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The roles of object and action, and concreteness and imageability, in the distinction between nouns and verbs: An ERP study on monosyllabic words in Chinese

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

[a] College of Chinese Language and Culture, Nankai University, Tianjin, China
[b] Research Centre for Language, Cognition, and Neuroscience, Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University, Hong Kong SAR, China
[c] Shenzhen Institutes of Advanced Technology, Chinese Academy of Science, Shenzhen, 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
Research Centre for Language, Cognition, and Neuroscience, Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University, Hong Kong
Phone: +852 3400 8462
Fax: +852 2334 0185
E-mail: *gpengjack@gmail.com*

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ABSTRACT

The dissociation between nouns and verbs has been reported in behavioral, electrophysiological, and neuroimaging studies. It is still unclear whether the spatial and temporal differences between nouns and verbs arise from semantic differences or morpho-syntactic differences associated with the two word classes. Regarding the semantic accounts, it is also unknown whether the word class effect should be attributed to differences in object and action, or in concreteness and imageability, associated with nouns and verbs. As the question with respect to semantic accounts for the word class effect is unsettled, the two types of semantic attributes have not been well distinguished in previous studies that support morpho-syntactic accounts, and this may lead to a confounding effect between morpho-syntactic factors and semantic factors. Therefore, to better understand the origins of the noun-verb distinction, it is essential to figure out whether the word class effect is driven by the contrast between object and action or by concreteness and imageability. With tight matching of stimuli and the use of event-related potentials (ERPs), we investigated the neural processing of monosyllabic nouns and verbs in Chinese that were presented without context. The results showed that when concreteness and imageability were balanced, nouns elicited more negative N400 than verbs over a broad scalp region, suggesting distinct semantic processing between the two word classes. Furthermore, nouns elicited more late negativity than verbs at frontal sites, which may reflect differences in the semantic representation of nouns and verbs in the working memory or differences in the working memory load associated with the word classes. These ERP results showed that the distinction between nouns and verbs persists even after concreteness and imageability are matched, revealing that the semantic account for the word class effect might arise from the contrast of object and action rather than the concreteness and imageability effect. The findings of the current study draw attention to the importance of object and action distinction in studies on nouns and verbs.

Keywords: Word class effect, Object vs. action, Concreteness & imageability, Chinese, Monosyllabic words, N400

1. Introduction

A central issue in the cognitive neuroscience of language is how word categories are represented and processed in the human brain. Nouns and verbs are fundamental word classes in all known languages (Langacker, 1987; Robins, 1952). The distinction between the two word classes is manifested at the syntactic, semantic, morphological, and pragmatic levels (for a review of the literature, see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). Such differences between nouns and verbs have also been demonstrated in empirical studies. Research on aphasics has found that patients with injuries to the left temporal lobe experience difficulty processing nouns, while patients with lesions in the left frontal lobe have difficulty processing verbs (e.g., Bates, Chen, Tzeng, Li, & Opie, 1991; Caramazza & Hillis, 1991; Damasio & Tranel, 1993; but see Silveri, Perri, & Cappa, 2003; Aggujaro, Crepaldi, Pistarini, Taricco, & Luzzati, 2006; for a review, see Mätzig, Druks, Masterson, & Vigliocco, 2009). The spatial dissociation between nouns and verbs has also been identified in healthy people using brain imaging techniques. These neuroimaging studies indicated that nouns tend to elicit stronger activations in the temporal regions than verbs (e.g., Shapiro et al., 2005; Tyler, Randall, & Stamatakis, 2008), while verbs are likely to generate greater activations than nouns in the left frontal regions (e.g., Palti, Ben-Shachar, Hendler, & Hadar, 2007; Perani et al., 1999; Shapiro et al., 2005; but see Momenian, Nilipour, Samar, Oghabian, & Cappa, 2016; Tyler, Russell, Fadili, & Moss, 2001; for a review, see Crepaldi et al., 2011). In addition to the noun-verb distinction in the spatial domain, temporal differences between the processing of the two word classes have been found in several event-related potential (ERP) studies. The word class effect was consistently reflected on the N400, with more negative N400 for nouns than verbs in some studies (e.g., Federmeier, Segal, Lombrozo, & Kutas, 2000; Kellenbach, Wijers, Hovius, Mulder, & Mulder, 2002; Lee & Federmeier, 2006, 2008; Xia, Lü, Bai, & Shi, 2013; Zhang, Ding, Guo, & Wang, 2003) while a reversed N400 pattern in other studies (Khader, Scherag, Streb, & Rösler, 2003; Liu et al., 2007; 2008; Xia, Wang, & Peng, 2016). Although the observed N400 results were not consistent, possibly due to differences in experimental design and materials (see Xia et al., 2016 for a discussion), the above ERP studies indicate that nouns and verbs are processed differently on-line.

Table 1. An overview of accounts for noun-verb distinction and related studies that present stimuli without context

Accounts for noun-verb distinction		**Methods**	**Papers**
semantic account	object and action	neuropsychological studies on patients	**English:** McCarthy and Warrington (1985) **Chinese:** Bates et al. (1991); Chen and Bates (1998); Bi, Han, Shu, and Caramazza (2007)
		ERP studies	**German:** Pulvermüller, Lutzenberger, and Preissl (1999); Pulvermüller, Mohr, and Schleichert (1999) **Chinese:** Zhang et al. (2003); Zhao, Dang, and Zhang (2017)
		fMRI studies	**English:** Moseley and Pulvermüller (2014) **Chinese:** Yang et al. (2017); Zhang et al. (2018)
	concreteness and imageability	neuropsychological studies on patients	**English:** Bird, Howard and Franklin (2000, 2003)
		ERP study	**Chinese:** Tsai et al. (2009)
morpho-syntactic account		fMRI studies	**English:** Bedny, Caramazza, Pascual-Leone, and Saxe (2008); Longe, Randall, Stamatakis, and Tyler (2007)

Recent efforts have therefore been focusing on the underlying determinant of the spatial and temporal distinctions between nouns and verbs. A central question is whether noun-verb distinction in the spatial and temporal domains emerges as a consequence of semantic differences or morpho-syntactic differences associated with the two grammatical classes (see Vigliocco et al., 2011 for a discussion). Table 1 provides a brief summary of semantic and morpho-syntactic accounts and related studies. As the processing differences between nouns and verbs are greatly influenced by context, and consequently make it difficult to detangle the word class effect and contextual effects (will be discussed later in Introduction), only the studies that presented nouns and verbs without context are listed here[1]. The semantic account of noun-verb distinction is mainly based on the findings in linguistic typology. Croft (2001) argued that the combinatorial criteria, which are syntactic distribution and morphological properties, for defining grammatical categories vary across languages, and therefore should not be taken as valid criteria for cross-linguistic distinction of word categories. He suggested that, on the contrary, the identical semantic/pragmatic features indicating grammatical class distinction are shared in most languages, such that prototypical nouns refer to object and prototypical verbs predicate action and event. Thus, the semantic/pragmatic properties are assumed to be a universal principle for determining prototypical grammatical class (Kemmerer & Eggleston, 2010; Kemmerer, 2014). According to this view, it is possible that nouns and verbs across languages, in particular the prototypical ones, are governed by a shared and specific locus in the brain that depends on semantic properties associated with the two grammatical classes.

[1] The lexical account is not included here since it assumes that the grammatical class information is only activated when the word is processed in a sentence, and not when it is used as a single word (Levelt, Roelofs, & Meyers, 1999).

Therefore, the distinction between nouns and verbs have been investigated in consideration of the semantic dimension. Among these studies, most explored whether noun-verb distinction arises from semantic differences between object and action, since object and action are typical semantic features of nouns and verbs respectively. The results obtained in neuropsychological, electrophysiological, and neuroimaging studies showed that object nouns and action verbs were processed differently, indicating the noun-verb distinction originates from the semantic difference between object and action (see Table 1). Different from the object and action account, some other studies suggested that imageability discrepancies between nouns and verbs are the source of noun-verb distinction. Imageability, which reflects the ease with which a word arouses a mental image (Paivio, Yuille, & Madigan, 1968), was found to be rated higher for nouns than verbs in the norming procedure (Bird et al., 2000). Once such imageability difference was controlled for, the poorer naming performance for verbs than nouns disappeared in patients with verb deficits, suggesting that the noun-verb distinction is driven by imageability (Bird et al., 2000, 2003). Since imageability is highly correlated with concreteness, a factor referring to the word feature that can be experienced by the senses (Paivio et al., 1968), the noun-verb distinction was also considered to stem from the concreteness effect. Tsai et al. (2009) manipulated concreteness and word class of disyllabic words in Chinese, but failed to find main effect of word class. The results of Bird et al. (2000, 2003) and Tsai et al. (2009) support the idea that noun-verb distinction is due to concreteness and imageability difference associated with the two word classes. Altogether, the above findings reveal that the neural distinction between nouns and verbs in terms of their spatiality and temporality should be attributed to their semantic differences. But current research has not yet been able to determine what type of semantic attribute (object and action or concreteness and imageability) induces the processing differences between nouns and verbs.

Apart from semantic accounts, as shown in Table 1, it has also been suggested that morpho-syntactic differences between nouns and verbs give rise to the word class effect. Nouns and verbs play different roles in a sentence, with verbs determining the argument structure and nouns serving as arguments (e.g., the agent or the patient; Goldberg, 2003). In languages with rich morphology, the differences between nouns and verbs are also shown via inflectional morphology (e.g., inflection of nouns for number, gender, etc. vs. inflection of verbs for tense, aspect, etc.). For these reasons, the crucial difference between nouns and verbs is determined by their respective syntactic and morphological properties, and consequently the noun-verb distinction is realized in the combinatorial and integrative processes that apply to words (Baker, 2003; McCawley,1998). Following this combinatorial view, some studies have explored whether morpho-syntactic properties lead to the distinction between nouns and verbs. Bedny et al. (2008) investigated brain activations of nouns and verbs that vary in semantic features (e.g., visually perceived motion features). The results showed that regardless of semantic properties, verbs activated more strongly than nouns in the left middle temporal and superior cortices, which was considered to be induced by grammatical properties, such as morphological complexity. Instead of manipulating semantic features, Longe et al. (2007) controlled for imageability and compared the brain activation by bare noun and verbs, and inflected nouns and verbs. The results showed greater blood-oxygen-level-dependent (BOLD) responses in the left inferior frontal regions for inflected verbs than for inflected nouns but no difference in the comparison between noun and verb stems, which suggests that the word class effect is due to morpho-syntactic differences.

However, in the studies that support syntactic accounts for the word class effect, object and action, and concreteness and imageability were either neglected (Bedny et al., 2008) or not carefully differentiated (Longe et al., 2007), aspects of these studies which may have confounded the word class effect with semantic factors. Bedny et al. (2008) found that regardless of visual motion properties, verbs consistently elicited greater BOLD responses than nouns in the middle temporal and superior temporal cortices. In particular, mental verbs (verbs associated with mental activities, e.g., to think) activated more strongly than animal nouns in the temporal cortices despite their lower visual and motor ratings. The authors thus attributed the spatial dissociation between nouns and verbs to lexical grammatical properties rather than semantic meaning. Nevertheless, the neglect of semantic contrast (e.g., object and action) in stimuli selection may lead to a confounding of the word class effect with semantic factors. As Moseley and Pulvermüller (2014) pointed out, animal nouns and action verbs, which were classified as the high visual-motion words in Bendy et al. (2008), were not equivalent in terms of action-relatedness because animal nouns did not activate action-related brain regions (Moseley, Carota, Hauk, Mohr, & Pulvermüller, 2012). Similarly, the semantic object-relatedness may not have been controlled for in the high visual-motion words as well, since animal nouns are likely to have more object properties, such as shape and color, than action verbs. Furthermore, another type of semantic attribute, namely concreteness, appears not to have been taken into consideration in Bedny et al. (2008), at least not to the extent that concreteness was accounted for in relation to mental verbs and action nouns used in the study, with mental verbs being more abstract. Previous studies showed that brain responses to abstract words are larger than they are to concrete words in the left middle temporal cortex (Sabsevitz, Medler, Seidenberg, & Binder, 2005; Pexman, Hargreaves, Edwards, Henry, & Goodyear, 2007; for a review, see Wang, Conder, Blitzer, & Shinkareva, 2010, a meta-analysis) and left superior temporal cortex (Sabsevitz et al., 2005; Binder, Desai, Graves, & Conant, 2009; Wang et al., 2010). These temporal cortices for abstract word processing substantially overlap with the aforementioned temporal cortices for noun-verb dissociation in the left hemisphere. As the concreteness of stimuli was not provided in Bedny et al. (2008), one may argue that the observed neural differentiation between nouns and verbs is possibly induced by concreteness difference between the two word classes. Adopting another approach to tease apart semantic and morpho-syntactic properties, Longe et al. (2007) controlled for imageability and found no cortical region that was significantly activated by either nouns or verbs in bare form, which was taken as evidence for the morpho-syntactic account for noun-verb distinction. However, close examination of the stimuli used in Longe et al. (2007) shows that more than half of the nouns involved little object-related information, and about one quarter of the verbs entailed little action-related information. As previous studies have documented an object and action explanation for the noun-verb distinction, the null word class effect in bare nouns and verbs is possibly due to a lack of clear differences between object and action associated with the two word classes. Taken together, since object and action, and concreteness and imageability were either ignored or not properly distinguished, the observed spatial dissociation between nouns and verbs may have been confounded by semantic factors. If so, the word class effect may not conclusively be attributed to morpho-syntactic differences between the two word classes. It is important to keep in mind, however, that the question of whether object and action, or concreteness and imageability are the semantic origin of the noun-verb distinction is underdetermined. Therefore, for both semantic and morpho-syntactic approaches to the word class effect, it is essential to determine whether the noun-verb distinction is due to the contrast of object and action or to concreteness and imageability differences.

Furthermore, as the above studies examined the noun-verb distinction in languages with a rich morphology, the inflectional processing may also impact the observed findings. The processing of inflectional affixes, which is argued to be an essential part of the word class effect in languages that are rich in morphology (Shapiro, Shelton, & Caramazza, 2000; Shapiro & Caramazza, 2003), was reported to load neuronal circuit linking with inflectional operation (Longe et al., 2007; Tyler, Bright, Fletcher, & Stamatakis 2004). To avoid this possible confounding factor, a potential alternative is to examine the word class effect in a language with little morphological inflection, such as Chinese. Chinese is a language with a comparatively simple morphological system, with virtually no noun declension or verb conjugation (Wang, 1973). The inflectional processing can presumably be avoided in the comparison between nouns and verbs in Chinese. Previous studies on Chinese indicated that the neural distinction between nouns and verbs might be driven by their semantic differences (see Table 1), although some other studies failed to find spatial dissociation between the two word classes (Chan et al., 2008; Li, Jin, & Tan, 2004; Yang, Tan, & Li, 2011). Among the studies that support semantic accounts of the word class effect, some revealed that it is object and action that lead to the distinction between nouns and verbs, whereas others suggested that the word class effect results from the concreteness effect (see Table 1). Thus, the question as to what type of semantic attributes account for the word class effect in Chinese is still unsolved.

Xia et al. (2016) seem to have solved this question. In their studies, monosyllabic and disyllabic nouns and verbs in Chinese were embedded in the syntactic contexts. Results showed that, irrespective of number of syllables, verbs elicited more negative N400 than nouns, which was attributed to the semantic differences between object and action rather than concreteness and imageability. However, as the two word categories were embedded in the contexts, such an N400 effect was unlikely to be induced only by semantic properties of nouns and verbs. According to experimental design, previous ERP studies on word class effect in Chinese may be classified into two main groups: studies with stimuli presented with and without context. The first group showed that, when primed by context, verbs elicited more negative N400 than nouns (Liu et al., 2007, 2008; Feng, Gong, Shuai, & Wu, 2019). On the contrary, a reversed N400 pattern was observed in the second group. When presented in isolation, nouns activated more negative N400 than verbs (Tsai et al., 2009; Zhang et al., 2003; Zhao et al., 2017). Since two inconsistent N400 patterns were shown in the comparisons between two groups of studies, we assumed that the N400 effect found in Xia et al. (2016) was not driven only by the semantic properties of nouns and verbs, but might also reflect the integration of context with the two word categories. To test this assumption in this study, we plan to present nouns and verbs in Chinese out of context.

Furthermore, to preclude the possible confounding of internal structure and syntactic ambiguity, monosyllabic nouns and verbs were selected as stimuli. In the second group of studies, the word class effect was mainly examined in disyllabic nouns and verbs in Chinese (Tsai et al., 2009; Zhang et al., 2003; Zhao et al., 2017). However, previous studies on Chinese compound showed that internal structure (or morphological structure, relation information), referring to the ways in which constituents form a compound (e.g., 雪人, *xue3ren2*, “snowman”, a subordinate compound), is processed in the semantic composition (Ji & Gagné, 2007; Liu &

McBride-Chang, 2010) and hence modulates the amplitude of N400 (Jia, Wang, Zhang, & Zhang, 2013). With one-syllable words, internal structure processing is not required in the lexical process, and its interference can be avoided. Similarly, the confounding effect of syntactic ambiguity can also be avoided as long as monosyllabic words are employed. In modern Chinese, there are two main types of verbs: monosyllabic and disyllabic. In both linguistic studies (Hu, 1996; Zhan, 1998; Zhang, 1989) and ERP studies (Xia et al., 2016), disyllabic verbs have been demonstrated to be syntactically ambiguous words because they have the syntactic functions of both nouns and verbs, but the meanings of the verbs and their nominalizations are almost identical (e.g., 爆炸, *bao4zha4*, "to explode" or "explosion"). Unlike disyllabic verbs, most monosyllabic verbs do not function as nouns and are regarded as the prototypical verbs in Chinese (Chen, 1987). In the current study, the use of monosyllabic verbs allowed us to bypass the confounding effect of syntactic ambiguity.

Therefore, in this study we aim to investigate the neural processing of monosyllabic nouns and verbs in Chinese and to determine whether the word class effect is due to semantic differences between object and action or to semantic differences in concreteness and imageability. The current study contributes to the understanding of noun-verb distinction in the following ways. First, an important question whether neural differences between nouns and verbs arise from semantic differences or morpho-syntactic differences associated with the two word classes has not yet been answered. Regarding the semantic accounts, the roles of object and action, and concreteness and imageability in the word class effect were unclear. As this question is unsettled, the two types of semantic attributes were not well distinguished in the studies that support morpho-syntactic accounts, and this may lead to a confounding effect between morpho-syntactic factors and semantic factors. Therefore, to better understand the origins of the noun-verb distinction, it is essential to figure out whether the word class effect is driven by the contrast between object and action or by concreteness and imageability. Thus, we tried to control for concreteness and imageability while keeping object and action contrast for nouns and verbs, and then we compared the ERPs in response to their activation. Second, nouns and verbs in Chinese are indistinguishable via inflectional morphology. Any possible inflectional processing is thus minimized in the investigation of noun-verb distinction. Third, nouns and verbs were presented without context so as to preclude any contextual influence on the result. Fourth, monosyllabic nouns and verbs were employed to avoid the interference of internal structure and syntactic ambiguity. Fifth, several lexical-semantic variables, such as valence, age of acquisition (AoA), and neighborhood size, were balanced between nouns and verbs.

2. Methods

2.1 Participants

Twenty-four native speakers of Mandarin were paid to participate in the experiment (12 males, 12 females; mean age = 24.0 years, SD = 3.7). All the participants were from mainland China and were undergraduate and graduate students of The Chinese University of Hong Kong. They could also speak English but should be classified as late Chinese-English bilinguals as they began to learn English between the ages of 10 and 12. Since the representation of Chinese nouns and verbs in late Chinese-English bilinguals is consistent with that in monolingual speakers of Chinese (Yang et al., 2011), their English abilities should have limited effect on the results. Moreover, only a few of the participants could speak limited Cantonese and thus their Cantonese abilities was not likely to influence the results. All of the participants were right-handed, with normal or corrected vision and no reported history of neurological illness. The data from three participants (two males, one female) were excluded from the analysis because excessive artifact caused a low acceptance rate of the EEG data (less than 14 trials in at least one condition). None of the participants were majoring in linguistics, psychology, or any other related disciplines. The experiment was approved by the Survey and Behavioral Research Ethics Committee of The Chinese University of Hong Kong.

2.2 Stimuli and experimental design

Twenty-four monosyllabic nouns and 24 monosyllabic verbs were employed, all of which were semantically and syntactically unambiguous (see the Appendix A and B). To ensure the noun and verb stimuli are distinguishable in terms of word class, the norming procedure of word class was conducted by native speakers of Chinese who were instructed to judge whether the words were used as nouns or verbs according to their daily usage. The results of word class norming showed that the nouns were significantly different from the verbs ($ps < 0.001$). With respect to semantics, two norming procedures concerning object nouns and action verbs were conducted. Nouns were chosen according to their shape relatedness because shape has been reported to carry greater weight than other modality-specific features in recognizing objects (Gainotti et al., 2009, 2013; Hoffman & Lambon Ralph, 2013). Likewise, verbs that are strongly relevant to action were selected. In order to match concreteness and imageability, five nouns selected did not link to an object to a large degree (lower than the average rating values of object-relatedness). Even so, the rating values of object relatedness were significantly higher for the nouns than for the verbs (*ps* < 0.001), and the verbs were rated significantly higher than the nouns in the comparison of action relatedness (*ps* < 0.001). This means that the nouns and verbs selected differ in terms of object and action contrast. In addition, concreteness and imageability, as well as other lexical-semantic variables, such as word frequency, number of strokes, valence, AoA, familiarity, and neighborhood size, were matched between the nouns and verbs (*ps* > 0.05; see Table 2).

The experimental design of the present study largely followed that of Tsai et al. (2009). The word pairs comprised two words of the same word class. The target stimuli were the first words of these pairs. Such arrangement was intended to elicit a semantic processing of the target words while at the same time minimizing the contextual influence. For the target words, there were 48 word pairs in the experiment, half of which were semantically related and half semantically unrelated. The degree of semantic relatedness of each word pair was determined by a norming procedure. Twenty native speakers of Mandarin who did not take part in the EEG experiment were asked to rate the degree of semantic relatedness between the first and second words on a 7-point scale (ranging from 1 = *closely related* to 7 = *not related*). The ratings for the semantically related pairs (mean = 1.67, SD = 0.36) were significantly different from the ratings for the semantically unrelated pairs (mean = 6.19, SD = 0.64, *p* < 0.01). Another 54 word pairs (including six warm-up trails), half of which were semantically related, were included as fillers. From the total of 106 word pairs, 96 consisted of two monosyllabic words with different semantic radicals so as to prevent the participants from using semantic radicals to do tasks (see Appendix C for detailed information on word pairs of stimuli and fillers). All the stimuli were presented in a white Songti 20-point font against a black background. The characters of the stimuli were in simplified Chinese.

Table 2. Examples of the stimuli and lexical-semantic variables for each condition

Condition	Word Class	Object relatedness	Action relatedness	Log frequency	No. of Stroke	Concreteness
Noun	2.08 (0.47)	4.83 (1.56)	2.3 (0.47)	1.11 (0.37)	10.42 (1.82)	5.93 (0.81)
Verb	9.83 (0.61)	3.2 (0.44)	5.6 (0.38)	1.24 (0.39)	10.88 (2.33)	5.83 (0.25)

Condition	Imageability	Valence	AoA	Familiarity	Neighborhood Size
Noun	6.03 (0.77)	3.14 (0.41)	4.42 (0.64)	6.22 (0.50)	6.71 (5.1)
Verb	6.05 (0.35)	2.9 (0.39)	4.24 (0.44)	6.38 (0.32)	5.54 (4.6)

Note. 1) The respective means of the variables (with the standard deviations in parentheses) are given. 2) The ratings of word class, object-relatedness, action-relatedness and valence were collected from a norming procedure by native speakers of Mandarin (Word class: 1 = absolute noun, 11 = absolute verb; Object relatedness & Action relatedness: 1 = least relevance, 7 = most concordance; Valence: 1 = the most negative, 5 = the most positive). There were a total of

137 native speakers of Mandarin who attended the norming procedure (32 for word class rating, 35 for object-relatedness rating, 40 for action-relatedness rating, 30 for valance rating) but did not participate in the EEG experiment. 3) The frequency data were logarithmically transformed. 4) The values of frequency, AoA, familiarity, concreteness, and imageability were taken from the Chinese single-character word database (Li, Zhao, & Liu, 2013). 5) The number of strokes and neighborhood size were collected from the Contemporary Dictionary of Chinese (2016).

2.3 Procedure

The participants were seated in front of a computer monitor at a distance of 80cm in a dim, quiet, electromagnetically shielded room. Each trial began with a fixation appearing in the center of the screen for 300ms, followed by an inter-stimulus interval (ISI) of 200ms. Then, the first word was presented for 1,500ms. During this period, the participants were instructed to think about the meaning of this word. Five hundred milliseconds after the offset of the first word, the second word appeared. The participants were asked to make a semantic relatedness judgment by pressing different keys, whereby they attempted to indicate if the first word and second word were semantically related or not. The second word remained on screen for 2,000ms unless a response was given sooner. The interval between trials was 2,500ms. Before the formal experiment, a 20-trial practice session was arranged to familiarize the participants with the experimental procedure and environment. There were two blocks in the formal experiment. The first three trials were fillers that appeared at the beginning of each block as a warm-up. After the warm-up trials, the stimuli were pseudo-randomly presented, with no more than three trials of one word class (noun, verb) being presented in direct succession. A 5-minute rest was arranged between blocks. The presentation order of blocks was counterbalanced across subjects. The whole experiment lasted approximately 25 minutes.

2.4 EEG recording and data analysis

The electroencephalographic (EEG) signal was amplified using a SynAmps 2 amplifier (NeuroScan, Charlotte, NC, U. S.) and recorded from 64 Ag/AgCl electrodes placed on the scalp. Vertical eye movements were recorded from bipolar channels placed above and below the left eye, and horizontal eye movements were recorded from the channels attached to the outer canthi of the left and right eyes. The online reference electrode was placed on the left mastoid, and two electrodes (one attached to the left mastoid and one to the right mastoid) were used as offline references. The impedance of each electrode was kept below 5kΩ. The recordings were digitized at a sampling rate of 500Hz and a band pass between 0.15Hz and 400Hz.

The Curry Neuroimaging suite 7.0.5 XSBA was used to analyze the data. The EEG data were re-referenced offline against average signals of left and right mastoids and were filtered with a 0.5-30Hz band pass zero-phase shift digital filter (slope 24dB/Oct). The epochs ranged from 100ms before 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$120μV on any channel were excluded from the analysis. As Fig. 3 shows, the typical ERP components, N1 and P2, were elicited by visual stimuli in all the conditions. After N1 and P2, N400 and late frontal negativity were found. On the basis of the global field power (see Fig. 1), the time windows of N400 and late frontal negativity were determined to be 300-450ms and 550-800ms, respectively. Different sets of electrodes were selected for N400 and late frontal negativity. According to topographic distribution (Fig. 2) and previous studies (Holcomb & Grainger, 2006; Kutas & Federmeier, 2000), 20 frontal, central, and parietal electrodes (FPz, Fz, Cz, Pz, FP1/2, AF3/4, F3/4, F1/2, C3/C4, C1/C2, P3/P4, P1/P2) were chosen for N400. Twelve prefrontal and frontal electrodes (FPz, Fz, FP1/2, AF3/4, F5/6, F3/4, F1/2) were selected where frontal negativity amplitude was expected to be maximal, as shown in the topographic map. Even though the linear mixed-effect modeling was applied in recent ERP studies (e.g., Wang, Verdonschot, & Yang, 2016; Law, Yum, & Cheung, 2017), this method seems not suitable for being implemented in current experimental design. This is because the number of trials for participant and item intercepts are limited in this study, which will lead to low signal-to-noise ratio of ERP. Thus, the mean amplitudes of N400 and late frontal negativity were calculated for each condition and for each subject. And the repeated-measures ANOVA and Greenhouse-Geisser correction methods (Greenhouse & Geisser, 1959) were employed in the analysis of the ERP data.

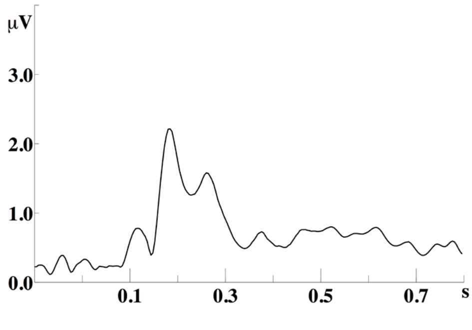

Fig. 1. Global field power averaged across all experimental conditions and across the 21 participants.

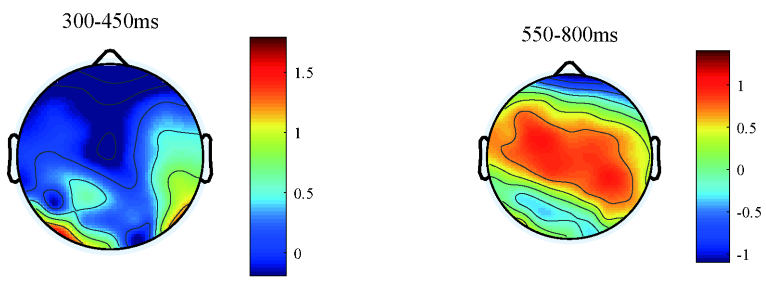

Fig. 2. Topographic maps of two components: N400 (300-450ms) and late frontal negativity (550-800ms).

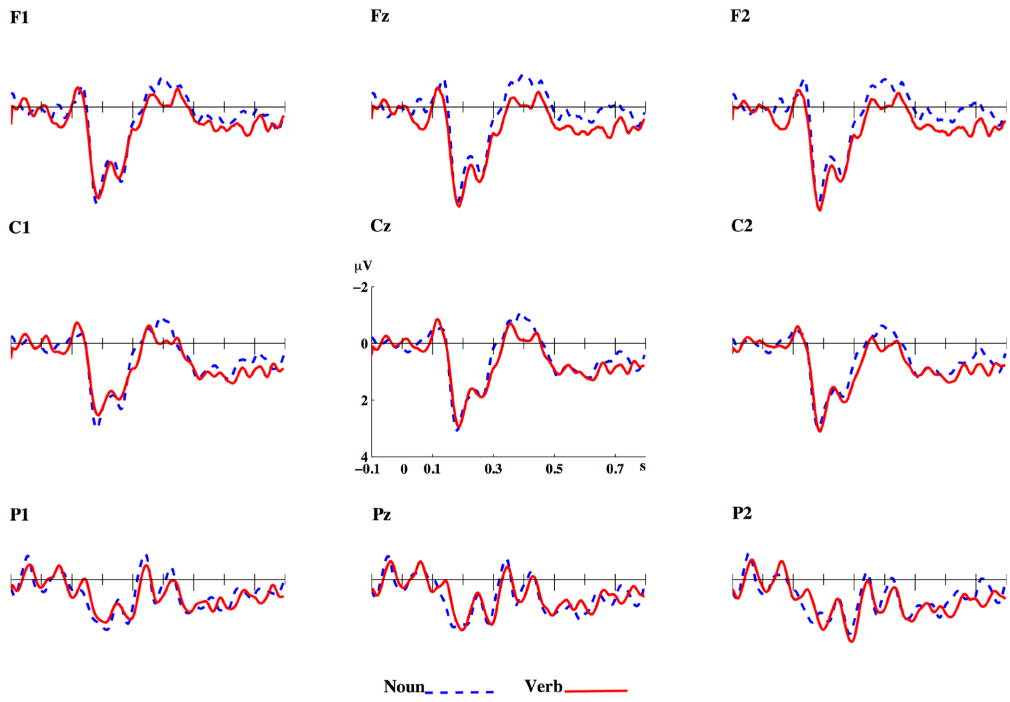

Fig. 3. Grand average ERPs from 21 participants in the time window of 100ms pre-target onset and 800ms post-target onset for monosyllabic nouns and verbs at frontal, central, and posterior sites.

3. Results

3.1 Behavioral results

There are no behavioral data available to assess the word class effect because the participants made semantic relatedness judgments of the first and second words in the word pairs rather than responding to the first target words. The overall high accuracy (mean = 96%, SD = 1.86, ranging from 92% to 99%) indicates that the participants understood the task and were attending to the stimuli during the experiment.

3.2 Electrophysiological results

3.2.1 N400

Two-way repeated measures ANOVAs were performed, with two levels of word class (noun/verb) and 20 sites as within-subject factors. There was a significant main effect of word class on N400 (F (1, 20) = 8.385, $p < 0.01$, $\eta^2 = 0.295$). Nouns elicited more negative N400 than verbs over the frontal, central, and parietal sites (-0.27μV vs. 0.18μV).

3.2.2 Late frontal negativity

Two-way repeated measures ANOVAs were performed, with two levels of word class (noun/verb) and 12 frontal sites as within-subject factors. There was a significant main effect of word class on late frontal negativity (F (1, 20) = 7.186, $p < 0.05$, $\eta^2 = 0.264$). Nouns elicited more late frontal negativity than verbs (-0.3μV vs. 0.21μV).

4. Discussion

The present ERP study aimed to answer the following question: "Which semantic properties lead to the neural distinction between nouns and verbs: object and action, or concreteness and imageability?" Unlike previous studies on Chinese in which disyllabic words were used, we employed monosyllabic nouns and verbs to avoid confounding effects due to internal structure and syntactic ambiguity. Moreover, the nouns and verbs were presented without context to preclude any contextual influence. ERP results revealed a temporal distinction between nouns and verbs in Chinese, which was shown on N400 and late frontal negativity. Relative to the verbs, the nouns elicited more negative N400 over a broad region and more late negativity at frontal sites. These ERP differences between nouns and verbs could not be attributed to concreteness or imageability as they were controlled for. Considering that the nouns and verbs in this study were mostly associated with object and action features, respectively, we propose that the observed neural distinction between nouns and verbs might be due to object and action.

N400 indexes access to lexical representation and semantic memory retrieval (Kutas & Federmeier, 2011). The N400 effect here indicates a distinct semantic processing between nouns and verbs. Previous studies showed that the amplitude of N400 could be influenced either by concreteness (Kounios & Holcomb, 1994; Zhang et al., 2006;

Law et al., 2017) and imageability (West & Holcomb, 2000; Nittono, Suehiro, & Hori, 2002) or by object and action differences (Zhang et al., 2003; Xia et al., 2016; Zhao et al., 2017). For this reason, N400 is an important ERP component for identifying the roles of concreteness and imageability versus object and action in the word class effect. Barber, Kousta, Otten and Vigliocco (2010) investigated the neural processing of Italian nouns and verbs that vary in their sensory and motor properties; the results showed that after imageability was balanced between the two word classes, the N400 differences between nouns and verbs were identical to those between sensory and motor words, suggesting that the word class effect originates from sensory and motor properties rather than imageability. However, since the stimuli in their study were presented as word stems with affixes, the inflectional operation is likely to confound the observed word class effect.

Since Chinese lacks inflectional morphology, researchers have taken this aspect of the language as an advantage to design studies that can avoid the potential confounding effects brought upon by morphological inflections. Tsai et al. (2009) manipulated concreteness and word class and further controlled for the grammatical category of constituents in compounds by using NN noun compounds and VV verb compounds. A lexical decision task and a semantic-relatedness judgment task were conducted separately. In both tasks, there was no main effect of word class or interaction between the word class and the concreteness. These results could be interpreted as suggesting that the word class effect is subject to the concreteness effect because a main effect of word class disappeared once the concreteness of the stimuli was manipulated. Contrary to these two studies, Zhao et al. (2017) found that despite concreteness and imageability being matched, the N400 differences between disyllabic nouns and verbs were significant in an auditory lexical decision task. Providing additional, supporting, evidence to Zhao et al. (2017), the present study using monosyllabic words also found a main effect of word class on N400, with more negative N400 for monosyllabic nouns than for monosyllabic verbs.

The lack of word class effect on N400 observed in the studies of Tsai et al. (2009) may arise from unequal emotional valence across lexical categories of the test stimuli. The emotional valence of a word, which indicates the extent to which the word's affect is positive, negative, or neutral, has been reported to impact word processing and modulate amplitudes of N400 (Herbert, Junghöfer, & Kissler, 2008; Kanske & Kotz, 2007; see Citron, 2012 for a review). Though Tsai et al. (2009) did not directly report emotional valence, the emotional valence of some of the examples in the study suggest that the test items were not matched across concrete nouns and verbs, and abstract nouns and verbs. Hence, it is possible that the absence of a main effect of N400 resulted from the confounding effects between emotional valence and the word class. Both Zhao et al. (2017) and the present study provide evidence in support of this possibility since a word class effect on N400 appeared once emotional valence was kept constant across nouns and verbs. Comparatively, the N400 effect here was more pronounced and more equally and broadly distributed over the scalp than that in the study of Zhao et al. (2017), which may be due to the added control of internal structure and syntactic ambiguity in the design and to the experimental task requiring semantic processing in the current study.

In this study, nouns and verbs were presented without context. Hence, the observed N400 effect, which was more negative N400 for nouns than verbs, should be attributed to the semantic properties associated with the two word classes. This suggests that the N400 effect in Xia et al. (2016) actually showed the integration of contexts and two word classes. As mentioned in the Introduction, two opposite N400 results were found in the comparisons between Chinese studies with stimuli presented with and without context. When presented in isolation, nouns activated more negative N400 than verbs; when primed by context, verbs activated more negative N400 than nouns. These two different N400 patterns may suggest that when the two word classes shift from being presented out of context to being presented with context, the semantic activation of verbs tends to enhance more than that of nouns. Such a trend was also found in the fMRI studies on Chinese. In the study that presented nouns and verbs in isolation, Yang et al. (2017) found that the representation of object nouns engaged the left inferior and middle frontal gyri, while the representation of action verbs engaged in the left inferior frontal gyrus and left middle and superior temporal gyri. In contrast to this study, when nouns and verbs were embedded in the syntactic and semantic contexts, verbs elicited greater BOLD responses than nouns in the left prefrontal lobe and the superior temporal gyri while nouns did not produce greater activity than verbs in any brain regions (Feng et al., 2020). Similarly, a picture-naming study showed that verbs activated more strongly than nouns in the motor system but no significant activations were observed when nouns were compared to verbs (Zhang et al., 2018). The pictures for naming could be considered as contexts for verbs since the nouns that are associated with verbs (e.g., objects and agents) also appear in the pictures. Thus, both ERP and fMRI studies seem to indicate more activation of verbs than nouns when the two word classes change from being presented out of context to being embedded in context. Such an improvement of verb activation might be due to additional cognitive demand for processing verbs in contexts. Previous studies showed that the semantic features of verb arguments were activated when verbs were processed in contexts (e.g., Boland, 1993; Li, Shu, Liu, & Li, 2006; Trueswell, Tanenhaus, & Kello, 1993). Unlike verbs, nouns do not contain such argument information, and so the changes of noun activation with and without context were not as obvious as verbs. Future studies should aim to investigate this preliminary explanation.

In addition, an enhancement of late frontal negativity was observed for nouns as compared to verbs. This late frontal negativity does not relate to imagery processes (West & Holcomb, 2000; Nittono et al., 2002; Barber et al., 2013) because the imageability was equivalent between nouns and verbs in this study. Barber et al. (2010) reported that larger amplitude was elicited in response to motor verbs than to sensory nouns at frontal sites in the late time window, which was attributed to sensory and motor representations in working memory. Compatible with this study, the late frontal effect here may also be interpreted as a manifestation of how nouns and verbs are represented differently in working memory. In our experiment, the participants were instructed to think of the meaning of the first (target) word and then judge whether the second word was semantically related to it or not. When the first word of each word pair appeared, participants retrieved its meaning and retained it for further decision-making. Meanwhile, the semantic features of nouns and verbs were temporarily represented in their working memory, thus eliciting the frontal negativity effect. Alternatively, the late frontal negativity effect may relate to working memory load. Late frontal negativity has previously been linked to working memory demands, maintenance, and selection among candidates during recollection (Chou, Huang, Lee, & Lee, 2014; King & Kutas, 1995; Lee & Federmeier 2006, 2009; Rugg, Allan, & Birch, 2000). When seeing the first word of word pairs, participants may not only access the word meaning but also try to predict what the following word would be -- using the information provided by the first word to provide a quick and correct response. During this process, all possible candidates for predicting the upcoming word would be stored in working memory for further use. As the nouns employed in our study had significantly more semantically related words than the verbs ($p < 0.01$, nouns vs. verbs, 2.47 vs. 2.13),[2] participants would need to maintain more possible candidates in their working memory for the nouns than for the verbs before the second words appeared, thus resulting in the nouns elicited more frontal negativity than the verbs in the late time window.

[2] Twelve native speakers of Chinese who did not join in the EEG experiment participated in a norming test. They were instructed to write down three words that were semantically related to the stimuli according to daily use. In addition, the words provided had to be monosyllabic words that were in the same class as the stimuli. This was because the first and second words in the word pairs were monosyllabic words that belonged to the same word class in the EEG experiment.

The ERP results of the current study indicate that the distinction between nouns and verbs might be due to object and action, which is in line with some previous studies (e.g., McCarthy & Warrington, 1985; Pulvermüller et al., 1999; Moseley & Pulvermüller, 2014) but incompatible with others. Bird et al. (2000, 2003) reported that patients with verb deficit aphasia had difficulties in processing verbs relative to nouns, but when imageability was matched between nouns and verbs, these patients did not demonstrate poorer performance with verbs than with nouns, suggesting that the dissociation between nouns and verbs resulted from imageability. Imageability, the rating of which is based on the ease of arousing a mental image from a word (Paivio et al., 1968), is supposed to reflect the richness of sensory information in word concepts (Bird et al., 2000, 2003). However, a regression analysis on 524 English words showed that imageability ratings do not consistently relate to any modality-specific features and cannot informatively predict the variance in response latency and accuracy in lexical decision and naming tasks (Connell & Lynott, 2012). Moreover, two literature reviews showed that the cortical regions for the imageability effect vary considerably across neuroimaging studies (Bendy & Thompson-Schill, 2006; Connell & Lynott, 2012), which might be a consequence of the uncertainty of imageability. Additionally, the study by Bird and colleagues may also have suffered from poor stimulus selection and matching. In an attempt to match imageability between the two word classes, the authors selected nouns and verbs that lacked an object and action contrast, with more than half of the nouns having little object-related information and around one sixth of the verbs having limited action-related information (Bird et al., 2003). Since previous studies, as well as the current study, indicate that object and action account for the word class effect, it is reasonable to question whether the diminished word class effect is due to the matched imageability between nouns and verbs or alternatively to the insufficient object and action information associated with the two word classes. Moreover, emotional valence was not controlled for in Bird et al. (2003), with more emotion words in nouns than verbs. As emotional valence is reported to have an impact on the processing of words (Citron, 2012; Herbert et al., 2008; Kanske & Kotz, 2007; Kousta et al., 2011), the unequal emotionality between the two word classes may lead to a confounding effect. Altogether, the uncertain nature of imageability, the lack of object and action contrast associated with nouns and verbs, and poor stimulus matching in emotional valence might cast doubts on their conclusion that the word class effect is due to imageability differences between nouns and verbs.

Previous studies have also proposed that the dissociation between nouns and verbs emerges as a consequence of morpho-syntactic properties. However, in some of these studies, not much importance was attached to object and action, which may have consequently influenced the findings. Longe et al. (2007) found that bare nouns and verbs engaged identical brain regions after their imageability was matched. However, as discussed in the Introduction, the nouns and verbs selected in the above study were not distinct in terms of their semantic aspects of object and action. Such a lack of object and action contrast associated with bare nouns and verbs may result in the absence of the word class effect. Different from Longe et al. (2007), Bendy et al. (2008) manipulated semantic properties, namely visually perceived motion, of nouns and verbs to trace the origins of the noun-verb dissociation. The results showed a main effect of word class in the middle temporal and superior temporal cortices, with consistently stronger activation for high and low visual-motion verbs than for high and low visual-motion nouns. Nevertheless, the high visual-motion nouns and verbs, referring to animal nouns and action verbs in Bendy et al. (2008), are likely to be different in terms of object and action as discussed in the Introduction. Relative to object words, action words activate more strongly in the posterior middle temporal and superior temporal cortices (for a review, see Kemmerer, 2014). The temporal cortices that indicate the contrast of object and action partly overlap with the temporal cortices for the dissociation between nouns and verbs reported in Bendy et al. (2008), which makes it difficult to conclude whether the observed spatial dissociation between nouns and verbs was caused by morpho-syntactic differences or by semantic properties associated with the two word classes. Therefore, it is important to take the contrast of object and action into consideration when examining the effects of morpho-syntactic properties on the noun-verb dissociation. As to the important question of whether semantic properties or morpho-syntactic properties are the primary determinant of the noun-verb distinction, we could not address it conclusively in this study, and thus the question merits further study.

5. Conclusion

Object and action, and concreteness and imageability, are proposed as the two semantic accounts for the distinction between nouns and verbs. As their roles in the word class effect are unclear, these two types of semantic attributes have not received much attention or have not been carefully distinguished in studies demonstrating morpho-syntactic differences as the source of the noun-verb distinction. Thus, for both semantic and morpho-syntactic approaches to the word class effect, it is crucial to discern whether the noun-verb distinction is due to object and action contrast or to concreteness and imageability. By carefully matching stimuli and presenting them without context, we found that even after controlling for concreteness and imageability, a neural distinction between nouns and verbs still exists, with more negative N400 and late frontal negativity for nouns than for verbs. These results indicate that the distinction between nouns and verbs in Chinese is due to object and action rather than concreteness and imageability and also point to the importance of object and action distinction in studies on nouns and verbs.

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Appendix A.

A1: The stimuli and data of lexical-semantic variables of nouns (Part I).

Noun	Pinyin	Meaning	Log frequency	No. of Stroke	Concreteness	Imageability	AoA	Familiarity	Neighborhood Size
斑	*ban1*	speckle	0.95	12	5.38	5.79	4.42	5.74	14
碑	*bei1*	monument	1.32	13	5.75	5.41	5.05	6.28	15
舱	*cang1*	cabin	1.11	10	6.14	6.43	4.83	5.61	2
柴	*chai2*	firewood	1.00	10	6.28	6.61	3.83	5.97	10
巢	*chao2*	nest	1.04	11	6.42	6.56	4.97	5.77	3
堤	*di1*	embankment	0.95	12	6.08	5.76	4.59	6.71	5
恩	*en1*	favor	1.23	10	3.3	4.47	4.21	6.39	17
腹	*fu4*	belly	1.30	13	6.46	6.3	4.38	6.58	16
钙	*gai4*	calcium	0.00	9	5.1	5.41	5.51	6.67	1
肝	*gan1*	liver	1.04	7	6.46	6.48	4.28	6.23	12
缸	*gang1*	vat	1.11	9	6.63	6.68	4	5.87	5
轿	*jiao4*	sedan chair	1.11	10	5.43	4.97	4.59	5.97	2
君	*jun1*	gentleman	1.23	7	4.67	4.84	4.45	6.45	11
郡	*jun4*	country	0.60	9	5.41	4.42	5.85	5.5	2
窟	*ku1*	hole	0.90	13	5.65	5.5	5.43	5	4
泪	*lei4*	tear	1.66	8	6.46	6.85	3.4	6.67	10
铃	*ling2*	bell	1.04	10	6.48	6.44	3.63	6.94	2
谜	*mi2*	puzzle	1.11	11	5.03	5.75	4.11	6.13	4
棋	*qi2*	chess	1.60	12	6.63	6.55	3.97	6.81	11
桥	*qiao2*	bridge	1.73	10	6.64	7	3.42	6.45	9
筒	*tong3*	barrel	1.45	12	6.16	6.5	4.22	5.81	5
胃	*wei4*	stomach	1.04	9	6.42	6.5	4.03	6.78	5
胸	*xiong1*	chest	1.52	10	6.54	6.73	3.89	6.83	23
猿	*yuan2*	monkey	0.60	13	6.71	6.74	4.97	6.07	2

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

A2: The stimuli and data of lexical-semantic variables of nouns (Part II).

Noun	Pinyin	Meaning	Word Class	Object relatedness	Action relatedness	Valence
斑	*ban1*	speckle	2.38(2.65)	4.78(1.82)	2.39(1.96)	2.72(0.52)
碑	*bei1*	monument	1.56(0.88)	6.17(1.13)	2.25(1.89)	2.84(0.85)
舱	*cang1*	cabin	1.63(1.07)	5.2(1.61)	1.92(1.57)	3.06(0.35)
柴	*chai2*	firewood	1.63(1.29)	5.69(1.49)	2.17(1.61)	2.88(0.66)
巢	*chao2*	nest	2.28(2.02)	6.19(1.14)	2.36(2)	3.28(0.68)
堤	*di1*	embankment	2(1.59)	5.51(1.72)	2.44(1.96)	3.06(0.5)
恩	*en1*	favor	3.56(3.12)	1.33(0.59)	1.81(1.21)	3.91(0.73)
腹	*fu4*	belly	2.09(2.13)	4.83(1.79)	1.83(1.23)	3.16(0.45)
钙	*gai4*	calcium	1.66(1.18)	2.54(1.72)	1.92(1.7)	3.53(0.62)
肝	*gan1*	liver	2.59(2.11)	5.77(1.4)	1.92(1.7)	2.78(0.42)
缸	*gang1*	vat	1.69(1.2)	6.11(1.17)	2.19(1.95)	2.84(0.51)
轿	*jiao4*	sedan chair	2.28(2.04)	5.46(1.8)	2.78(2.09)	3(0.44)
君	*jun1*	gentleman	2(1.88)	2.39(1.32)	1.67(1.31)	4(0.67)
郡	*jun4*	country	1.94(1.98)	1.97(1.21)	1.58(1)	3.22(0.61)
窟	*ku1*	hole	1.91(1.61)	3.97(2.05)	2(1.53)	2.41(0.61)
泪	*lei4*	tear	2.69(2.05)	5.69(1.45)	3.61(2.09)	2.34(0.65)
铃	*ling2*	bell	2.69(2.18)	5.97(1.44)	3.03(1.76)	3.5(0.67)
谜	*mi2*	puzzle	2.41(1.83)	1.97(1.38)	2.14(1.73)	3.06(0.56)

棋	*qi2*	chess	1.84(1.92)	5.77(1.31)	2.86(1.91)	3.63(0.71)
桥	*qiao2*	bridge	2.13(2.09)	6.23(1.21)	2.19(1.95)	3.5(0.62)
筒	*tong3*	barrel	1.84(1.37)	5.47(1.66)	2.78(2.09)	3.31(0.64)
胃	*wei4*	stomach	1.63(1.16)	5.54(1.31)	2.36(1.79)	3.19(0.47)
胸	*xiong1*	chest	2.06(1.85)	5.63(1.48)	2.67(1.96)	3.19(0.74)
猿	*yuan2*	monkey	1.44(0.88)	5.77(1.4)	2.75(2.03)	2.94(0.44)

Appendix B

B1: The stimuli and data of lexical-semantic variables of verbs (Part I)

Verb	Pinyin	Meaning	Log frequency	No. of Stroke	Concreteness	Imageability	AoA	Familiarity	Neighborhood Size
踩	*cai3*	step	1.36	15	6.26	6.12	3.95	6.74	4
搓	*cuo1*	rub	1.15	12	5.58	5.97	4.49	6.45	7
钓	*diao4*	fish	0.30	8	5.83	6.48	4.11	6.69	4
割	*ge1*	cut	1.30	12	5.9	6.2	4.26	6.5	17
裹	*guo3*	wrap	1.11	14	5.78	5.71	4.84	6.29	9
绘	*hui4*	draw	0.48	9	5.8	6.09	4.08	6.74	8
捡	*jian3*	pick up	1.38	10	6.08	6.06	3.73	6.66	5
啃	*ken3*	nibble	1.34	11	6.03	5.65	4.45	6.23	1
拦	*lan2*	block	1.41	8	5.78	6.59	3.94	6.06	15
描	*miao2*	depict	0.48	11	5.19	6.41	4.06	6.13	8
扭	*niu3*	twist	1.41	7	5.67	5.32	4.18	6.31	13
挪	*nuo2*	move	1.28	9	5.51	5.93	4.75	5.68	5
揉	*rou2*	crumple	1.00	12	5.85	6.03	4.6	6.22	2
售	*shou4*	sell	1.76	11	5.83	6.03	4.28	6.8	3
拴	*shuan1*	tie	1.36	9	5.41	5.13	4.8	5.94	0
踢	*ti1*	kick	1.65	15	6	6.17	3.83	6.59	6
剃	*ti4*	shave	1.00	9	6.03	6.11	4.44	5.77	5
吞	*tun1*	swallow	1.04	7	6	6.39	3.21	6.47	12
握	*wo4*	hold	1.57	12	6.24	5.97	3.85	6.74	5
掀	*xian1*	lift	1.41	11	5.8	5.97	4.89	6.45	1
摇	*yao2*	shake	1.95	13	5.68	6.16	3.7	6.5	25
跃	*yue4*	jump	1.26	11	5.89	6.33	4.43	6.13	9
遮	*zhe1*	cover	1.20	14	5.95	5.84	4.9	6.13	15
睁	*zheng1*	open eyes	1.52	11	5.88	6.44	3.95	6.8	1

B2: The stimuli and data of lexical-semantic variables of verbs (Part II)

Word	Pinyin	Meaning	Word Class	Object relatedness	Action relatedness	Valence
踩	*cai3*	step	10.28(1.17)	3.22(1.97)	5.94(1.33)	2.41(0.56)
搓	*cuo1*	rub	10.22(1.75)	3.46(1.99)	5.86(1.44)	2.56(0.62)
钓	*diao4*	fish	9.41(2.78)	3.89(1.94)	5.33(1.85)	3.06(0.56)
割	*ge1*	cut	10.22(1.24)	2.94(1.8)	5.39(1.73)	2.09(0.64)
裹	*guo3*	wrap	8.19(2.25)	2.97(1.74)	5.58(1.48)	2.81(0.59)
绘	*hui4*	draw	9.41(1.74)	3.56(1.78)	5.08(1.79)	3.69(0.64)
捡	*jian3*	pick up	10.56(0.72)	2.94(1.79)	5.75(1.42)	3.06(0.5)
啃	*ken3*	nibble	10.53(0.76)	3.63(1.91)	5.89(1.24)	2.69(0.54)
拦	*lan2*	block	9.38(2.43)	3.25(1.75)	5.64(1.61)	2.59(0.56)
描	*miao2*	depict	9.16(2.4)	2.74(1.72)	5.53(1.61)	3.28(0.52)
扭	*niu3*	twist	9.59(2.2)	3.49(1.98)	5.75(1.63)	2.84(0.51)
挪	*nuo2*	move	10.34(1.1)	1.97(1.3)	5.47(1.81)	2.84(0.57)
揉	*rou2*	crumple	10.41(0.8)	3.4(2.02)	5.92(1.34)	3.25(0.51)
售	*shou4*	sell	9.41(1.95)	2.54(1.85)	4.72(1.86)	3.19(0.47)
拴	*shuan1*	tie	10.00(1.39)	2.89(1.77)	4.89(1.92)	2.66(0.65)
踢	*ti1*	kick	10.59(0.71)	3.69(1.98)	6.25(1.2)	2.78(0.49)
剃	*ti4*	shave	9.06(2.61)	3.29(1.95)	5.61(1.29)	2.34(0.87)
吞	*tun1*	swallow	9.69(2.35)	3.06(1.96)	5.72(1.3)	2.66(0.55)
握	*wo4*	hold	9.22(2.41)	3.53(2.02)	5.69(1.43)	3.19(0.69)
掀	*xian1*	lift	10.06(1.85)	3.46(2.12)	5.81(1.47)	3.06(0.62)
摇	*yao2*	shake	10.47(0.84)	3.36(1.84)	6(1.26)	2.97(0.47)

跃	*yue4*	jump	10.03(1.38)	3.69(1.77)	6.25(1.36)	3.72(0.77)
遮	*zhe1*	cover	10.19(1.2)	2.58(1.65)	5.28(1.77)	2.84(0.57)
睁	*zheng1*	open eyes	9.44(2.4)	3.29(1.86)	5.39(1.5)	3.09(0.39)

Appendix C Word pair

C1: The word pairs of nouns

1st word (Target)	Pinyin	Meaning	2nd word	Pinyin	Meaning	Relatedness
斑	ban1	speckle	点	dian3	spot	related
柴	chai2	firewood	木	mu4	tree	related
巢	chao2	nest	穴	xue2	cave	related
堤	di1	embankment	岸	an4	bank	related
恩	en1	favor	惠	hui4	benefit	related
肝	gan1	liver	胆	dan3	gall bladder	related
郡	jun4	country	县	xian4	county	related
棋	qi2	chess	琴	qin2	musical instrument	related
胃	wei4	stomach	肠	chang2	intestines	related
胸	xiong1	chest	心	xin1	heart	related
窟	ku1	hole	洞	dong4	cavity	related
泪	lei4	tear	水	shui3	water	related
碑	bei1	monument	伞	san3	umbrella	unrelated
舱	cang1	cabin	碗	wan3	bowl	unrelated
腹	fu4	belly	球	qiu2	ball	unrelated
钙	gai4	calcium	车	che1	vehicle	unrelated
缸	gang1	vat	掌	zhang3	palm	unrelated
轿	jiao4	sedan chair	儒	ru2	confucianism	unrelated
君	jun1	gentleman	径	jing4	path	unrelated
铃	ling2	bell	草	cao3	grass	unrelated
谜	mi2	puzzle	翎	ling2	plume	unrelated
桥	qiao2	bridge	气	qi4	air	unrelated
筒	tong3	barrel	粉	fen3	face powder	unrelated
猿	yuan2	monkey	玉	yu4	jade	unrelated

C2:The word pairs of verbs

1st word (Target)	Pinyin	Meaning	2nd word	Pinyin	Meaning	Relatedness
绘	hui4	draw	画	hua4	paint	related
啃	ken3	gnaw	咬	yao3	bite	related
拦	lan2	block	阻	zu3	obstruct	related
描	miao2	depict	摹	mo2	copy	related
剃	ti4	shave	刮	gua1	scrape	related
吞	tun1	swallow	咽	yan4	swallow	related
掀	xian1	lift	揭	jie1	uncover	related
摇	yao2	shake	晃	huang4	sway	related
跃	yue4	jump	腾	teng2	soar	related
遮	zhe1	cover	挡	dang3	obstruct	related
售	shou4	sell	赚	zhuan4	make a fit	related
踢	ti1	kick	打	da3	beat	related
踩	cai3	step	镶	xiang1	inlay	unrelated
搓	cuo1	rub	懂	dong3	understand	unrelated
钓	diao4	fish	渗	shen4	seep	unrelated
割	ge2	cut	踹	chuai4	kick	unrelated
裹	guo3	wrap	砍	kan3	chop	unrelated
捡	jian3	pick up	睡	shui4	sleep	unrelated

扭	niu3	twist	悟	wu4	realize	unrelated
挪	nuo2	move	览	lan3	view	unrelated
揉	rou2	crumple	沁	qin4	seep	unrelated
拴	shuan1	tie	觅	mi4	hunt for	unrelated
握	wo4	hold	灌	guan4	irrigate	unrelated
睁	zheng1	open eyes	擎	qing2	support	unrelated

C3: The word pair of fillers

1st word (Target)	Pinyin	Meaning	2nd word	Pinyin	Meaning	Relatedness
唇	chun2	lip	齿	chi3	tooth	related
葱	cong1	onion	姜	jiang1	ginger	related
醋	cu4	vinegar	盐	yan2	salt	related
福	fu2	good fortune	祸	huo4	disaster	related
箭	jian4	arrow	弓	gong1	bow	related
街	jie1	street	路	lu4	road	related
鹿	lu4	dear	马	ma3	horse	related
瓢	piao2	gourd ladle	盆	pen2	basin	related
诗	shi1	poem	歌	ge1	song	related
雁	yan4	wild goose	雀	que4	sparrow	related
纸	zhi3	paper	笔	bi3	pen	related
竹	zhu2	bamboo	兰	lan2	orchid	related
裱	biao3	mount	装	zhuang1	decorate	related
炒	chao3	stir-fry	煎	jian1	fry	related
赴	fu4	go to	去	qu4	leave	related
聚	ju4	assemble	集	ji2	collect	related
陪	pei2	look after	伴	ban4	accompany	related
娶	qu3	marry (a woman)	嫁	jia4	(of a woman) marry	related
溶	rong2	dissolve	化	hua4	melt	related
晒	shai4	shine on	晾	liang4	dry in the air	related
躺	tang3	lie	卧	wo4	lie down	related
添	tian1	add	增	zeng1	increase	related
蓄	xu4	store up	存	cun2	keep	related
斟	zhen1	pour	酌	zhuo2	drink	related
匾	bian3	horizontal inscribed board	崖	ya2	edge of a cliff	unrelated
岛	dao3	island	脚	jiao3	foot	unrelated
盾	dun4	shield	巾	jin1	piece of cloth	unrelated
壶	hu2	kettle	鹏	peng2	roc	unrelated
库	ku4	storehouse	幅	fu2	width	unrelated
林	lin2	forest	盒	he2	box	unrelated
税	shui4	tax	布	bu4	cloth	unrelated
铜	tong2	copper	天	tian1	sky	unrelated
霞	xia2	morning or evening glow of the sun	弟	di4	younger brother	unrelated
熊	xiong2	bear	礼	li3	gift	unrelated
鸭	ya1	duck	窗	chuang1	window	unrelated
粥	zhou1	congee	线	xian4	thread	unrelated
掰	bai1	break off with one's hands	吼	hou3	shout	unrelated
变	bian4	change	召	zhao1	call up	unrelated
沸	fei4	boil	办	ban4	handle	unrelated

俯	fu3	bow	洗	xi3	wash	unrelated
建	jian4	build	扫	sao3	sweep	unrelated
救	jiu2	rescue	买	mai3	buy	unrelated
瞟	piao2	cast a sidelong glance at	浇	jiao1	water	unrelated
舔	tian3	lick	拿	na2	hold	unrelated
献	xian4	present	啄	zhuo2	peck	unrelated
驻	zhu4	halt	仰	yang3	face upward	unrelated
煮	zhu3	boil	携	xie2	take along	unrelated
助	zhu4	help	贴	tie1	paste	unrelated

C4: The word pairs in practice session

1st word (Target)	Pinyin	Meaning	2nd word	Pinyin	Meaning	Relatedness
雷	lei2	thunder	电	dian4	lightning	related
砖	zhuan1	brick	瓦	wa3	tile	related
牛	niu2	bull	羊	yang2	sheep	related
锣	luo2	gong	鼓	gu3	drum	related
湖	hu2	lake	海	hai3	sea	related
征	zheng1	go on a campaign	伐	fa2	attack	related
弹	tan2	catapult	拨	bo1	adjust with slight finger movement	related
蹬	deng1	press down with the foot	踏	ta4	step on	related
瞧	qiao2	look	看	kan4	see	related
返	fan3	return	回	hui2	turn round	related
蛙	wa1	frog	朋	peng2	friend	unrelated
蝶	die2	butterfly	鞋	xie2	shoe	unrelated
兄	xiong1	older brother	晨	chen2	morning	unrelated
岭	ling3	mountain	臣	chen2	feudal official	unrelated
锹	qiao1	shovel	口	kou3	mouth	unrelated
埋	mai2	bury	愿	yuan4	be willing	unrelated
填	tian2	fill	击	ji1	hit	unrelated
映	ying4	reflect	攻	gong1	attack	unrelated
浸	jin4	soak	拈	nian1	pick up	unrelated
拭	shi4	wipe (away)	凑	cou4	gather together	unrelated

C5: The warm-up trails in block 1 and block 2

block	1st word (Target)	Pinyin	Meaning	2nd word	Pinyin	Meaning	Relatedness
1	绑	bang3	tie	捆	kun3	tie	related
1	蜂	feng1	bee	桶	tong3	bucket	unrelated
1	豹	bao4	leopard	虎	hu3	tiger	related
2	荷	he2	lotus	叶	ye4	leaf	related
2	漱	shu4	rinse	赠	zeng4	give as a present	unrelated
2	译	yi4	translate	砌	qi4	build by laying bricks	unrelated