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Nouns and verbs in Chinese are processed differently: Evidence from an ERP study on monosyllabic and disyllabic word processing

Quansheng Xia[a,b*], Lan Wang[c], and Gang Peng[a,c,d*]

[a] Department of Linguistics and Modern Languages, The Chinese University of Hong Kong, Shatin, Hong Kong SAR, China

[b] College of Chinese Language and Culture, Nankai University, Tianjin, China

[c] Shenzhen Institutes of Advanced Technology, Chinese Academy of Science, Shenzhen, China

[d] Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University, Hong Kong SAR, China

[*] Corresponding authors:

Quansheng Xia
College of Chinese Language and Culture, Nankai University,
Tianjin, China
Phone: (+86) 13820015428
E-mail: *xiaqsh@nankai.edu.cn*

Gang Peng
Joint Research Centre for Language and Human Complexity,
The Chinese University of Hong Kong, Hong Kong
Phone: +852 3943 4711
Fax: +852 2603 7755
E-mail: *gpengjack@gmail.com*

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ABSTRACT

This event-related potential (ERP) study aims to investigate the neural processing of nouns and verbs in Chinese, especially the processing of monosyllabic nouns (MNs) and verbs (MVs) versus disyllabic nouns (DNs) and verbs (DVs). All four types of words were embedded in syntactically well-defined contexts and a semantic relatedness judgment task was performed. Results showed that, regardless of the number of syllables, verbs elicited more negative N400 than nouns, which may be due to the semantic difference between object and action rather than concreteness or imageability. Furthermore, DVs elicited a greater N1 and a smaller late positive component than DNs whereas such differences were absent in the comparison between MNs and MVs. The N1 and late positive component seem to reflect the early detection and late integration of the syntactic mismatch between the verb contexts and noun usage of DVs, respectively. The findings of the current study indicated that the word class effect in Chinese is due to the semantic differences between nouns and verbs, calling into attention the importance of distinguishing monosyllabic words from disyllabic words when examining the word class effect in Chinese.

Keywords: Chinese; Word Class Effect; Syntactic Ambiguity; N1; N400; Late Positive Component;

1. Introduction

Nouns and verbs are fundamental members of word classes in languages. They differ systematically at several linguistic levels, e.g., semantic level, syntactic level, and pragmatic level. In languages with rich morphology, the grammatical class difference is also realized at the morphological level. Such linguistic differences raise the question of whether there are distinct neural implementations for noun vs. verb processing.

Numerous studies have tried to address this question. Research on aphasic patients has found a dissociation between nouns and verbs at the semantic (e.g., McCarthy & Warrington, 1985), lexical (e.g., Caramazza & Hillis, 1991) and morphological levels (e.g., Miceli & Caramazza, 1988). The distinctive lesions in the brain were taken as evidence that specific regions respond to the noun and verb representations. Such a dissociation between nouns and verbs in the brain areas was found in some research on normal people. These neuroimaging studies suggested that verbs tend to generate greater activations than nouns in left frontal regions (e.g., Palti, Ben-Shachar, Hendler, & Hadar, 2007; Perani et al., 1999; Shapiro et al., 2005; Yokoyama et al., 2006) and nouns tend to activate temporal regions more strongly than verbs (Shapiro et al., 2005; Tyler, Randall, & Stamatakis, 2008). However, some other studies failed to find segregated brain regions for nouns and verbs (e.g., Longe, Randall, Stamatakis, Tyler, 2007; Momenian, Nilipour, Samar, Oghabian, & Cappa, 2016; Tyler, Russel, Fadili, & Moss, 2001). The inconsistency across studies may have stemmed from the differences in experimental paradigms, materials, and techniques. To assess the convergence of results in the previous studies, Crepaldi, Berlingeri, Paulesu, and Luzzatti (2011) reviewed the studies in which same techniques and similar tasks were employed but were not able to find compelling evidence supporting the segregation of nouns and verbs in the brain. The conflicting results in the previous studies indicated that nouns and verbs engage overlapped rather than separated neural networks. This claim was further confirmed by a meta-analysis of neuroimaging studies (Crepaldi et al., 2013).

Although the data obtained so far failed to demonstrate spatial segregation between the processing of nouns and verbs, the studies that used event-related potential (ERP) showed that nouns and verbs are processed differently online. According to stimulus presentation, the previous ERP studies could be roughly divided into two major groups: studies with stimuli presented in isolation and studies with stimuli presented in contexts. For the first group of studies, the processing differences between nouns and verbs were mainly reflected on two ERP components, P200 and N400. Verbs elicited more positive P200 than nouns (Kellenbach, Wijers, Hovius, Mulder, & Muler, 2002; Preissl & Pulvermüller, 1995; Pulvermüller, Mohr, & Schleichert, 1999; Xia, Lü, Bai, & Shi, 2013; Zhang, Ding, Guo, & Wang, 2003) while nouns activated more negative N400 than verbs (Barber, Kousta, Otten, & Vigliocco, 2010; Khader, Scherag, Streb, & Rösler, 2003; Tsai et al., 2009; Xia et al., 2013; Zhang et al., 2003). For the second group of studies, the results seem to be less consistent. Federmeier, Segal, Lombrozo, and Kutas (2000), Lee and Federmeier (2006, 2008) found that, regardless of ambiguity, English nouns elicited more negative N400 than verbs over central-posterior sites when they were embedded in the syntactically specified contexts. A sustained frontal positivity was additionally found only for unambiguous words, with more positive amplitudes elicited by verbs than by nouns. Nonetheless, a reversed ERP pattern was reported in a German study. When primed with the words of the same word classes (verbs primed by verbs and nouns primed by nouns, respectively), verbs elicited a more negative potential than nouns over the time window of 360-600ms (Rösler, Streb, & Haan, 2001).

Similar to German studies, studies on Chinese also showed that a negative potential (N400) was more negative for verbs than for nouns when the target words were presented in the contexts. Liu, Shu, and Weekes (2007) selected monosyllabic nouns and verbs as stimuli. When the stimuli were primed by animal nouns, verbs elicited more negative N400 than nouns, and nouns elicited more positive P200 and P600 than verbs. When they were primed by tool nouns, the word class effect could only be observed on N400, which was more negative for verbs as compared with nouns. These results indicated that the N400 is a relatively reliable index of the noun-verb distinction, irrespective of the category of primes. In addition to monosyllabic words, Liu et al. (2008, 2011) examined the word class effect by employing disyllabic nouns and verbs in Chinese. Two types of syntactic contexts, noun context 'one + noun classifier' and verb context 'not + auxiliary', were presented prior to nouns and verbs respectively. The results showed that verbs elicited more negative N400 than nouns, while nouns activated more positive P600 than verbs, implying the modulating effects of both semantic and syntactic features in the processing of Chinese nouns and verbs. Taken together, the previous ERP studies have found distinct neural processing of nouns and verbs, even though the detailed patterns observed were not consistent.

The above ERP studies generally support the neural distinction between nouns and verbs. However, the nature of noun-verb distinction is not well understood. Some studies suggested that the dissociation between the two word classes arises from the semantic differences associated with nouns and verbs (Barber et al., 2010; Bird, Franklin, & Howard 2001; Pulvermüller, Lutzenberger, & Preissl, 1999; Warrington & McCarthy, 1987; also see Kemmerer, 2014 for review), while some other research indicated that the word class effect is due to the morphological differences between the two word classes. Once the semantic factors were controlled for, the word class effect could be found only when morpho-syntactic processing was involved (Longe et al., 2007; Tyler, Bright, Fletcher, & Stamatakis, 2004; but see Momenian et al., 2016 for a different view). It is still unclear, given the inconsistency across studies, whether the neural distinction between nouns and verbs should be attributed to the morpho-syntactic differences or the semantic feature differences between these two word classes (see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011 for a discussion). Since the previous studies mainly focused on the languages rich in morphology, the processing of nouns and verbs may always involve both semantic and morphological processing. It is, therefore, reasonable to investigate the word class effect in a language with a simple morphological system, such as Chinese. In Chinese, there is virtually no declension for nouns or conjugation for verbs (Wang, 1973), which makes it unlikely to induce the processing of inflection. The results from the previous studies on the Chinese speakers with noun or verb impairment revealed that the neural distinction between nouns and verbs might be due to the semantic differences (Bates, Chen, Tzeng, Li, & Opie, 1991; Bi, Han, Weekes, & Shu, 2007; Chen & Bates, 1998; Lin, Guo, Han, & Bi, 2010). Such a finding was supported by neuroimaging studies. By employing monosyllabic and disyllabic nouns and verbs and using semantic tasks, Yu, Law, Han, Zhu, and Bi (2011) and Yu, Bi, Han, Zhu, and Law (2012) found the left posterior superior and middle temporal cortices were specifically activated for Chinese verbs. On the contrary, when only disyllabic nouns and verbs were selected and a lexical decision task was performed, no cortical region was significantly activated for either nouns or verbs (Chan et al., 2008; Li, Jin, & Tan, 2004; Yang, Tan, & Li, 2011).

The inconsistent neuroimaging results could be attributed to different experimental tasks. As Yu et al. (2011) argued, more semantic processing may be involved in the semantic tasks rather than in the lexical decision tasks. More than that, different experimental materials used in the two series of studies may also lead to the divergent results. Chan et al. (2008), Li et al. (2004) and Yang et al. (2011) selected disyllabic nouns and verbs as stimuli, whereas Yu et al. (2011, 2012) included both monosyllabic and disyllabic nouns and verbs in the research. Linguistic research showed that most disyllabic verbs are syntactically ambiguous. According to a survey of grammatical classes in contemporary Chinese, there is an on-going word class shift from verbs to nouns, which has mostly occurred in disyllabic verbs (Hu, 1996). Compared with monosyllabic verbs, disyllabic verbs are more flexible to function as the heads in nominal phrases, such as ‘N + *de* + V’ (N’s V)

(Zhan, 1998) or as subjects and objects in sentences (Zhang, 1989). Without any change in word form, large number of disyllabic verbs could be used as nouns that refer to events (e.g., 爆炸 *bao4zha4*, 'to explode, explosion'), and some are polysemous words that could also refer to one of the constituents (e.g., patients, receipts, tools etc.) involved in the verb meaning (e.g., 翻译 *fan1yi4*, 'to translate, translation, translator'). Unlike disyllabic verbs, a majority of monosyllabic verbs do not function as nouns and they are regarded as the prototypical verb in Chinese (Chen, 1987).

Given the disyllabic verbs in Chinese have certain syntactic functions of nouns, the processing of disyllabic verbs should be, to some extent, similar to that of disyllabic nouns. However, most previous studies focused on the neural distinction between disyllabic nouns and verbs in Chinese, which may lead to the reduced or limited word class effect. To test this, it is necessary to include monosyllabic verbs that are less syntactically ambiguous and to examine whether processing difference between monosyllabic nouns and verbs is identical to that between disyllabic nouns and verbs. As far as we can see, there is only one study that made a comparison of word class effect in Chinese between the monosyllabic words and disyllabic words. Yang, Liang, Gu, Weng and Feng (2002) manipulated the word class (noun/verb) and the number of syllables (one/two), and controlled the word frequency between nouns and verbs. The stimuli, including monosyllabic nouns, verbs and disyllabic nouns, verbs, were embedded in the same type of syntactic contexts as in Liu et al. (2008, 2011). The participants were instructed to judge as to whether the targets fitted the preceding contexts or not. The results showed that monosyllabic verbs elicited more negative N2 than monosyllabic nouns, but disyllabic verbs elicited less negative N2 than disyllabic nouns. Furthermore, disyllabic verbs elicited more positive LPC than nouns while such LPC effect disappeared in the comparison between monosyllabic nouns and verbs. These findings suggested the word class effect in Chinese is discrepant between monosyllabic and disyllabic words. However, several lexical and contextual variables were not matched between nouns and verbs (to be discussed later), which might interfere the observed word class effects in the monosyllabic and disyllabic words.

Therefore, the present study, by controlling for nuisance variables, aims to investigate the neural processing of nouns and verbs in Chinese, especially the processing of monosyllabic nouns and verbs versus disyllabic nouns and verbs. The current study contributes to the understanding of the noun-verb distinction in three ways. First, an important but unsolved the question is whether word class effect is due to the semantic differences or the morpho-syntactic differences associated with nouns and verbs (Vigliocco et al., 2011). Different from Indo-European languages that have been investigated, Chinese is a language with limited inflections, in which nouns and verbs in Chinese are indistinguishable in the word form. The morpho-syntactic operations may be avoided in the comparison of nouns and verbs in Chinese. If nouns and verbs in Chinese are processed differently, the noun-verb distinction is probably due to the semantic differences between the two word classes. Otherwise, nouns and verbs in Chinese may not be dissociable. Thus, we tried to select object nouns and action verbs as stimuli because they are prototypical members of each word class in typology (Croft, 2001), and are represented in separate brain regions (Kemmerer, 2014).

Second, the word class effect in Chinese will be further investigated in this study. In the previous studies, disyllabic nouns and verbs were usually compared, which may skew the word class effect in Chinese. Because linguistic study suggested that most disyllabic verbs could be used as nouns in modern Chinese. Comparatively, monosyllabic verbs are syntactically less ambiguous. Thus, after better controlling for several nuisances, we investigated whether the processing differences between monosyllabic nouns and verbs is identical or not to the processing between disyllabic nouns and verbs. Third, the previous studies on Chinese confounded semantic constraint effect of context with word class effect, while it is controlled in the current study. Yang et al. (2002) and Liu et al. (2008, 2011) used 'one + noun classifier' as noun contexts and used 'not + auxiliary' as verb contexts, but did to match the semantic constraint between these two syntactic contexts. In Chinese, the classifier often constraints the semantic features of the following nouns (Gao & Malt, 2009; Zhang, 2007), but the auxiliary does not provide any semantic information of the following verbs. The classifiers used in the noun contexts, such as '间'（*jian1*, 'room'）in '一间屋'（*yi4 jian1 wu1*, 'one room'）in Yang et al. (2002) and '把'（*ba3*, 'handle'）in '一把钥匙'（*yi4 ba3 yao4shi*, 'one key or a bunch of keys'） in Liu et al. (2008), carry meaning about the semantic features of the entities being classified. However, the auxiliary, such as '能'（*neng2*, 'can'） and '愿'（*yuan4*, 'be willing to'）, in the verb contexts do not provide any semantic information of the following verbs. Such mismatch in semantic constraint between noun and verb contexts may affect the findings. One previous study found that N400 reflected the effect of semantic constraint on word processing (Chou, Huang, Lee, & Lee, 2014) while this component also showed the semantic differences between nouns and verbs in the contexts (e.g., Rösler et al., 2001; Liu et al., 2007). To avoid this interference, we selected the classifiers such as 个 *ge4*, 种 *zhong3*, 块 *kuai4*, to form weakly constraining noun contexts. In this way, the semantic constraint of noun contexts is comparable with that of verb contexts. Furthermore, several lexical variables (such as AoA, and neighborhood size) may not be taken into consideration in the previous study (Yang et al., 2002) because the information of these variables is not available. These variables were controlled in this study to rule out the possible confounding effects.

2. Methods

2.1. Participants

Twenty-three right-handed native speakers of Putonghua were paid to participate in the experiment (10 males, 13 females; mean age=23 years, SD=2.6). One additional female participant was excluded from the analysis because excessive eye movement and muscle activity caused low acceptance rate of her EEG data (less than 15 trials in two conditions). All the participants were undergraduates and graduate students from The Chinese University of Hong Kong, with normal or corrected-to-normal vision and no reported history of neurological illness. None of the participants was majoring in linguistics, psychology or any other related disciplines. The experimental procedures were approved and informed written consent was obtained from each participant in compliance with a protocol approved by the Joint Chinese University of Hong Kong – New Territories East Cluster Clinical Research Ethics Committee.

2.2. Materials

Stimuli were first classified into a monosyllabic group and a disyllabic group based on their number of syllables. Each group then consisted of two word classes, noun and verb respectively. There were monosyllabic nouns (MNs), and monosyllabic verbs (MVs) in the monosyllabic group, and disyllabic nouns (DNs) and disyllabic verbs (DVs) in the disyllabic group. Each type of words contained 22 stimuli. Several lexical variables, such as word frequency, number of strokes[1], AoA, familiarity, and neighborhood size were matched between nouns and verbs within the monosyllabic and disyllabic groups respectively ($ps > 0.05$; see Table 1). The concreteness and imageability could not be well controlled for nouns and verbs because prototypical nouns are usually more concrete and more imaginable than prototypical verbs. However, the differences in concreteness and imageability between monosyllabic nouns and verbs matched those between disyllabic nouns and verbs. Two-way ANOVA applied to concreteness and imageability ratings with two levels of syllable

[1] For disyllabic words, the number of strokes of the first and second characters was matched between nouns and verbs ($ps > 0.05$).

(monosyllable/disyllable) and two levels of word class (noun/verb) showed no interaction effect between word class and syllable ($p > 0.05$). Based on the ratings by native speakers of Chinese[2], all the nouns and verbs were semantically unambiguous. Homonymous and polysemous words were not included. The stimuli were presented in a Songti 20-point font in white text against a black background. The characters of the stimuli were simplified Chinese.

Table 1. Lexical variables of stimuli for each condition

Condition	Log Frequency	No. of Stroke	AoA	Familiarity	Neighborhood Size	Concreteness	Imageability
MN	1.3(.4)	11.1(2.9)	4.12(.4)	6.45(.5)	9.8(13.8)	6.66(.2)	6.45(.3)
MV	1.4(.3)	10.2(2.2)	4.27(.3)	6.35(.3)	10.5(10.3)	5.46(.3)	5.94(.5)
DN	1.3(.4)	16.5(3.6)	3.94(.8)	5.72(.4)	.77(1.48)	4.89(1)	4.81(.9)
DV	1.1(.5)	16.7(5)	3.95(.8)	5.59(.7)	.23(.43)	3.26(.7)	4.22(.6)

Note. 1) The variables were shown in the form of mean (standard deviation). 2) The frequency were collected from the online corpus LCSMCS (http://www.dwhyyjzx.com/cgi-bin/yuliao/). 2) The neighborhood size was collected from the Contemporary Dictionary of Chinese (2005). Based on Huang et al. (2006), the neighborhood size for monosyllabic words is calculated based on the number of neighbors that share the first character; the neighborhood size for disyllabic words is calculated based on the number of neighbors that share the first two characters. 3) The number of strokes was collected from the Contemporary Dictionary of Chinese (2005). 4) The ratings of familiarity, AoA, concreteness, and imageability of monosyllabic words were based on the Chinese character corpus (http://www.personal.psu.edu/pul8/psylin_norm/psychnorms.html). For disyllabic words, the data of these four variables were collected from four norming procedures. The procedures, largely followed Liu, Shu, and Li (2007), were done by a total of 72 native speakers of Chinese (18 people for each variable) who did not participate in the experiment.

The noun context and verb context were syntactically well-defined. The noun contexts were 一 + 名量词 '(one + noun classifier)', after which the words were obligatory for nouns rather than other word classes. The verb contexts were 不 + 能愿动词[3] '(not + auxiliary)', after which only verbs were allowed to appear. Both

[2] Twelve native speakers of Chinese judged whether the words were semantically ambiguous words or not based on their daily usage. All these subjects did not participate in the EEG experiment.

[3] '不' *bu4* (not) was used as a part of verb contexts because one important syntactic feature of verbs in Chinese is that verbs should be modified by '不' (Huang & Liao, 1991). And ERP studies showed the negation 'not' may not immediately influence the brain potential (e.g. N400) of the upcoming words (Fischler, Bloom, Childers, Roucos, & Perry, 1983; Kounios & Holcomb, 1992). For auxiliary, some auxiliary verbs, such as '想' *xiang3* (to wish), also function as verb (e.g., '想' to miss) in Chinese. Nouns can thus legally appear after these words when they serve as verbs (e.g., '我不想家。' I do not miss family.). These types of auxiliary verbs were not selected.

noun and verb contexts, composed of two Chinese characters, were presented prior to target stimuli (Table 2 shows the examples).

Table 2. Examples of contexts and stimuli

Context	Stimuli			
	MN	MV	DN	DV
Noun context (one + noun classifier)	一个+岛 (one *ge*+ island)	——	一个+书包 (one *ge* + bag)	——
Verb context (not + auxiliary)	——	不该+搬 (should not + move)	——	不该+迎接 (should not + greet)

In addition to constraint strength in syntax, the semantic constraint and cloze probability of the contexts were also taken into consideration. Word processing can be influenced by both semantic constraint and cloze probability of the preceding context (Chou et al., 2014; Federmeier, Wlotko, DeOchoa-Dewald, & Kutas, 2007; Wlotko & Federmeier, 2007). The norming procedure on the semantic constraint and cloze probability was conducted with 22 native speakers of Chinese, who did not participate in the experiments. They were instructed to write down three monosyllabic words and three disyllabic words that fit the contexts according to daily usage. The cloze probability of words was calculated based on the first and second answers in order to avoid the possibility that some unexpected items within the set of the second answers were actually used to complete the fragments. According to the previous studies (Chou et al., 2014; Federmeier et al., 2007; Wlotko & Federmeier, 2007), the contexts selected in this study were weakly constraining in semantics because the cloze probability values of the best completions of the contexts were below 22% (MN: 21.9%, DN: 12%, MV: 18.7%, DV: 12.7%). The target words were plausible but unexpected completions of the contexts (the percentages of appearance were blow 3%, MN: 2.33%, MV: 0.1%, DN: 1.25%, DV: 0.44%). Even though the values of cloze probability were not well matched between different categories, the cloze probability effect was not significant if the words were embedded in the weakly constraining context (Chou et al., 2014).

2.3. Procedures

Participants were seated 80cm in front of a computer in a dim, quiet, and electromagnetically shielded room. The experiment started with a 20-trial practice session to familiarize the participants with the experimental procedures and environment. There were four blocks in the formal experiment, with two blocks containing monosyllabic words only, and the other two containing disyllabic words only. The blocks for monosyllabic words were not mixed with the blocks for disyllabic words. The presentation order of the two types of blocks (monosyllable vs. disyllable) was counterbalanced across subjects. The stimuli were equally and pseudo-randomly assigned to nouns and verbs in each block. Eighty-eight trials and three lead-in trials constituted one block. Each trial started with a fixation presented in the center of the screen for 500ms. After an inter-stimulus interval (ISI) ranging from 500 to 1000ms (the random ISI was adopted in order to reduce the slow potential elicited by anticipation, Lee & Federmeier, 2006, 2008), the context appeared followed by the target, each with a presentation time of 200ms. Jittered ISIs (ranging from 300 to 700ms) between the contexts and the target words were used to minimize the transient effect of the contexts (Woldorff, 1993). One thousand milliseconds after the offset of the targets, two types of phrases in red appeared as a whole, one of which was a semantic probe phrase and one was a message '下一组' (*xia4yi1zu3*, 'next trial'). In both cases, the phrases did not disappear until the participants gave responses. Participants were encouraged to control eye blinks and muscle movements before making responses. The interval between trials was 2500ms. A one-min break was given in the middle of each block, and a five-min rest was arranged between blocks. The whole experiment lasted for approximately one hour.

The participants were told that both the probe phrases and the message '下一组' would be presented after targets unpredictably. When they saw the message '下一组', they could press any button to initiate the next trial. When they saw the probe phrases, they should make a semantic relatedness judgment between the targets and the probe phrases. The probe phrases contained syntactic contexts and words (e.g., 一个灯泡 *yi1ge4 deng1pao4*, 'a bulb'). The syntactic contexts in the target and probe phrases were always of the same type (e.g., if a noun context preceded the targets, the context in the probe phrase would also be a noun context). The words in the probe phrases were always of the same word class and with the same number of syllables as the target words. Half of the probe phrases were semantically related to the target phrases (e.g., the target phrase 一个按钮 *yi1ge4 an4niu3*, 'a button' was paired with the probe phrase 一个开关 *yi1ge4 kai1guan1*, 'a switch') and half were not (e.g., the target phrase 一份档案 *yi1fen4 dang3an4*, 'an archive' with the probe phrase 一份心意 *yi1fen4 xin1yi4*, 'a regard'). As assessed by native speakers of Putonghua, semantic relatedness was significantly different between related and unrelated trials ($p < 0.01$)[4].

2.4 EEG recording and data analysis

The SynAmps 2 amplifier (NeuroScan, Charlotte, NC, U.S.) was used for recording. The Electroencephalographic (EEG) signals were recorded from 64 electrodes placed on the scalp at the standard locations according to the extended international 10-20 systems. The signals from these electrodes were referenced to the signals of the left mastoid online and re-referenced to the averaged signals of the left and right mastoids offline. The vertical electrooculogram (VEOG) was recorded from channels placed above and below the left eye, and the horizontal EOG (HEOG) was recorded from the electrodes attached to the outer canthi of each eye. The impedance of each electrode was kept below 5kΩ. The signals were recorded at a

[4] Twenty native speakers who did not join the EEG experiment did a norming test to determine the semantic relatedness.

band-pass of 0.15 to 400 Hz and were digitized at the sampling rate of 1000 Hz.

The data analysis was done by Curry Neuroimaging Suite 7.0.5 XSBA. The EEG signals were filtered with 0.5 –30 Hz band-pass zero-phase shift digital filter (slope 24 dB/Oct) offline and were extracted from 100ms pre-stimuli onset to 800ms post-stimuli onset. Baseline correction was performed on the activity 100ms prior to the stimuli onset. Epochs with amplitudes exceeding $\pm$120 μV at any channel were excluded from analysis. The epochs for monosyllabic and disyllabic nouns and verbs were averaged respectively. As can be seen in Figures 1 and 2, the amplitudes of N1 and P2 evoked by DVs were different from those evoked by DNs on the frontal sites, while such differences appeared not to be significant between MNs and MVs. According to the previous studies (Lee, Liu, & Tsai, 2012; Ye, Luo, Friederici, & Zhou, 2006; Zhang, Yu, & Boland, 2010), the time windows of N1 (50-120ms) and P2 (120-250ms) were determined and 10 frontal electrodes (Fz, FCz, F3/4, F1/2, FC3/4, FC1/2) were chosen for the analysis of these two components. After N1 and P2, the centrally and posteriorly located N400 was also found. The time window of N400 (250-500ms) was determined according to the previous studies (Lee & Federmeier, 2006, 2009). Fifteen central and posterior electrodes (Cz, CPz, Pz, C3/4, C1/2, CP3/4, CP1/2, P3/4, P1/2) were selected where they were reported to show maximal amplitude for N400 (Kutas & Federmeier, 2000; Holcomb & Grainger, 2006). In addition, we also observed a difference between DVs and DNs from 450 to 800ms. But such a difference seemingly disappeared between MVs and MNs. According to the previous studies (e.g., Friederici, Hahne, & Saddy, 2002) and inspection of the data, the time window (450 to 800ms) were determined, and 10 frontal electrodes (Fz, FCz, F3/4, F1/2, FC3/4, FC1/2) were chosen for the analysis of late positive component (LPC). The mean amplitudes of N1, P2, N400 and LPC were calculated for each condition and each subject. The repeated measures ANOVA and Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) were employed.

Fig.1 about here

Fig.2. about here

3. Results

3.1. Behavioral results

The accuracy was calculated for the trials that contain probe phrases. The high overall accuracy (mean= 91%, SD=3.32, ranging from 87% to 96%) indicated that the participants understood the task and were attending to the stimuli during the experiment.

3.2. Electrophysiological results

3.2.1 N1

The three-way repeated measures ANOVAs with two levels of word class (noun/verb), two levels of the number of syllables (one/two) and 10 frontal sites as within-subject factors were performed. The results showed a significant interaction effect of *word class* by *syllable numbe*r (F (1,22) = 8.788, $p < 0.01$). Post-hoc analyses showed that the N1 for DVs was significantly more negative than DNs (-0.427 μV vs. 0.07 μV, $p < 0.05$) while the difference in N1 between MVs and MNs was not significant (-0.25 μV vs. 0.14 μV, $p > 0.05$). No other effect reached significance.

3.2.2 P200

The same analysis was performed on P200. The results show neither a significant main effect of word class nor syllable number (*word class*, F (1,22) = 3.199, $p > 0.05$; *syllable number*, F (1,22) = 0.38, $p > 0.05$) nor any significant interactions between the two variables ($p > 0.05$).

3.2.3 N400

The three-way repeated measures ANOVAs with two levels of word class (noun/verb), two levels of the number of syllables (one/two) and 15 central and posterior sites as within-subject factors were performed. There was a significant main effect of *word class* (F (1,22) = 11.133, $p < 0.01$). No other effect reached significance. Verbs elicited significantly more negative N400 than nouns. This N400 effect applied to both monosyllabic words (MVs vs. MNs, -0.37 μV vs. 0.05 μV) and disyllabic words (DVs vs. DNs, -0.53 μV vs. 0.12 μV).

3.2.4. Late Positive Component (LPC)

The three-way repeated measures ANOVAs with two levels of word class (noun/verb), two levels of number of syllables (one/two) and 10 frontal sites as within-subject factors were conducted on mean amplitudes between 450-800ms. The results revealed a significant main effect of *word class* (F (1,22) = 7.829, $p < 0.05$) and a significant interaction effect of *word class* by *number of syllables* (F (1,22) =4.616, $p < 0.05$). Post-hoc comparison showed that the word class effect was evident in the disyllabic words ($p < 0.001$) but not in the monosyllabic words ($p > 0.05$), suggesting that DVs elicited less positive (more negative) LPC than DNs (0.45 μV vs. 1.32 μV) while such a difference was absent in the comparison between MVs and MNs (0.82 μV vs. 0.9 μV).

4. Discussion

In this study, we aim to investigate whether neural processing differs between nouns and verbs in Chinese, and whether the processing differences between monosyllabic nouns and verbs are the same as those between disyllabic nouns and verbs. Different from the previous study (Yang et al., 2002), the ERP results of the current study showed that, irrespective of the number of syllables, the verbs elicited more negative N400 than nouns. Moreover, DVs elicited greater N1 and less positive (more negative) LPC than DNs, whereas such a difference disappeared in the comparison between MNs and MVs. These results suggested that the nouns and the verbs are processed differently in Chinese, and the processing difference between MNs and MVs is not identical to that between DNs and DVs.

The ERP data demonstrated a significant interaction of word class by number of syllables on the frontal N1. The N1 elicited by DVs was more negative than that by DNs, while such an N1 effect was not found in the comparison between MNs and MVs. N1 reflects the allocation of attentional resources (Luck & Hillyard, 1995; Mangun & Hillgyard, 1991). The previous study showed that N1 elicited by a local syntactic violation (很/裙子, *hen3/qun2zi*, 'very skirt') was more negative than the syntactically correct phrases, indicating more attention was assigned to the local syntactic violation (Zhang et al., 2010). In this study, DVs elicited enhanced N1 than DNs because DVs do not fully match the local verb contexts with respect to syntax. Hu (1996) reported that, in modern Chinese, there is a class shift from verbs to nouns in progress, which mainly occurs in DVs. DVs are more likely to function as the heads in nominal phrases, such as 'N + de + V' (Zhan, 1998) or as subjects and objects in sentences (Zhang, 1989) in comparison to MVs. The investigation on DVs showed that, there is a proportion of 74.6 % DVs that could be used as the heads in the nominal structure 'N + de + V' (Qi et al., 2004). A majority of DVs could appear in both noun and verb contexts, and have the syntactic functions of noun and verb. It is possible that both the syntactic functions of noun and verb were activated automatically and the noun usage of DVs did not match the preceding verb context, which induced local syntactic violation and captured more attention. Unlike DVs, most DNs are syntactically unambiguous words that could fit the noun context. Hence, more negative N1 was observed for DVs as compared with DNs. For the monosyllabic words, both nouns and verbs used here are unambiguous words in both word class and meaning. They did not violate the syntactic contexts, and thus no significant difference in N1 was found between MNs and MVs.

Different from N1, monosyllabic words and disyllabic words showed a similar pattern on N400. Both MVs and DVs elicited more negative N400 than MNs and DNs respectively in the syntactically well-defined contexts. The N400 results, in agreement with the findings of Liu et al. (2007) on monosyllabic words and the findings of Liu et al. (2008, 2011) on disyllabic words, revealed that nouns and verbs in Chinese, regardless of the number of syllables, were processed differently in the brain. As mentioned in the Introduction, the question of whether neural distinction between nouns and verbs should be due to semantic differences or morpho-syntactic differences between the two word classes is still unsolved. In this study, there is no inflection for either nouns or verbs in Chinese, which implies the morphological processing is probably not involved in the processing of these two word classes. Since N400 indexes the access to lexical representation and semantic memory (Kutas & Federmeier, 2011), the neural distinction between nouns and verbs in Chinese should be attributed to their semantic differences.

Concreteness and imageability, as two semantic variables, were not well matched between nouns and verbs in this study. The N400 difference possibly arises from concreteness and imageability effect. However, the ERP data did not support this assumption. Concrete words were reported to elicit more negative N400 than abstract words (Barber, Otten, Kousta, & Vigliocco, 2013; Kounios & Holcomb, 1994; West & Holcomb, 2000). In this study, nouns were more concrete than verbs. If the difference in N400 results from the concreteness effect, nouns should have elicited more negative N400 than verbs. But the current N400 data showed the opposite pattern. Furthermore, imageability effect was reported to show on the amplitudes of N700, with more negative N700 in response to more imaginable words (West & Holcomb, 2000). The rating of imageability was higher for nouns than verbs in this study, whereas the ERP results failed to show more negative N700 for nouns than verbs. Therefore, the semantic difference between nouns and verbs does not seem to give rise to an effect related to concreteness or imageability.

In the previous studies, the contribution of concreteness/imageability to word class effect has attracted much attention (Bird et al., 2001, 2003; Lee & Federmeier, 2008; Tsai et al., 2009; Zhang et al., 2003). As nouns tend to be rated as more concrete and imageable than verbs, Bird et al. (2001) argued that the semantic differences in concreteness and imageability result in the distinction between nouns and verbs. However, other studies suggested that the word class effect should be due to the semantic difference between object and action (Barber et al., 2010; Kemmerer, 2014; Pulvermüller et al., 1999; Warrington & McCarthy, 1987). The result in the current study indicated that the N400 difference between nouns and verbs is unlikely to arise from the concreteness/imageability effect. As object nouns and action verbs were selected, the N400 effect here might be due to the semantic contrast between object and action.

In addition, a late frontal positive component was observed for DNs as compared with DVs. Nonetheless, there was no difference in this component between MNs and MVs. This LPC may be frontal P600, given its positive-going and frontal distributions. The frontal P600 was related to syntactic complexity (Friederici et al.,

2002) or discourse level complexity (Kaan & Swaab, 2003), with larger amplitudes for the syntactically complex but grammatical sentences. However, the late positive component in this study was induced by syntactic violation, in which the noun usage of DVs did not syntactically fit the verb contexts. If the LPC here relates to the processing of syntactic complexity, DVs that are syntactically more complex than DNs (recall that DVs have noun and verb usage but DNs have only noun usage) should have elicited larger LPC. But our results showed the opposite pattern, which suggested the LPC does not reflect syntactic complexity. The LPC may also be frontal positivity that was found to index word class effect, with greater frontal positivity for unambiguous verbs than for unambiguous nouns (Lee & Federmeier, 2006, 2008). If the LPC in this study relates to such a word class effect, MVs should have elicited greater LPC than MNs. This is not the case in our findings. In addition, the late frontal positivity was reported to reflect a cost associated with implausible and low cloze words in the strongly constraining contexts (Federimeier et al., 2007; Chou et al., 2014). The contexts in this study were weakly constraining in semantics, indicating the LPC was not associated with cloze probability effect either.

Visual inspection of the figures suggests, in addition to the positive-going peak around 500ms, another negative-going peak of LPC occurs around 700ms. The waveform of LPC here is similar to the late component found in Zhang et al. (2010) study, in which the late component also had a positive peak and a following negative peak on the frontal electrodes. This late component, or the so-called late negativity in Zhang et al. (2010), was more negative for the conditions with syntactic violations, and syntactically and semantically combined violations than for the correct conditions. The authors, thus, suggested that the frontal negativity might reflect the secondary semantic integration for the conditions that contained syntactic violations. In another study on Chinese sentence processing (Ye et al., 2006), the sentences containing syntactic violations and, syntactic and semantic violations elicited enhanced frontal negativity than the correct sentences and sentences containing the semantic violations, indicating the late frontal negativity is elicited in response to syntactic violation. Together, the late frontal negativity may reflect difficulty in the integration of semantic or syntactic information for interpretation.

If the LPC in the current study relates to the late frontal negativity mentioned above, the LPC effect is more likely to reflect the syntactic violation rather than semantic violation since the targets in this study fit their contexts in terms of semantics. The LPC was pronounced only in the disyllabic word condition but not in the monosyllabic word condition, which might be due to the syntactic mismatch between the noun usage of DVs and the preceding verb contexts. Thus, the DVs in the current study partly violated the verb contexts (recall that only the noun usage of DVs violated the verb contexts but the verb usage of DVs fit the contexts). However, the target words in Zhang et al. (2010) fully violated the syntactic contexts (e.g. 很/裙子, *hen3/qun2zi*, ‘very skirt’). This might be the reason why the negative peak in the LPC is reduced as compared with that in the frontal negativity in Zhang et al. (2010). In addition, the absence of posterior P600 in this study, which was elicited by syntactic violations in Zhang et al. (2010), may be due to the difference in experimental paradigm. In the Zhang et al. (2010) study, participants were instructed to judge the correctness of each sentence after each trail. Such a task possibly encouraged strategies that elicited P600-like brain responses (e.g., Gunter & Friederici, 1999). The participants in the present study were asked to give responses, 1000ms after the offset of target words, when the probe phrase appeared. The participants did not make explicit judgment when the targets appeared and thus, the posterior P600 effects were not obtained in the current study.

In the current study, both N1 effect and LPC effect were found in the disyllabic word group rather than the monosyllabic word group. The N1 and LPC effects might reflect the early detection and late integration of the syntactic mismatch between the verb contexts and noun usage of DVs, respectively. According to the three-stage processing model proposed by Friederici (2002), the local syntactic structure is built in phase 1, lexical-semantic and morphosyntactic processes take place in phase 2, and the semantic and syntactic information is integrated in phase 3. The results of N1 in this study revealed the initial processing of critical words, in which the noun usage of DVs violated the verb contexts and captured more attention. Although DVs failed to build a local structure, such a failure did not block the following semantic processing (Zhang et al., 2010; Zhang, Li, Piao, Liu, Huang, & Shu, 2013). Thus, the N400 differences between nouns and verbs were found for both monosyllabic and disyllabic words in the phase 2. In the phase 3, all the semantic and syntactic information was integrated. It is possible that the failure of syntactic phrase building caused by DVs required a secondary integration for final interpretation. But the syntactic ambiguity of DVs was not resolved in the preceding phases and led to integration difficulty, which elicited less positive (more negative) LPC than DNs. Future studies will add conditions in which the targets fully violate the syntactic contexts, such as nouns primed by verb context, to investigate the function of LPC.

No matter how to interpret the results of LPC, the LPC effect, as well as N1 effect, refected the processing differences between DNs and DVs when the target words were embedded in contexts. But if they were presented in isolation, it is probably that the word class effect will be reduced because DVs have both noun and verb syntactic functions. Such syntactic ambiguity may give rise to one discrepancy between fMRI studies and ERP studies in Chinese. Most ERP studies in Chinese found neural distinctions between nouns and verbs, which were mainly manifested in N400. However, some fMRI studies found certain brain regions specific to the activation of verbs (Yu et al., 2011, 2012) while some other studies did not find any dissociative neural correlates of either noun or verb processing (Chan et al., 2008; Li et al., 2004; Yang et al., 2011). The null word class effect in these studies may emerge as a consequence of reduced or limited differeces between DNs and DVs when they were presented in isolation. Other factors, such as experimental task and low temporal resolution of fMRI, may also lead to the null word class effect.

The brain responses to noun/verb ambiguous words were also investigated in the previous studies on English. Federmeier et al. (2000) compared the brain responses to English ambiguous words with unambiguous words in the sentence contexts. Lee and Federmeier (2006, 2008) further divided the ambiguous words into two types, homonymy (e.g., duck) and polysemy (e.g., hint), and explored the processing of homonymy, polysemy and unambiguous nouns and verbs in the syntactic biasing phrases. The results showed that N/V homonymy elicited greater frontal negativity than unambiguous words, but N/V polysemy showed smaller frontal negativity than unambiguous words. Although the paradigm used in this study largely follows the paradigm in Lee and Federmeier (2006, 2008), the stimuli and contexts in the current study differ from those in the previous studies on English. For the stimuli, the ambiguous words in English studies consisted of homonymous and polysemous words. DVs in this study, on the one hand, are not homonymous words. Homonymous words are the words that share the identical word form but have distinct and unrelated meanings (Lyons, 1995). Different from homonymy, the meanings of DVs and their nominalization are highly related. Zhu (1983) proposed two approaches of verb nominalization in modern Chinese, self-designation and transferred-designation. If one verb is nominalized through self-designation, its nominalization will refer to an event that the verb predicate (e.g., 爆炸 *bao4zha4*, ‘to explode, explosion’). The meaning of a verb and its nominalization is almost identical. While if one verb is nominalized by transferred-designation, its nominalization will refer to one of the constituents (e.g., patients, receipts, tools, etc.) associated with a verb meaning (e.g., 翻译 *fan1yi4*, 'to translate, translator'). In this study, all the DVs could be nominalized only by self-designation (see Appendix), which leads their nominalizations to activities or events. On the other hand, the DVs are not the same type as N/V polysemy used in the previous studies on English. After checking the wordlists in Lee and Federmeier (2006, 2008) study, we found at least three subtypes of N/V polysemous words, the nominalizations of verbs that only refer to events and activities (e.g., fight, dance), the nominalizations of verbs that could refer to constituents associated with their meanings (e.g., drink, guess), and the denominal verbs that predicate states, events or processes in which the parent nouns denote their roles (Clark & Clark, 1979) (e.g., bag, hammer). These three subtypes were grouped together in Lee and Federmeier (2006, 2008). The DVs might belong to the first subtype but differ from the other two subtypes. Thus, DVs used here are not the same type of ambiguous words as those used in the previous studies.

For the contexts, the verb context here is not the same type as that in the previous studies. In Lee and Federmeier (2006, 2008), the verb-predicting cue 'to' is not effective in constraining the word class of upcoming words, after which both nouns and verbs could legally appear in English. Whereas the verb context 'not + auxiliary' in Chinese is syntactically well-defined, which is obligatory for verbs rather than other word classes. Thus, the syntactic constraint of 'to' is dissimilar to that of 'not + auxiliary'. Different from the verb contexts in Lee and Federmeier (2006, 2008), the verb context used in Federmeier et al. (2000) is syntactically well-defined. The verbs were embedded in the sentence contexts (e.g., 'John wanted to [verb] but …'), which is obligatory for verbs in English. Empirical evidence showed that the semantic features of the verb arguments are activated in the verb representation (Boland, 1993; Li, Shu, Liu, & Li, 2004; Trueswell, Tanenhaus, & Kello, 1993). Since the agents appeared before the onset of verbs (e.g., in 'John wanted to [verb] but …', 'John' is the agent of the verb), the semantic feature of an agent does not necessarily need to be represented in the processing of a verb, which may reduce the degree of semantic activation. However, the verb context 'not + auxiliary' does not provide any information about agents or other thematic roles of verbs. So the degree of semantic activation of critical verbs probably varies between Federmeier et al. (2000) and this study. Altogether, as the stimuli and verb contexts employed are not identical, the ERP results of this study and the studies on English ambiguous words are inconsistent.

In the current study, we did not match script and sub-lexical level variables between different categories. The previous studies showed that the semantic radicals play a role in the word class recognition of its host character. If a character involves a semantic radical that refers to a material, it is likely to be predicted as a noun; if a character has a semantic radical that relates to an organ or a tool, the character will be predicted as a verb (Li & Chen, 2012; Zhang, Fang, & Chen, 2006). Such semantic information in the radicals was not matched for monosyllabic words. A survey on Chinese character showed the semantic radicals "扌", "刂" were useful for predicting verbs and the semantic radicals "钅", "木" were useful for predicting nouns (Zhang et al., 2006). As MVs more frequently entail these semantic radicals than MNs in this study (see Appendix), the MVs should be easier to be integrated with the syntactic context than MNs, which implies a less negative N400 for MVs. But the N400 data provided an opposite pattern, indicating the script-level feature may not have a strong impact on the word class effect in monosyllabic words.

Furthermore, the impact of radical on the word class identification is likely to vary between monosyllabic and disyllabic words. Dissimilar to monosyllabic words, the processing of two-character words might undergo decomposition and assembly processes (Tan & Perfetti, 1999; Zhou, Marslen-Wilson, Taft, & Shu, 1999). Hsu, Tzeng, and Hung (2004) found that the noun-noun combinations of nouns and verb-verb combinations of verbs were processed faster and more accurately than other types of combinations, suggesting the word class of constituent characters influences the word class recognition of compounds. This factor was generally controlled for the disyllabic words, in which most DNs are noun-noun combinations and most DVs are verb-verb combinations. However, we could not estimate the influence of semantic radicals on the word class recognition of disyllabic words because the word class predictability of most radicals in the DNs and DVs were not reported in the previous survey. We believe, similar to the case of monosyllabic words, the script-level information may not have much effect on the processing of nouns and verbs. A cross-language study indicated that, in comparison to English readers, Chinese readers rely more on context and less on information carried by individual characters or words (Chen, 1992). Chinese reader could immediately take advantage of contexts to predict the syntactic roles of the following words (Ye et al., 2006; Zhang et al., 2010; also in this study). When and how the context interacts with the script and sub-lexical level factors in the word class recognition of Chinese is an interesting question which merits further studies.

5. Conclusions

Chinese is a language with a simple morphological system. Unlike European languages, Chinese nouns and verbs could not be distinguished via word forms. Thus, the inflectional processing could be avoided in the comparison between nouns and verbs. In this study, we found that, regardless of the number of syllables, the N400 was more negative for verbs than for nouns, which may result from the difference between object and action. Furthermore, the discrepancy in the N1 and LPC between monosyllabic and disyllabic words revealed a syntactic mismatch between the verb context and noun usage of DVs. The results indicated that DVs are verb-noun ambiguous in terms of syntactic roles, which may lead to the confounding between word class effects with ambiguity effects. This study reveals the word class effect in Chinese is due to the semantic differences between nouns and verbs, and it also points to the importance of distinguishing monosyllabic words from disyllabic words in studies on nouns and verbs in Chinese.

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Appendix. Experimental Stimuli

Monosyllabic noun			Monosyllabic verb			Disyllabic noun			Disyllabic verb		
Word	Pinyin	Meaning	Word	Pinyin	Meaning	Word	Pinyin	Meaning	Word	Pinyin	Meaning
匾	*bian3*	plaque	搬	*ban1*	move	按钮	*an4jiu3*	button	打听	*da3ting1*	pry into
柴	*chai2*	firewood	拌	*ban4*	mix	乘客	*cheng2ke4*	passenger	包围	*bao1wei2*	surround
葱	*cong1*	scallion	捕	*bu3*	seize	地图	*di4tu2*	map	奔跑	*ben1pao3*	run
醋	*cu4*	vinegar	插	*cha1*	insert	夫妇	*fu1fu4*	couple	编织	*bian1zhi1*	weave
岛	*dao3*	island	炒	*chao3*	fry	胳膊	*ge1bo*	arm	查看	*cha2kan4*	check
肺	*fei4*	lung	搓	*cuo1*	rub	海洋	*hai3yang2*	ocean	打开	*da3kai1*	open
肝	*gan1*	liver	救	*jiu4*	rescue	号码	*hao4ma3*	number	打扫	*da3sao3*	clean
缸	*gang1*	vat	聚	*jü4*	gather	核桃	*he2tao*	walnut	抚摸	*fu3mo1*	touch
鹤	*he4*	crane	拦	*lan2*	block	画家	*hua1jia1*	painter	购买	*gou4mai3*	purchase
湖	*hu2*	lake	拎	*lin1*	carry	空间	*kong1jian1*	space	搅拌	*jiao3ban4*	mix
剑	*jian4*	sword	扭	*niu3*	twist	喇叭	*la3ba*	trumpet	聚集	*ju4ji2*	gather
街	*jie1*	street	挪	*nuo2*	move	日程	*ri4cheng2*	schedule	庆祝	*qing4zhu4*	celebrate
鹿	*lu4*	deer	陪	*pei2*	accompany	士兵	*shi4bing1*	soldier	跳跃	*tiao4yue4*	jump
瓢	*piao2*	ladle	娶	*qü3*	marry	水库	*shui3ku4*	reservoir	宣布	*xuan1bu4*	announce
铁	*tie3*	iron	晒	*shai4*	dry	体质	*ti3zhi4*	physique	询问	*xun2wen4*	inquire
铜	*tong2*	copper	拴	*shuan1*	tie	线路	*xian4lu4*	line	迎接	*ying2jie1*	welcome
筒	*tong3*	barrel	撕	*si1*	tear	形象	*xing2xiang4*	image	赠送	*zeng4song4*	present
胃	*wei4*	stomach	添	*tian1*	add	学员	*xue2yuan2*	trainee	张望	*zhang1wang4*	look around
鸭	*ya1*	dunk	挖	*wa1*	dip	钥匙	*yao4shi*	key	召集	*zhao1ji2*	convene
鹰	*ying1*	eagle	眨	*zha3*	blink	药物	*yao4wu4*	medicine	招收	*zhao1shou1*	recruit
枣	*zao3*	jujube	织	*zhi1*	weave	珍珠	*zhen1zhu1*	pearl	撞击	*zhuang4ji1*	strike
粥	*zhou1*	gruel	煮	*zhu3*	cook	祖先	*zu3xian1*	ancestor	走路	*zou3lu4*	walk

Note. The Pinyin is to illustrate the pronunciation of the words. The number in Pinyin denotes the tone of the syllable.

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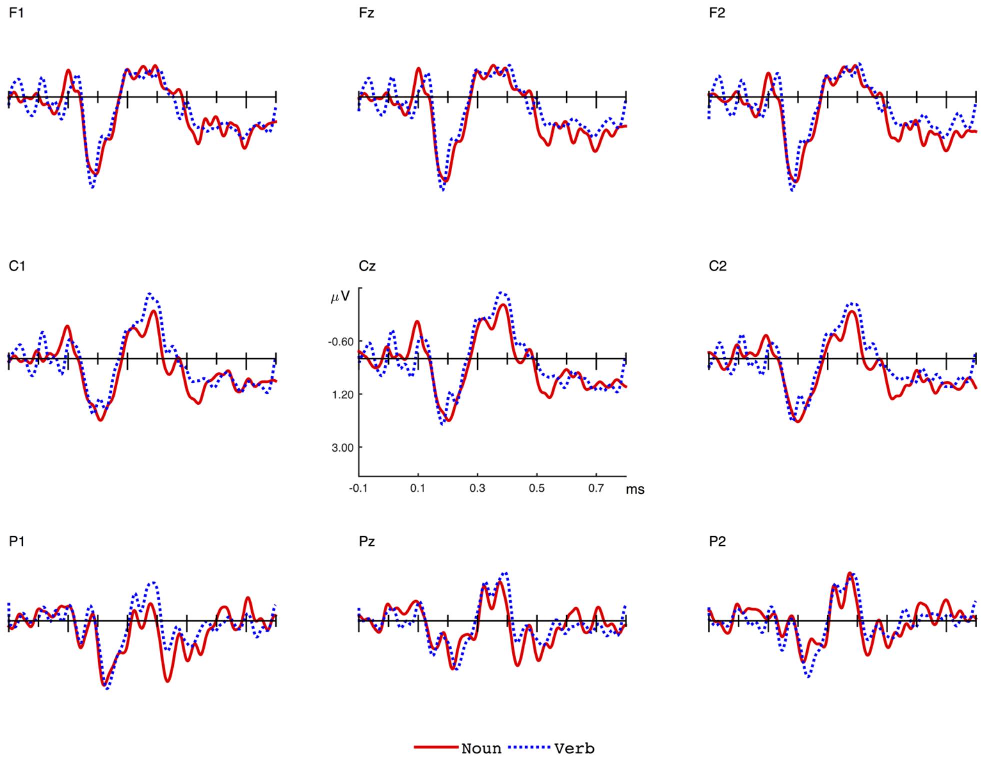

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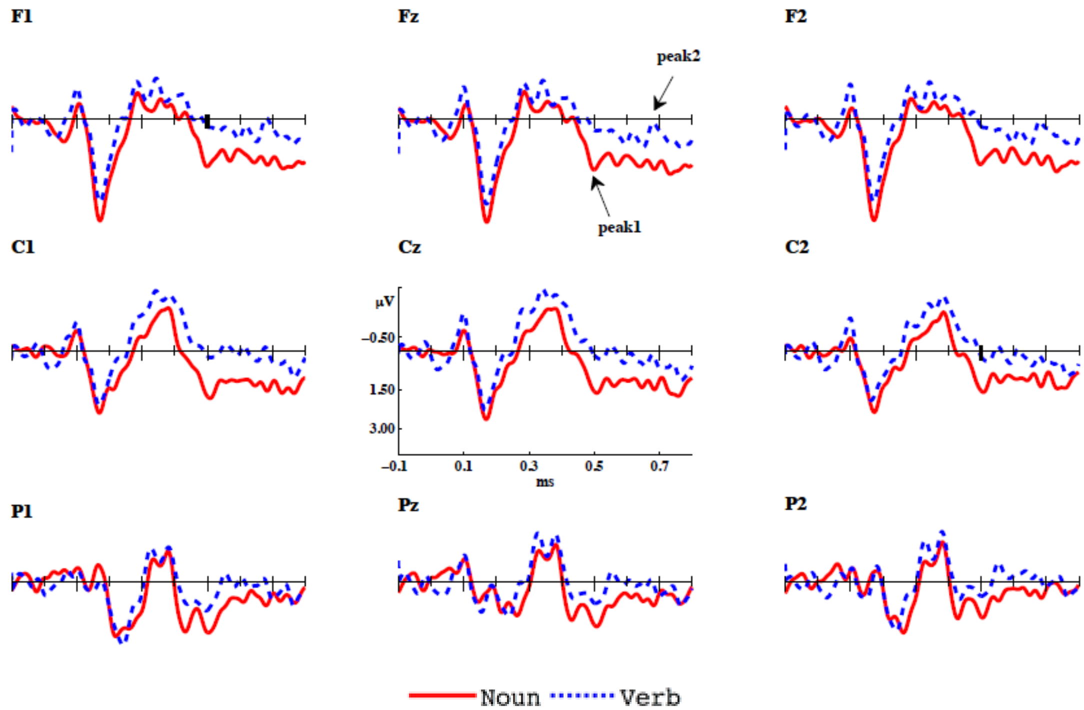

Figure 2. Grand average ERPs from 23 subjects in the time window of 100 ms pre-target onset and 800 ms post-target onset for disyllabic nouns and verbs at frontal, central and posterior sites.