < 0.05; -0.73μV vs. -0.20μV).

### *N400-500 ms time window*

ANOVA results showed that the main effect of Word Frequency ($F$ (1, 15) = 12.65, $p$ < .01) and Morpheme Frequency were significant ($F$ (1,15) = 12.85, $p$ = .003). For Word Frequency, smaller negativities were observed for high word frequency words (1.88 μV) compared to the low word frequency ones (0.52 μV). For Morpheme Frequency, the high morpheme frequency words (0.54 μV) elicited significant larger negative ERPs than the low morpheme frequency words(1.85 μV). Moreover, a two-way interaction of Word Frequency by Region was found ($F$ (2, 30) = 9.78, $p$ = 0.001). Further comparison showed that word frequency effect was significant restrict in both medial-central ($F$ (1, 15) = 19.16, $p$ = 0.001; 2.29μV vs. 0.54μV) and posterior regions ($F$ (1, 15) = 13.43, $p$ = 0.002; 3.31μV vs. 1.45μV), and the high frequency words elicited significantly smaller negative ERPs than the low frequency ones in these two regions. Moreover, there was a significant three-way interaction between Hemisphere, Region, and Morpheme Frequency ($F$ (2,30) = 8.79, $p$ = .001). Further comparisons showed that high morpheme frequency words elicited significant less positive component than that in low morpheme frequency words in the following five interested brain regions, left-anterior region ($F$ (1, 15) = 5.36, $p$ = 0.035; -0.88μV vs. 0.20μV) left-medial region($F$ (1, 15) = 15.46, $p$ = 0.001; 0.50μV vs. 1.99μV), left-posterior region ($F$ (1, 15) = 12.48, $p$ < 0.01; 1.63μV vs. 2.97μV), right-anterior region ($F$ (1, 15) = 10.28, $p$ < 0.01; -0.85μV vs. 0.71μV) and right-medial region ($F$ (1, 15) = 10.34, $p$ < 0.01; 0.70μV vs. 2.480μV).

## Discussion

In the present study, we applied the ERP technique to examine effects of morpheme and word frequency in Chinese compound word reading. A delay response lexical decision task was used with strict controls of potential confounding factors, such as the same constituent morpheme, semantic transparency, concreteness, word headedness, and stroke number. In general, ERP results showed similar trends of word and morpheme effects for compound word processing; moreover, the ERPs revealed greater detail on it. The ERP result showed a dynamic changing effect of morpheme frequency in the time windows of 150-250 ms, 250-400 ms for morpheme-initial word condition and a straightforward morpheme frequency effect in 400-500 ms time windows for morpheme-final word condition. Specifically, in morpheme-initial condition, a reverse pattern of morpheme frequency effect firstly showed in 150-250 ms time windows and an inhibitory effect in for high frequency words while a facilitative effect for low frequency words; as LL-1 words elicited more positive wave than that in LH-1 words, and HL-1 words elicited less positive wave than that in HH-1 words. Later on, the morpheme effect changed to inhibitory pattern in 250-400 ms time windows for the words with low word frequency as LL-1 words elicited less positive ERPs than that in LH-1 words, and low morpheme frequency elicited more negativity than that for words with Differently, the word frequency factor showed consistence facilitative effect cross 150-250ms,250-400ms and 400-500ms time windows as high word frequency words elicited less positive ERPs than that for words with low word frequency. Something different from the other two time windows, this effect only exists for low morpheme frequency words (LL-1 and LH-1 in 150-250 ms time window. For the morpheme-final words, there was an robust inhibitory effect of morpheme frequency range from the time windows of 250-400 to 400-500 ms as words with high morpheme frequency elicited less negativity than words with low morpheme frequency. Similar to the morpheme-initial words, a consistent facilitative word frequency f effect was revealed for morpheme- final words; However, this facilitate effect was demonstrated only in the time windows of 150-250 and 400-500 ms, with high frequency words elicited larger negativity ERPs than the low one.

The facilitative effect of word frequency was found in a large time course which ranged from 150 to 500ms in morpheme-final word condition. But this facilitative word frequency effect only showed in 150-250ms and 400-500ms time windows for morpheme-initial condition,

The facilitative effect of word frequency in 150-250 ms time window found in the current study was consistent with previous studies suggesting a role of word frequency in compound word recognition (e.g., Chen & Peng, 2003; Juhasz, Starr, Inhoff, & Placke, 2003). More importantly, our experiment reported here contribute to a burgeoning literature, which suggests the processing of compound words involved a sub-lexical decomposition of compound words into their constituent lexemes (Andrews, Miller, & Rayner, 2004; Juhasz, Starr, Inhoff, & Placke, 2003). For instance, our findings fit nicely with previous studies showing that first constituents with high frequency elicited more negativity than those with low frequency (Vergara-Martínez, Duñabeitia, Laka, & Carreiras, 2009). Also, our results are consistent with the finding in eye movement research with compound words that readers decompose the compounds into their lexemes during their recognition, with the presence of a high-frequency root or lexeme led to shorter fixation durations on the morphologically complex word (e.g., Inhoff, Starr, Solomon, & Placke, 2008; Juhasz, 2007, 2008; Kuperman, Bertram, & Baayen, 2008).

An interesting finding is that we found a salient modulation effect of word frequency on the effect of Chinese morpheme frequency in compound word processing, which varied as a function of morpheme position. Our results extended the finding of Vergara-Martínez et al. (2009) in that Chinese morpheme frequency played a facilitative role in words with low word frequency in early time course, and then it changed into an inhibition role in a relatively later processing time course, when the morpheme was the first constituent of the compound word.



For the words in morpheme-final condition, the inhibitory morpheme effect was found in both high and low word frequency conditions in the time windows of 250-400 and 400-500 ms, which is much later than the morpheme effect found in morpheme-initial condition (in two early time windows of 150-250 and 250-400 ms). The current finding that an inhibition role of second morpheme frequency was found in the comprehension of compound word seem to contradict toJuhasz et al.'s (2003) and Pollatsek et al.'s (2000) results which showed a robust second constituent lexeme effect: compound words with a high-frequency second constituent were read faster than those with a low-frequency second constituent and the results of Vergara-Martinez et al. (2009) that high-frequency second constituents elicited smaller N400 amplitudes than low-frequency second constituents.

On the one hand, as vocabulary development is cumulative, the differences between alphabetic language and logographic language are compounded over time (Alexander, Entwisle, & Horsey, 1997). Thus, it is expected that the ability to use print morphology and print morphological awareness may well vary across languages, possibly making the role of morpheme frequency in compound word processing differs between alphabetic language and logographic language (e.g., Chinese).

On the other hand, previous studies in English have found mixed evidence for a first constituent frequency effect (Vergara-Martinez, Dunabeitia, Laka, & Carreiras, 2009) and Juhasz (2008) has been attributing that to constitutes' morphologic family size as a possible confound. The analyzing base on the data from the *Dictionary Of Frequently Used Words* (Liu, 1990) showed that there was a significant correlation between morpheme frequency and morphological family size for Chinese compound words ($r$ = 0.478,p<0.001), which indicated that the high frequency morphemes were formed more compound words than the low one. In current study, the morphological family size of constituent morphemes is much larger for the high frequency morpheme in both word-initial and –finial word conditions (for morpheme-initial condition, high frequency morpheme: 27.7; low frequency morpheme: 7.6. for morpheme-final condition, high frequency morpheme: 33.4; low frequency morpheme: 6.8 ); Our results further suggested that morphological family size was also a possible moderator in the inhibitor morpheme frequency effect in later processing stage of compound words

Previous research has shown that morphologically structured non-words that contain existing affixes are particularly difficult to reject in lexical decision (e.g., Caramazza, Laudanna, & Romani, 1988; Crepaldi, Rastle, & Davis, 2010; Laine, Vainio, & Hyönä, 1999; Wurm, 2000). This is thought to indicate that affix identification is subject to some position-specific constraints (e.g., Crepaldi, Rastle, & Davis, 2010). Our results possibly reflect such similar position-specific constraints in Chinese words used in the current study. It should be noted that the headedness of our Chinese words is not biased to either left or right morpheme. That is, the first and second morpheme contribute similarly to the understanding of the Chinese words, which differ from the stimuli used in previous study that their second constituents might play a main role in the selection of the final lexical candidate (Juhasz et al., 2003;Vergara-Martinez et al., 2009). Additionally, Chinese people are typical left-to-right readers. There is evidence that right-to-left readers showed a statistically significant preference for pictures with right-to-left directionality and the reading habits for both words and numbers contribute to the spatial representation of numbers (Shaki, Fischer, & Petrusic, 2009). Our results indicate that Chinese compound words are recognized from left to right in a serial way as opposed to processed in parallel. After lexical access to the first morpheme was initiated, whole word lexical activation would rely more on the activation of the first morpheme at the early stage and more on the second morpheme at the later stage. That is probably why the frequency of the first morpheme had significant effect on the ERP waveforms in the early time windows and the frequency of the second morpheme in the later time windows.

Analogous to typical frequency effect on ERP responses, the higher the frequency of the first morpheme, the easier its lexical activation, resulting in the reduced amplitude in the 150-250 time window for high-frequency first morphemes than low-frequency ones for low frequency whole words; however, after the whole word lexical activation gets to completion, the higher the frequency of first morpheme reversed to increase the amplitude in the 250-400 ms time widow, i.e., the higher its frequency, the larger the ERP amplitude it elicited. And the similar larger ERP amplitude also elicited for high frequency second constituent words during the 400-500 ms time window. The effect of the second morpheme in the current study resembles what was found in some behavioral studies on Chinese compound words showing inhibitory effects (e.g., Myers, 2006; Myers, Derwing, & Libben, 2004; Pollatsek, Hyönä, & Bertram, 2000). Toward later stages of the recognition process, as whole word lexical activation gets to completion, the precise meaning of the morpheme needs to be suppressed as it usually involves some conflicts with the whole word meaning (which is a typical feature of Chinese compound words). This may explain why in the 250-400 ms time window and also later 400-500 ms time window, an opposite pattern of morpheme frequency effect was observed, i.e., the higher its frequency, the smaller the ERP amplitude it elicited.

To our knowledge, Vergara-Martinez et al.'s (2009) study was the first ERP investigation of constituent frequency in compound word reading, and showed that compound word recognition in Basque supports an activation–verification framework where the first morpheme contributes to activation of candidates, later verified and selected based on information from the second morpheme. That is, each constituent of a compound word is operating differently during the lexical access of the whole compound. This conclusion was in line with our suggestion that the recognition of Chinese compound word also followed a left to right serial order. However, the two studies differed in the effect of the second morpheme. It remains to see whether this difference reflects some linguistic differences of the two writing systems. Such a speculation, while interesting, will require more evidence.

## Conclusion

In line with previous findings, the present study showed that lexical access in Chinese two-character compound words involved access via morphemic units, indicating that recognition of Chinese compound words involves the morpheme representation. Moreover, such activation is affected by the whole word frequency and the position of morpheme so that initial morphemic units are accessed earlier and then give way to the activation of second morphemic units and whole word later on. This is the first study to demonstrate the morpheme activation in logographic language which varies as a function of whole word frequency and morpheme position.

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