NeuroImage 58 (2011) 912–922

Contents lists available at cienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Dissociative neural correlates of semantic processing of nouns and verbs in Chinese — A language with minimal inflectional morphology

Xi Yu [a], Sam Po Law [a], Zaizhu Han [b], Caozhe Zhu [b], Yanchao Bi [b,*]

[a] Division of Speech and Hearing Sciences, The University of Hong Kong, Hong Kong SAR
[b] National Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China

ARTICLE INFO

Article history:
Received 9 November 2010
Revised 30 April 2011
Accepted 16 June 2011
Available online 29 June 2011

Keywords:
fMRI
Word class effect
Chinese nouns and verbs
Semantic judgment

ABSTRACT

Numerous studies using various techniques and methodologies have demonstrated distinctive responses to nouns and verbs both at the behavioral and neurological levels. However, since the great majority of these studies involved tasks employing pictorial stimuli and languages with rich inflectional morphology, it is not clear whether word class effects resulted from semantic differences between objects and actions or different inflectional operations associated with the two word classes. Such shortcomings were addressed in this study by using a language with impoverished inflectional morphology — Chinese. Both concrete and abstract words were included, while controlling for nuisance variables between the two word classes, including imageability, word frequency, age-of-acquisition, and number of stroke. Participants were asked to judge the semantic relatedness of noun or verb pairs by pressing different buttons. The results revealed specific neural correlates for verb class in left lateral temporal and inferior frontal regions. Furthermore, the patterns of neural distribution of nouns and verbs were consistent with observations from Indo-European languages. Plausible accounts for neural separation of word classes were considered.

Introduction

Nouns and verbs exist in all human languages (Robins, 1952). They differ systematically at various grammatical levels. With respect to semantics, nouns very often refer to objects and entities, which are individuated and relatively atemporal, while verbs frequently describe actions or processes, which are by contrast dynamic and temporal in nature (Frawley, 1992). Syntactically, their distinctions are more clear-cut, in terms of their unique contribution to the construction of a proposition. The noun can function as the subject or object of a verb, as well as the object of a preposition, while the verb serves as a predicate, defining/describing the subject with respect to certain aspect(s). Their grammatical differences are further realized at the morphological level in languages with rich morphology. Noun declensions express number, case, and/or gender (e.g., man vs. men, in English) of an entity, while verb conjugations indicate tense, mood, voice, and/or aspect of an event. At the pragmatic or discourse level, nouns typically play the role of the topic or subject, while verbs play the comment or predicate. In other words, the differences between nouns and verbs are multi-faceted, and none of them should be excluded a priori (Laudanna and Voghera, 2002).

Consistent with the fundamental linguistic differences between nouns and verbs, behavioral and neuropsychological evidence for word class dissociation[1] has been accumulated from various research approaches (see Laiacona and Caramazza, 2004; Vigliocco et al., 2010 for comprehensive reviews). Studies reporting double dissociation between deficits of nouns and verbs among individuals with aphasia at the semantic (e.g., Caramazza and Hillis, 1991; Damasio and Tranel, 1993; Daniele et al., 1994; McCarthy and Warrington, 1985; Miceli et al., 1988; Warrington and McCarthy, 1983; Zingeser and Berndt, 1988), lexical (e.g., Baxter and Warrington, 1985; Caramazza and Hillis, 1991), and morphosyntactic levels (e.g., Miceli and Caramazza, 1988; Shapiro and Caramazza, 2003; Shapiro et al., 2000; Tsapkini et al., 2002), and their corresponding lesion sites have been taken by many as evidence for neural separation of these word classes. However, such a view is challenged by two recent and extensive reviews of the literature on noun and verb processing[2] (Crepaldi et al., 2010; Vigliocco et al., 2010).

Although Crepaldi et al. (2010) and Vigliocco et al. (2010) have both concluded that there is at present no compelling evidence showing that word class distinctions constitute an organizing principle of lexical knowledge at the brain level, their conclusions are based on somewhat different observations. Crepaldi et al. drew attention to the inconsistent findings from studies using similar

[1] We used the terms "dissociation" or "noun/verb specific" to describe relative effects, i.e., stronger effects for nouns than verbs or vice versa.

[2] Given that it is notoriously difficult to distinguish between storage and access (Rapp and Caramazza, 1993), "processing" is used to loosely refer to either or both. Following the convention in the field, the neural mechanisms for processing are inferred from the location information, i.e., brain regions showing noun/verb effects.

* Corresponding author at: National Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, 100875, China. Fax: +86 10 5880 2911.
E-mail address: ybi@bnu.edu.cn (Y. Bi).

1053-8119/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.neuroimage.2011.06.039

research paradigms and the same investigative techniques. They left open the possibility that the investigation of neural separability of nouns and verbs might be limited by the spatial resolution currently employed in most neuroimaging studies, but did not explore how differences in the characteristics of stimuli, formats of presentation, and methods of balancing relevant variables across conditions might have contributed to the discrepant observations. Vigliocco et al., on the other hand, demonstrated that studies reporting distinct neural correlates of nouns and verbs often confounded grammatical class with semantic features of actions (usually with stronger activation in left prefrontal cortex) and objects (more strongly activated in left inferior temporal cortex). Once such semantic factors were controlled for, grammatical class effects were only observed when morphosyntactic processing was involved, either through employing inflected word forms or presenting stimuli in syntactic contexts (see also Tyler et al., 2001, 2003, 2004, 2008).

Vigliocco et al. (2010) further argued that word class effects at the morphosyntactic level could be reduced to a difference in processing demand. This was supported by the frequent observations of longer response latency (RT) in processing verbs than nouns in various tasks (e.g., Bedny et al., 2008; Berlingeri et al., 2008; Bogka et al., 2003; Saccuman et al., 2006; Siri et al., 2008; Szekely et al., 2005; Tyler et al., 2001), and the positive correlation between RT, either longer for verbs (e.g., Bedny et al., 2008; Tyler et al., 2001) or longer for nouns (Berlingeri et al., 2008; Siri et al., 2008), and activation level in the left inferior frontal gyrus (LIFG), an area typically associated with task demand (but see also Berlingeri et al., 2008; Palti et al., 2007; Sahin et al., 2006).

However, several methodological issues need to be considered *together* before conclusions about neural distinctions between nouns and verbs, either present or absent, can be accepted. First, as pointed out in Bird et al. (2000), among many others, pictured objects (concrete nouns) are almost always rated more imageable than pictured actions (concrete verbs). Since most studies showing word class effects employed tasks with pictorial stimuli, such as picture naming and picture–name matching, it is plausible that previously reported behavioral or neural differences between nouns and verbs are confounded with imageability or other semantic variables associated with the object/action distinction, which has been shown to exert substantial influence on language processing (Coltheart et al., 1980; Franklin et al., 1994; Nickels and Howard, 1995; Noppeney and Price, 2004; Sabsevitz et al., 2005; Walker and Hulme, 1999).

More fundamentally, the semantic differences between nouns and verbs are not restricted to a contrast between objects and actions, or some other semantic features such as sensory vs. functional/motor. There are also conceptually abstract nouns (e.g. peace, talent) and abstract verbs (e.g. avoid, prosper). Furthermore, as stated at the beginning of this paper, the noun/verb contrast is multi-faceted; as such, an effect of word class mainly derived at the semantic level nonetheless represents a distinction in grammatical class. Put another way, to properly address the question of neural representation of semantic processing of nouns and verbs as grammatical classes, both concrete and abstract words must be examined. Focusing on the nine studies that employed a semantic task discussed in Crepaldi et al. (2010), five used mainly concrete or high imageability words (Kable et al., 2002; Palti et al., 2007; Tyler et al., 2001, 2003, 2004). Although the other four studies included both concrete and abstract items, all words of the same class were grouped together in the analysis of word class effect (Bedny and Thompson-Schill, 2006; Davis et al., 2004; Longe et al., 2007; Tyler et al., 2008). Therefore, the overall noun–verb effects might be driven by the concrete items. Note that the analysis that regressed out imageability effect in Bedny and Thompson-Schill (2006) does not exclude this possibility, as the concrete noun–verb effect may be caused by differences in semantic features other than imageability such as the "motor" aspects.

Regarding the claim of Vigliocco et al. (2010) about grammatical class effects being largely attributed to morphosyntactic processing, five of the nine studies assessing semantic processing of nouns and verbs described in Crepaldi et al. (2010) presented word stimuli either in inflected forms (Kable et al., 2002; Palti et al., 2007; Tyler et al., 2003, 2004) or in a phrasal context (Bedny and Thompson-Schill, 2006) only. Tyler et al. (2008) presented homophonic nouns and verbs in bare form, i.e. grammatical class ambiguous and used a dominance index based on the relative frequencies of noun vs. verb usage to indirectly infer brain regions associated with noun and verb effects. However, the finding from event-related potentials (ERPs) that word class ambiguous items are processed differently from word class unambiguous words both in latency and topography in syntactic contexts (Federmeier et al., 2000) renders the results of Tyler et al. difficult to interpret and integrate into the present discussion. The only study that has included both abstract nouns and verbs matched in imageability and presented in both uninflected stems and inflected forms is Longe et al. (2007). They found no regions differentially activated for either word class in the stem form condition, greater activation for inflected verbs in the LIFG and left middle temporal gyrus (LMTG) compared with inflected nouns, and no area more strongly activated by inflected nouns than verbs. The finding with significantly stronger activation in the LIFG associated with inflected verbs is also consistent with the account of processing demand.

Given the possibility that morphosyntactic processing differences between nouns and verbs, which may arguably be associated with a difference in processing demand, may always be an integral part of word class effects in languages rich in inflectional morphology (see Shapiro and Caramazza, 2003), a desirable alternative to examine word class effects along the semantic dimension is to work with languages with little inflectional morphology (Li and Thompson, 1981; Wang, 1973), such as Chinese. In Chinese, there is no third-person singular or tense marking for verbs; neither is there agreement in case, gender, or number between a noun and its modifier. The morphological and phonological structures of Chinese words stay the same during sentence construction. Therefore, the comparison between nouns and verbs in Chinese would be less likely to be confounded with morphosyntactic processing or processing demand. Similar to findings of lesion studies with English-speaking aphasic individuals, cases of Mandarin Chinese speakers with aphasia exhibiting either noun or verb specific impairment in tasks assessing comprehension and production of picturable nouns and verbs have been reported (Bates et al., 1991), suggesting a possible word class effect apart from syntactic operation. More recently, Bi and colleagues reported two Mandarin aphasic speakers, who exhibited particular difficulty in processing nouns (Bi et al., 2007; Lin et al., 2010). Although careful selection of stimuli in these studies allows one to rule out unbalanced age-of-acquisition (AOA), visual complexity, or imageability as possible accounts for word class dissociation, due to the use of pictorial stimuli, the dissociation can be argued to be due to semantic differences between actions and objects.

Thus far, there is only one neuroimaging study concerning the processing of nouns and verbs in Chinese. Li et al. (2004) reported no cortical regions with activation specific to either word class, consistent with the view that the distinct neural distribution revealed in Indo-European languages is only an artifact of inflectional differences between nouns and verbs. However, the findings should be interpreted with caution because a lexical decision task was employed, which may minimally involve representations at the semantic level.

The current study contributed to the investigation of neural representations of semantic processing of nouns and verbs through taking measures to avoid shortcomings in previous research01k7t5.7irst,-226.2

processing at the lexical–semantic level. Fourth, imageability across word classes was balanced between abstract noun and verb stimuli, while concrete materials were exclusively prototypical object and action words. This was done on purpose in light of an earlier report of a noun effect in left prefrontal cortex using imageability balanced materials (Bedny and Thompson-Schill, 2006). Since no RT difference was evident between the word classes, the authors attributed this unusual pattern to the atypical low imageability nouns employed in that study in order to match with verbs. Therefore, to obtain the regular activation pattern of grammatical processing, and also to compare with previous findings, prototypical nouns and verbs were selected for the high-imageability condition, resulting in unbalanced imageability as expected. Nonetheless, our purpose of examining neural representations of nouns and verbs as grammatical classes could be addressed through a conjunction analysis of grammatical contrasts at concrete and abstract levels to preclude areas responding to imageability, and reveal those brain regions that are differentially activated for nouns and verbs, for both concrete and abstract items.

Methodology

Participants

Twenty-one native Mandarin speakers were recruited from Beijing Normal University (BNU, 11 females, Mean age = 22.4, SD = 2.56). All participants were right-handed (Edinburgh inventory, Oldfield, 1971, Laterality Quotient (LQ) = 84 ± 16), with normal or corrected to normal visual acuity and no history of psychiatric or neurological disorders. They completed a screening form required by the BNU Imaging Center for Brain Research to ensure image quality and participants' safety. Informed consents were obtained following the protocol of the Institutional Review Board of the BNU imaging center.

Materials

Word class and concreteness were both considered forming four experimental conditions: High-imageability Noun (HN, concrete nouns), Low-imageability Noun (LN, abstract nouns), High-imageability Verb (HV, concrete verbs), and Low-imageability Verb (LV, abstract verbs). In each condition, 48 word class unambiguous words were chosen with the criterion that the frequency of occurrence in the target word class is at least ten times greater than that as the second most frequent word class (Shu et al., 1997, see full version of materials in Appendix A), constituting 24 semantically associated word pairs. Most of the pairs were composed of disyllabic words. There were three monosyllabic pairs in the LV condition, and two in the other conditions (see Table 1 for examples, and Appendix A for the full list of materials). The rating of imageability was obtained for each word from a group of 21 participants who did not take part in the fMRI experiment. Such data were used to ensure a valid control of imageability, which was achieved at the low imageability level. As expected, the imageability of nouns in the HN condition was rated significantly higher than the items in the HV condition. Other common linguistic variables, such as frequency, number of stroke, and AOA (rated by a new group of 20 participants) were matched between word classes in either imageability group. (See Table 1 for a summary of the properties of the materials.)

The associated word pairs were then rearranged within each condition to form unrelated trials, serving as negative trials in the experiment. An additional 20 participants were recruited to rate the relatedness of all stimulus pairs. Based on the rating results, three unrelated pairs (two from LV and one from LN) were excluded due to high relatedness values (all > 3.5). One unrelated LN pair was further deleted in order to balance the trial number between LV and LN. The rest of the stimuli were matched on relatedness between LN and LV, and HN and HV, for related and unrelated pairs, respectively (see Table 1), ensuring a comparable "relatedness" scale/criteria for both grammatical conditions.

An additional set of 35 noun and verb pairs with words different from the experimental stimuli was added to serve as stimuli in the practice session (20 trials), or fillers (15 trials).

Design

A total of 188 trials (96 related and 92 unrelated pairs) were divided equally into three blocks (63 experimental trials for two blocks and 62 for the other), with no repeated words in the same block. Each block formed one experimental run. Within each block, stimuli were arranged according to the optimal scheduling computed by the Optseq software (http://surfer.nmr.mgh.harvard.edu/optseq/), with the restriction of no onset overlapping of the first syllable of the first word or no semantic relationship between word items across consecutive trials. In addition, five fillers were inserted into each run, with two of them appearing in the beginning as lead-in trials. During the experiment, the item order within each block was fixed for every participant. We were aware of the possibility of the arbitrary order effect emerged from the fixed item order, therefore, block orders were counterbalanced in a Latin square fashion across participants, in order to remediate the undesired order effect and keep a relatively simple design at the same time.

The whole experiment started with a practice session out of the scanner, helping participants familiarize with the instruction and procedure. Every subject then received three experimental runs in the scanner. After finishing scanning, they would return within 24 h to repeat the same experiment outside the scanner.

Table 1
Examples and lexical-semantic variables for each condition.

Condition	Related pair example	Syllable length	Frequency	# of stroke	AoA	Imageability	Word pair relatedness	
							Relatedness	Unrelatedness
HN	种子vs. 果实 (seed vs. fruit)	1.9 ± 0.3	1.0 ± 0.4	8.6 ± 2.2	4.1 ± 0.6	6.4 ± 0.4	6.2 ± 0.5	1.6 ± 0.5
HV	追逐 vs. ▫ 跑 (chase vs. run)	1.9 ± 0.3	1.0 ± 0.5	8.8 ± 1.8	4.2 ± 0.7	5.1 ± 0.6	6.0 ± 0.6	1.7 ± 0.5
LN	信念 vs. 意志 (belief vs. will)	1.9 ± 0.3	1.3 ± 0.6	8.2 ± 2.3	5.2 ± 0.6	2.6 ± 0.5	6.2 ± 0.4	2.2 ± 0.6
LV	诅咒 vs. 痛恨 (curse vs. hate)	1.9 ± 0.3	1.3 ± 0.6	8.9 ± 2.0	5.1 ± 0.7	2.7 ± 0.4	6.1 ± 0.5	2.0 ± 0.4
t-test at HN and HV	–	–	t = 1.0; n.s.	t = −0.5; n.s.	t = −0.9; n.s.	t = 12.6; p < 0.001	t = 1.3 ; n.s.	t = −0.4; n.s.
t-test at LN and LV	–	–	t = 0.4; n.s.	t = −1.5; n.s.	t = 0.6 ; n.s.	t = −1.2; n.s.	t = 0.5; n.s.	t = 1.5; n.s.

Note. Frequency data have been logarithmically transformed to ensure a normalized distribution, based on which statistical analysis was done. Each variable was presented in form of Mean ± standard deviation.

Procedure

Each run began with a blank screen for 18 s (24 s for the 62-item block) before the experimental trials. In each trial, a word pair appeared on the screen for 4000 ms, during which participants judged the relationship in meaning between the two words and responded by pressing a "yes" or "no" button as quickly and accurately as possible with their left hand. The choice of hand was to abstain from involvement of left-hemisphere dominant language cortex during motor responses, as in Burton et al. (2009), Sabsevitz et al. (2005), and Sahin et al. (2006). Each trial was followed by a jittered inter-stimulus interval (ISI, computed by the Optseq software to optimize the partition of the hemodynamic responses overlapping between consecutive trials: mean = 4 s; interval rang: 2 s ~ 18 s). Throughout the session, a red dot remained in the center of the screen as the fixation point. Each run lasted 9.3 min, and a 2-minute break was given between runs. The entire experiment, including the preparation time, took approximately 45 min.

Behavioral data analysis

Participants' response accuracies and latencies were collected twice, once inside and once outside the scanner. The two sets of data were analyzed separately. Before data analysis, RT values of trials were discarded if a) incorrect responses were given or b) the RT was 3 standard deviations from each participant's mean. The former type was labeled as errors and entered into error analysis. To precisely compute the main effect of grammatical class, ANCOVA tests were applied with imageability as the covariate. Moreover, to assess the possibility of the task difficulty confounding, direct comparisons of the noun and verb conditions at high- and low-imageability levels were performed using *t*-tests with items and participants as random factors. Since grammatical class is a between-item but within-subject variable, independent and pair-wise *t*-tests were applied respectively.

fMRI data acquisition and processing

MRI scans were collected on a 3.0 Tesla Siemens scanner using a 12-channel transmit/receive gradient head coil (Beijing Normal University, China). A T2*-weighted gradient-echo planar imaging (EPI) sequence was applied to acquire the blood oxygen level-dependent (BOLD) signals (flip angle = 90°, TE = 30 ms, TR = 2000 ms, in-plane resolution = 3.125 × 3.125 mm, slice thickness = 4 mm, slice gap = 0.8 mm).

Data preprocessing and analysis were performed using SPM5 (http://www.fil.ion.ucl.ac.uk/spm/software/spm5/). The first 16 volumes were removed from each run (20 for the shorter run), before functional images were slice-time and head motion corrected for each run per subject. Subsequently, data were normalized to a standard template in Montreal Neurological Institute (MNI) space and then smoothed with an isotropic 8-mm full-width-half-maximal Gaussian kernel.

Due to excessive head motion (>2 mm or 2° within one run), the data of one participant were excluded from subsequent analysis. The images of the other 20 participants were entered into a two-step statistical analysis to examine the noun–verb effects at each of the two imageability levels. A conjunction analysis was then carried out to uncover regions showing grammatical effects across both types (high and low imageability) of nouns and verbs. Finally, using a Region of Interest (ROI) analysis, previously reported brain regions specifically activated for nouns or verbs were evaluated against our data, to evaluate the consistency of neural substances for word class processing of different languages.

The procedure of data analysis is detailed as follows.

Main effect and direct comparison analyses for the noun–verb contrasts

In the first-level analysis, a general linear model (GLM) was applied to explore the fixed-effect within each subject. Four experimental conditions — HN, HV, LN, and LV were modeled in an ER fashion, and convolved with a standard HRF (hemodynamic response function) as implemented in SPM5. The filler trials (F) were also included in the model so that the remaining TRs were all fixation trials, ensuring neat contrasts between the experimental conditions and the fixation period. Nuisance covariates included run effect, an intercept term, and motion. The default value of the high-pass filter (128 s) was also included to remove confounding influences on the BOLD signal, such as physiological noises from cardiac and respiratory cycles. We further checked the frequency domain figure after model estimation to ensure that our relatively high filter setting did not erroneously eliminate any trials signals. Contrasts between each experimental condition and fixation (i.e., HN-fixation, HV-fixation, LN-fixation, LV-fixation) were built and computed for every subject, generating contrast images with each carrying participant-specific statistical information for the given condition in comparison with the fixation period. Then, to generalize statistical inferences to the population level, a flexible factorial design was applied at the second-level analysis, to accommodate our 2 × 2 within-subject design in the SPM. Specifically, the contrast maps obtained at the first-level analysis, were selected to represent the subject-specific values for the corresponding conditions, and entered into the model in a subject-wise fashion. In addition to the usual main effects (grammatical class and concreteness) and their interaction, a subject effect was also included to isolate "subject variability due to general responsiveness of each subject" from the residual errors (Penny and Henson, 2006), making the model more sensitive.

Since our focus was on word class comparisons, the main effect of grammatical class was first computed and reported. Furthermore, direct comparisons between the noun and verb conditions at each imageability level were performed to 1) render our study more comparable to previous studies that used concrete materials or failed to balance imageability (HN vs. HV) and 2) to assess the noun–verb effects with minimal confounding with the object/action contrast or imageability (LN vs. LV).

For reporting of whole-brain analysis, only clusters with 77 or more voxels, in which voxel activity was significant at $p_{unc} < 0.01$ were considered, as confirmed by 10,000 Monte-Carlo iterations (by "AlphaSim" program installed in the REST toolbox, available for free download from http://restfmri.net/forum/?q=rest) to survive the corrected clusterwise significance threshold at 0.05. This method could be used to control for clusterwise type I error because the probability of random clustering of signal declines as the cluster size increases (http://afni.nimh.nih.gov/pub/dist/doc/manual/AlphaSim.pdf). With the information of voxelwise significance, smoothing range, as well as brain scale, the program could simulate the random distribution of signal across the whole brain. After 10,000 permutations (as applied here), a probabilistic curve against cluster size could be acquired. Any cluster with size larger than that of a given significance threshold (e.g., $p = 0.05$) could be considered as a true activated region with less than 5% false positive rate. For the current voxel-level significance of $p_{unc} < 0.01$, the choice of a cluster size of 77 voxels corresponded to a corrected clusterwise significance of $p = 0.0473$.

Conjunction analysis

To explore areas showing grammatical class effects common for various types of nouns and verbs, we conducted a conjunction analysis of the noun–verb comparisons at high- and low-imageability levels.

We adopted the method of conjunction analysis with a Monte-Carlo clusterwise correction applied in Slotnick and Schacter (2004, see also Shapiro et al., 2006). Specifically, direct grammatical comparisons at the high-imageability level was first computed with a significance threshold of $p_{unc} < 0.01$; the activation maps of which were used as masks for the corresponding comparison at the low-imageability level (i.e., mask of comparison, the significance threshold was also held at $p_{unc}<0.01$, but with a cluster extent threshold of 77 voxels, in order to survive a corrected clusterwise significance of 0.05 for both comparisons (at high- and low-imageability levels). Moreover, by applying the Fisher's (1973) equation, $\chi^2=-2\ln(P_1P_2)$, the chi-square value of the joint voxelwise probability for the current study could also be computed as $\chi^2=18.4$ ($p_1=p_2=0.01$), converted into a joint voxel level activity significance of $p_{joint}=0.001$, given $2\times n=4$ degree of freedom.

RT correlation

Previous behavioral studies have shown that nouns tended to be processed faster than verbs. The difference may be taken to indicate greater processing load required by verbs, which might confound with the word class effect. To assess the relationship between brain activation level and task demand, correlation between brain activation degree and response latency was evaluated. Specifically, with toolbox MarsBar (available for free download from http://www.mrc-cbu.cam.ac.uk/Imaging/marsbar.html), the subject-specific beta value for any established contrast could be extracted for any given area (averaged across all the voxels). Using this method, for every activated cluster, the beta values for the four contrasts (i.e., experimental conditions — fixation) were derived and then averaged as the activation level for each participant, which was then correlated with his/her corresponding averaged RT. The significance threshold was held at $p_{cor}<0.05$, after Bonferroni correction for multiple comparisons, corresponding to the original uncorrected significant level at $p_{unc}<0.05/n$, with n = number of ROIs. Furthermore, a more lenient threshold $p_{unc}<0.05$ was also applied to detect any weaker correlation.

Additional ROI analyses based on previous studies of Indo-European languages

To compare with neural correlates of word class effects associated with Indo-European languages, previously reported regions were analyzed using data from our experiment. Altogether, eight studies containing noun–verb contrasts or contrasts between either word class and baseline and using tasks involving semantic processing including picture naming and semantic judgment were considered (Bedny and Thompson-Schill, 2006; Bedny et al., 2008; Berlingeri et al., 2008; Longe et al., 2007; Saccuman et al., 2006; Tranel et al., 2005; Tyler et al., 2001; Warburton et al., 1996). Only anatomical regions reported in at least two studies were considered as reliable regions for grammatical processing, and selected as ROIs. Using this criterion, six anatomical areas (22 peak coordinates) were identified. With MarsBar, 22 ROIs were constructed based on the reported peaks (ROI radium: 6 mm, k = 33 voxels), from which subject specific β-values for each of the four conditions were extracted for each participant. Pairwise *t*-tests were carried out for each ROI to compute differences between HN and HV, as well as LN and LV, with subject as a random factor. An uncorrected significance threshold of $p<0.05$ and a threshold corrected for multiple comparisons were applied for each ROI.

Results

Behavioral results

The patterns of RT results exhibited by the participants in and outside the scanner were similar, though responses were generally slower during scanning, as illustrated in Table 2. For the error analysis, neither the main effect of grammatical class nor task difficulty evaluated through direct comparisons showed any significant result (see Table 2). In addition, since the directions of direct comparisons at both imageability levels were opposite for the data in the scanner, interaction analyses between grammatical class and imageability level were conducted. The results were only significant in the subject-wise analysis ($F_1(1,19)=5.21$, $p<0.05$; $F_2(1,\ 184)=2.46$, $p=0.12$). For the RT analysis, after covariating imageability, verb trials overall had longer RTs than noun trials, although the difference reached significance only for the results obtained in the scanner. Consistent with the ANCOVA results, significantly longer response time for the verbal trials in by-item and by-subject analyses in the low-imageability condition was found, as well as subject-wise *t*-test in the high-imageability condition.

Imaging results

Main effect and direct comparison analyses for the noun–verb contrasts

Whole brain analysis showed that, in comparison with verbs, nouns induced greater activation in frontal (left lateral cortex), temporal (left middle temporal gyrus, bilateral fusiform gyri), and occipital (middle occipital gyri bilaterally) lobes. Areas showing greater activation for verbs included left pars opercularis and insula gyri, bilateral superior and middle temporal gyri, right calcarine, as well as right cerebellum (see Table 3).

Direct comparisons at the high-imageability level revealed more bilateral activation for both HN and HV condition. HN induced greater activation than HV in bilateral inferior orbital frontal gyrus, ventral

Table 2
Error rates and response latencies in and outside scanner.

	Condition	Error rates		Item analysis	Response latencies		Item analysis
		Mean (%)	SD		Mean (ms)	SD	
In the scanner	Noun	4.5	0.073	$F_2(1, 185)=-0.06$	1211	142	$F_2(1, 185)=-3.93^{*}$
	Verb	4.8	0.067		1263	154	
	HN	5.0	0.084	$t_1\ (19)=1.30$;	1197	131	$t_1\ (19)=-3.83^{**}$;
	HV	3.8	0.048	$t_2\ (94)=0.90$	1228	134	$t_2\ (94)=-1.15$
	LN	3.9	0.060	$t_1\ (19)=-1.87^{+}$;	1226	153	$t_1\ (19)=-4.77^{***}$;
	LV	5.9	0.081	$t_2\ (90)=-1.31$	1300	167	$t_2\ (90)=-2.23^{*}$
Outside the scanner	Noun	4.1	0.069	$F_2(1, 185)=1.28$	1003	106	$F_2(1, 185)=-3.38^{+}$
	Verb	3.3	0.057		1038	111	
	HN	4.1	0.073	$t_1\ (19)=1.92^{+}$;	996	104	$t_1\ (19)=-2.35^{*}$;
	HV	2.3	0.034	$t_2\ (94)=1.53$	1012	93	$t_2\ (94)=-0.77$
	LN	4.2	0.067	$t_1\ (19)=-0.10$;	1010	109	$t_1\ (19)=-8.24^{***}$;
	LV	4.3	0.073	$t_2\ (90)=-0.08$	1065	122	$t_2\ (90)=-2.29^{*}$

HN = high imageability noun, HV = low imageability verb, LN = low imageability nouns, LV = low imageability verbs.
+ $p<0.1$.
* $p<0.05$.
** $p<0.01$.
*** $p<0.001$.

Table 3
Whole-brain analysis results.

Contrast	Activated areas	Peak			Z score	T	p	Cluster size
		X	Y	Z				
Noun–Verb	Left inferior and middle orbital frontal	−42	33	−18	4.58	5.06	0	191
	Left superior and middle frontal	−12	42	42	4.19	4.55	0	801
	Left rectus	−3	36	−24	3.24	3.41	0.001	132
	Left middle temporal	−54	3	−33	4.03	4.36	0	328
	Left fusiform	−30	−33	−21	5.21	5.92	0	439
	Right fusiform	33	−30	−21	3.63	3.87	0	82
	Left middle occipital	−33	−72	39	4.88	5.46	0	381
	Right middle occipital	45	−75	45	3.56	3.78	0	88
Verb–Noun	Left pars opercularis and insula	−51	9	6	5.21	5.92	0	3057
	Left superior and middle temporal	−45	−51	9	4.75	5.29	0	
	Right superior and middle temporal	51	−39	9	3.22	3.39	0.001	183
	Right calcarine	21	−63	9	3.83	4.11	0	564
	Right cerebellum	24	−69	−48	4.58	5.07	0	214
HN–HV	Left middle and superior medial frontal	−30	24	60	4.8	5.35	0	1407
	Left inferior orbital frontal	−45	39	−18	4.43	4.86	0	248
	Left superior temporal pole	−33	15	−21	3.51	3.72	0	
	Right inferior orbital frontal	36	39	−18	5.05	5.7	0	126
	Left inferior temporal	−54	3	−36	4.56	5.03	0	360
	Left fusiform	−33	−36	−18	5.32	6.09	0	382
	Right ventral temporal cortex (fusiform, inferior temporal, middle temporal)	36	−33	−18	3.89	4.18	0	322
	Left occipital and parietal junction (middle occipital and angular)	−33	−72	39	4.8	5.35	0	373
	Bilateral medial occipital and parietal junction (precuneus, lingual, calcarine)	−6	−57	12	3.64	3.88	0	151
HV–HN	Left pars opercularis and insula	−51	9	6	4.47	4.91	0	355
	Right pars opercularis and insula	39	18	12	3.72	3.97	0	85
	Bilateral paracentral cortex	12	−33	63	3.99	4.31	0	123
	Right precentral and postcentral	60	0	45	3.21	3.37	0.001	145
	Left superior and middle temporal	−57	−39	21	4.48	4.93	0	453
	Left middle occipital	−36	−96	9	4.03	4.35	0	130
	Right superior occipital and cuneus	18	−90	18	3.61	3.84	0	283
	Right cerebellum	24	−69	−48	5.05	5.71	0	164
	Left cerebellum	−30	−54	−48	3.63	3.86	0	129
LN–LV	None							
LV–LN	Left postcentral and precentral and pars opercularis	−60	3	36	3.99	4.31	0	505
	Right pars opercularis	36	0	30	3.67	3.91	0	228
	Bilateral SMA and superior frontal	−12	15	51	4.21	4.58	0	536
	Right superior frontal and cingulate	18	36	27	4.16	4.52	0	492
	Left middle and superior temporal	−66	−48	9	3.79	4.06	0	157
	Right superior and middle temporal	54	−36	9	3.55	3.77	0	131
	Right calcarine	30	−57	3	3.36	3.55	0	119
	Left cerebellum	−9	−75	−39	4.62	5.11	0	176

temporal cortex, medial occipital-parietal junction (OPJ), and left middle and superior medial frontal gyri, and left lateral OPJ. Higher activation for HV was observed in bilateral frontal lobe (left and right pars opercularis and insula gyri, bilateral paracentral cortex, and right precentral and postcentral gyri), occipital lobe (left middle occipital gyrus, right superior occipital, and cuneus gyrus), cerebellum, and left lateral temporal cortex. Direct comparisons at the low-imageability level showed similar verb-specific activation for the LV condition: bilateral regions in pars opercularis gyri, supplementary motor areas (SMA), lateral temporal cortex, right-lateralized superior frontal and cingulate gyri, calcarine, as well as left-lateralized cerebellum. No areas showing greater activation for LN than LV were observed.

Conjunction analysis

Due to the null result in the LN–LV comparison, conjunction analysis revealed no joint activation for the HN–HV and LN–LV contrasts. Left posterior superior and middle temporal cortex (Left posterior STG and MTG, or LpSTG&MTG) emerged for both HV–HN and LV–LN (peak at $X=-55$, $Y=-48$, $Z=12$; cluster size = 97). In addition, Brodmann area (BA) 44 lying over the boundary between LIFG left rolandic gyri showed marginally significant activation (peak at $X=-48$, $Y=6$; $Z=15$; cluster size = 75, corresponding to $p_{cor}=0.054$) (see Fig. 1).

Correlation between activation level and RT

ROI analysis showed that neither of the two areas more responsive to verb processing obtained in the conjunction analysis was sensitive to subject-level response latency (for left superior and middle temporal: $r_{18}=-0.25$, $p=0.29$; for BA 44: $r_{18}=-0.27$, $p=0.26$).

Additional ROI analyses based on previous studies

Table 4 presents the results of noun and verb comparisons in regions that were reported to exhibit grammatical class effects in the literature. For the left inferior temporal gyrus, which was commonly identified in previous research for noun processing, we observed stronger activation for HN relative to HV and comparable activation for LN and LV. Of the six verb-associated areas reported previously, several ROIs in the left lateral temporal cortex showed stronger verb activation for both high and low imageability conditions. Note that among these ROIs, there is one located in the left MTG (extending ventrally to the left inferior temporal) that was responsive to noun processing. Two clusters each from right middle and superior temporal gyri and left cerebellum also showed significantly higher activation for LV relative to LN, but comparable results for HV and HN. Once we have adopted thresholds corrected for the number of ROIs per region, the conflicting outcomes in left lateral temporal cortex

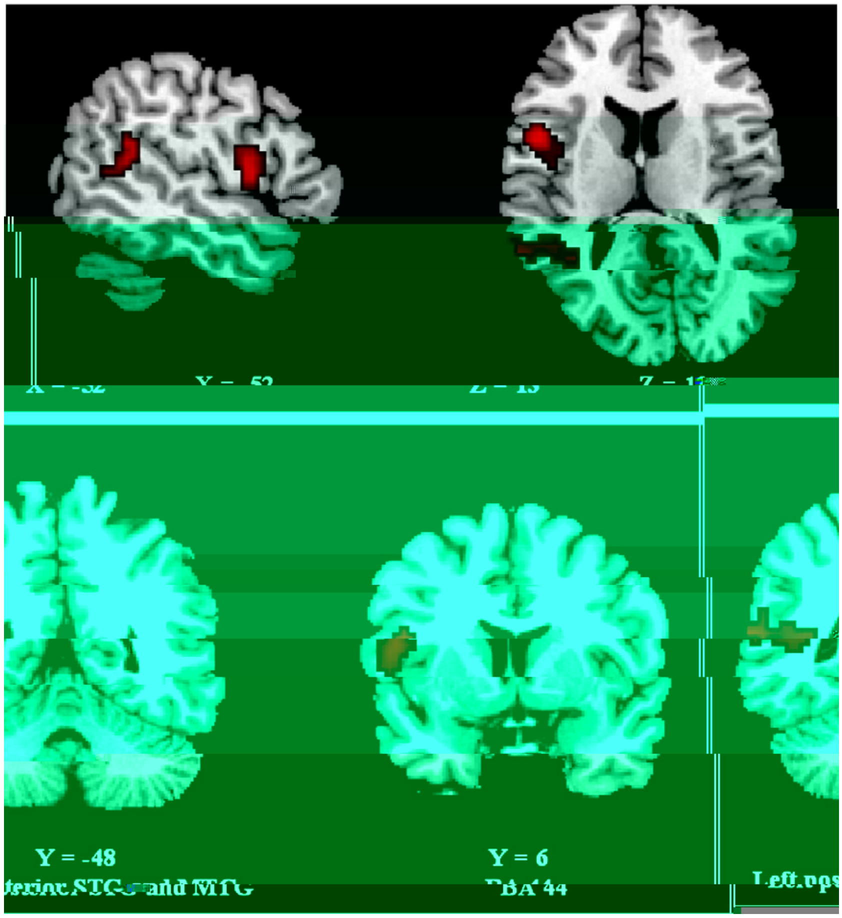

Fig. 1. Regions associated with verb processing based on conjunction analysis.

disappeared, while effects in the following regions still persisted: left inferior temporal gyrus (HN>HV); left lateral temporal (HV>HN and LV>LN), as well as left cerebellum (LV>LN).

Discussion

Our study examined the neural basis of semantic processing of nouns and verbs in a language with little inflectional morphology. To identify neural correlates that reliably reflect word class effects, the conjunction analyses based on comparisons between concrete nouns and verbs as well as between abstract nouns and verbs were carried out. We have found activation specifically associated with verbs, as revealed in the conjunction analyses, in left superior temporal and middle temporal gyri, as well as a region in the left inferior frontal cortex. No area more responsive to processing noun semantics was observed. It is important to note that our observation of separate neural representations of nouns and verbs cannot be seen as artifacts of unbalanced processing load measured by RT between the two word classes. Although behavioral data showed longer RT for verb stimuli, none of the noun/verb specific regions exhibited significant correlations between BOLD signal change and RT; these findings were consistent with the results in Burton et al. (2009). A range of brain regions was observed exhibiting noun–verb differences for only concrete items or abstract items.

As mentioned in the Introduction, the advantage of studying word class effects in Chinese is that comparisons between noun and verb conditions are less likely to be confounded with (automatic) morpho-syntactic processing, unlike the case with European languages. Given that the stimuli were presented in single word form in the current experiments, we argue that the brain areas sensitive to word class effects reflect distinctions between semantic processing of nouns and verbs as different word classes, at least for Chinese. Supporting evidence for our observations comes from neuropsychological cases reviewed in the Introduction (Bi et al., 2007; Lin et al., 2010), which exhibited specific deficits to concrete nouns due to lesions in ventral temporal cortex.

To compare with findings of previous studies of European languages, we carried out ROI analyses on regions that were reported to be specifically associated with semantic processing of nouns or verbs in the literature. Consistent with the whole brain analyses, the noun specific ROI in the inferior temporal lobe region showed greater activity for concrete items and not abstract items, suggesting that the noun–verb effects here might be due to imageability differences and/or other semantic differences between objects and actions (see detailed discussion below). Among the verb specific ROIs, the left lateral temporal regions (posterior middle and superior gyrus) showed significantly stronger activation for both concrete verbs and abstract verbs in comparison to nouns. By contrast, the verb effect was only significant for the abstract items in left cerebellum and did not reach significance for either concrete or abstract items in the LIFG, inferior temporal, right superior temporal and inferior parietal ROIs. Thus, among the regions showing noun–verb effects in previous studies, left posterior middle and superior temporal gyri were indeed sensitive to all types of verbs independent of concreteness/imageability and language types. It is worth mentioning that both regions reported to be more sensitive to inflected verbs than nouns in Longe et al. (2007) are close to our verb specific areas, but are more anterior and inferior, respectively. The fact that no significant effects were observed in these specific ROIs in our current analyses (using the corrected threshold) not only is

Table 4
ROI analysis of previously reported noun/verb associated regions.

ROIs	Peak	Source	HN–HV		LN–LV	
			T	p	T	p
Noun associated regions (noun>verb or noun>baseline (listed in bold))						
Left inferior temporal gyrus	−57, −30, −21	Bedny and Thompson-Schill (2006)	3.79**	0.001	0.54	0.595
	−26, −38, −12[1]	Tranel et al. (2005)[2]	4.55***	0.000	1.01	0.325
Verb associated regions (verb >noun or verb>baseline (listed in bold))						
Left inferior frontal gyrus	−52, 22, 0	Bedny et al. (2008)	0.03	0.979	−1.22	0.237
	−36, 22, 2[1]	Berlingeri et al. (2008)	0.82	0.423	−1.00	0.330
	−44, 24, 18[1]	Tranel et al. (2005)[2]	0.69	0.501	−0.18	0.860
	−22, 22, −14[1]	Longe et al. (2007)	0.91	0.376	1.02	0.323
	−52, 16, 16[1]	Warburton et al. (1996)[2]	0.38	0.707	1.40	0.177
Left inferior temporal gyrus	−45, −48, −10[1]	Tranel et al. (2005)[2]	0.31	0.761	0.74	0.467
	−48, −44, −26	Tyler et al. (2001)[2]	0.16	0.874	−0.04	0.969
	−56, −52, −4[1]	Warburton et al. (1996)[2]	−0.26	0.798	−0.11	0.915
Left lateral temporal cortex	−57, −39, 15	Bedny and Thompson-Schill (2006)	−4.19***	0.000	−1.50	0.150
	−62, −44, 20	Bedny et al. (2008)	−3.33**	0.004	−2.15*	0.045
	−58 −50, 6[1]	Berlingeri et al. (2008)	−1.94	0.068	−3.23**	0.004
	−46, −24, −14[1]	Longe et al., 2007	2.19*	0.041	−0.07	0.947
	−48, −60, 20[1]	Warburton et al. (1996)[2]	0.07	0.947	1.27	0.221
Right middle and superior temporal gyri	62, −32, 2	Bedny et al. (2008)	0.27	0.790	−2.24*	0.037
	52, −66, 0[1]	Berlingeri et al. (2008)	−1.02	0.322	0.04	0.965
Left inferior parietal	−44, −46, 44	Saccuman et al. (2006)	0.71	0.486	−0.06	0.951
	−52, −38, 32[1]	Warburton et al. (1996)[2]	−1.40	0.177	−1.03	0.317
Left cerebellum	−12, −78, −40	Saccuman et al. (2006)	−1.22	0.237	−2.68*	0.015
	−34, −36, −32[1]	Berlingeri et al. (2008)	0.19	0.851	−0.10	0.924
	−46, −54, −26[1]	Berlingeri et al. (2008)	0.56	0.583	−1.01	0.327

Note. Peak coordinates are reported in the MNI system, unless specified otherwise.
[1] Peak locations are reported in the Talairach system, converted into MNI coordinates manually before constructing ROIs.
[2] PET studies.
*** $p_{unc}<0.001$.
** $p_{unc}<0.01$.
* $p_{unc}<0.05$.

consistent with their proposal that those more anterior and inferior parts of lateral temporal and LIFG regions might be sensitive to the inflectional operations associated with verbs, but also supports our justification for the use of Chinese in this study.

Regarding the left lateral temporal activation for verbs, one view attempts to explain it with the different contribution of motion features in noun and verb concepts. Numerous reports showed that motion property is processed in this region, which is close to the visual motion area (MT) (Chao et al., 1999; Gainotti et al., 1995; Martin et al., 1995; Noppeney et al., 2005; Phillips et al., 2002). The relationship was further confirmed using point-light stimuli to prevent confounding from form processing (Beauchamp et al., 2003). It was, therefore, hypothesized that the verbs induced greater activation here because verb concepts contain more motion properties than nouns. Bedny et al. (2008) recently challenged this notion by showing that this region responds more strongly to verbs regardless of their motion content. They orthogonally manipulated the degree of motion content and word class, and observed that the area showed preference for verbs over nouns and was insensitive to motion types. Our findings here based on contrasts between abstract nouns and verbs provide further evidence for this view. Indeed, nouns and verbs (not only objects and actions) as two classes are associated with distinctive semantic emphases, in that nouns typically indicate static entities and expression, while verbs refer to dynamic and short-term events (e.g., Frawley, 1992; Langacker, 1999). It is possible that left posterior middle and superior temporal regions process information that is related to more abstract conceptual properties such as “dynamic event”. One further question is whether such verb-related “dynamic event” property is grounded in one or a combination of semantic dimensions other than motion such as “time”, “movement in space”, or “implied human actors”. One may test this by using nouns that imply time, movement and change, and human actors (e.g., “explosion”, “rainstorm”, “rocket”) and verbs that do not. While not systematically manipulated in the current study, many of the abstract verb stimuli do not involve time or movement/change (e.g., preserve, resemble). Our results therefore suggest that the noun/verb semantic difference is far more inclusive than sensory/motor features.

Another possible account for common neural substrates supporting the processing of both concrete and abstract verbs comes from language development (Caramazza, 1994). As hinted at in Vigliocco et al. (2010), the acquisition of syntactic classification is a fundamental issue in developmental psycholinguistics (e.g., Chomsky, 1965; Pinker, 1994; Tomasello, 2000). It is well established that concrete words (e.g., object and action words) are first learnt by children through sensomotor interaction with the physical world. Therefore, it is proposed that early concepts of nouns and verbs are aligned with objects and actions, respectively, i.e. semantic bootstrapping. Building on this, children later acquire the basic sentence structure by correlating thematic relations, such as agent, patient and action, with grammatical roles like subject, object, and predicate (Grimshaw, 1981; Pinker, 1982, 1984). Such knowledge is then used to parse sentence and obtain distributional cues, i.e. the word's serial position and adjacency relationship with other words in a phrase or sentence, or in relation to grammatical morphemes, which provide the foundation for subsequent learning of more abstract nouns and verbs, i.e. distributional bootstrapping (Finch and Chater, 1992; Redington, et al., 1998). Note that this explanation and the “abstract” verb semantic hypothesis discussed above are not mutually exclusive, rather, the developmental hypothesis may be seen as the mechanism for the abstract verb semantics to be where it is (closed to motion regions).

Both accounts for the verb specific effects may also apply to the left inferior frontal region (BA44). Another explanation that needs to be considered is that heavier processing load is associated with verbs, as LIFG has shown to be recruited in tasks with high demand on working memory (Fiebach et al., 2005; Paulesu et al., 1993; see a review in Owen et al., 2005). While verbs indeed had longer RTs than nouns in our study, simple processing demand accounts do not readily explain our results because the LIFG activation did not correlate with RT for the current task, and Chinese verbs are not associated with more complex inflectional paradigms than nouns. Nonetheless, verbs may be more complex than nouns in other aspects, e.g., in terms of number of senses or argument structures, and the existence of more subtle processing load differences that are not reflected by RT is still possible.

Worth highlighting is that the two verb-specific regions we observed – LIFG and LpSTG&MTG – roughly correspond to the two hubs for the verb processing network proposed by Crepaldi et al. (2010). Further connectivity analyses between these two regions and the other potential regions that function together with them in a network fashion are warranted.

We also observed a set of regions in both whole brain analyses and the ROI analyses that showed word class effects for only the concrete or only the abstract items. It is possible that the effects in the noun specific ROIs and the other regions that showing noun preferences for only concrete items (bilateral inferior orbital frontal gyrus, ventral temporal cortex, medial OPJ, left middle and superior frontal gyri, and left lateral OPJ) are driven by the imageability differences and/or other conceptual differences between objects and actions (Sabsevitz et al., 2005). Similarly, regions showing significant verb effects for only concrete verbs may have higher sensitivity to action related properties such as "somatic/motor" features (for bilateral paracentral lobules) or greater visual complexity being described (for bilateral middle occipital lobes, see also Berlingeri et al., 2008). The reason why some regions (left precentral gyrus, bilateral-SMA, right superior frontal and cingulate gyri, right calcarine, right superior and middle temporal gyri) showed verb effects only for the abstract items is less straightforward. We speculate that the greater activation in these areas might be due to particular difficulty in processing abstract verbs, as reflected by the longest RT (e.g., Mohamed et al., 2004). Further studies manipulating processing difficulties such as word frequencies are warranted.

In conclusion, word class effects were examined using a semantic judgment task carried out by speakers of a language which is unlikely to involve inflectional morphology. The results revealed that left posterior middle and superior temporal gyri, and left inferior frontal gyrus are more sensitive to both concrete and abstract verbs than nouns. As verbs and nouns differ along important semantic dimensions beyond inflectional morphology, our findings of separate neural correlates of semantic processing of these two word classes in Chinese are reasonable and indeed expected.

Acknowledgment

This study was supported by a General Research Fund from the Research Grant Council of Hong Kong (HKU 746608H). We thank Fang Fang and Han Zhang for their suggestions on experimental design and data analysis, and Nan Lin for his comments on a draft of this manuscript. We are also very grateful to all subjects for their participation.

Appendix A. Material list for current study (semantic related words are listed consecutively)

High-imageability Noun			High-imageability Verb			Low-imageability Noun			Low-imageability Verb		
Word	*Pronunciation*	Meaning	Word	*Pronunciation*	Meaning	Word	*Pronunciation*	Meaning	Word	*Pronunciation*	Meaning
墓	*/mu4/*	Grave	杀	*/sha1/*	Kill	贤	*/xian2/*	Virtue	试	*/shi4/*	Try
坟	*/fen2/*	Tomb	抢	*/qiang3/*	Rob	德	*/de2/*	Morals	猜	*/cai1/*	Guess
矿	*/kuang4/*	Mine	饮	*/yin3/*	Drink	财	*/cai2/*	Wealth		*/yu4/*	Compare
煤	*/mei2/*	Coal		*/he1/*	Drink	利	*/li4/*	Profit	拟	*/ni3/*	Resemble
稻草	*/dao4cao3/*	Straw	收听	*/shou1ting1/*	Listen	臣	*/chen2/*	Minister	感悟	*/gan3wu4/*	Feel
梯田	*/ti1tian2/*	Terrace	□看	*/guan1kan4/*	Watch	官	*/guan1/*	Officer	领略	*/ling3lüe4/*	Appreciate
□状	*/jiang3zhuang4/*	Award	告别	*/gao4bie2/*	Farewell	信念	*/xin4nian4/*	Belief	采取	*/cai2qu3/*	Adopt
勋章	*/xun1zhang1/*	Medal	送行	*/song4xing2/*	See off	意志	*/yi4zhi4/*	Will	施行	*/shi1xing2/*	Put in force
洞穴	*/dong4xue2/*	Cave	洗涤	*/xi3di2/*	Wash	□点	*/yao4dian3/*	Gist	归纳	*/gui1na4/*	Conclude
蝙蝠	*/bian1fu2/*	Bat	打扫	*/da3sao3/*	Sweep	核心	*/he2xin1/*	Crux	概括	*/gai4kuo4/*	Generalize
酒	*/pi2jiu3/*	Beer	叫卖	*/jiao4mai4/*	Hawk		*/tiao2li3/*	Quality of being well-organized	判断	*/pan4duan4/*	Judge
汽水	*/qi4shui3/*	Soda	吆	*/yao1he4/*	Cry out	逻辑	*/luo2ji4/*	Logic	推理	*/tui1li3/*	Deduce
宝石	*/bao3shi2/*	Gem	切割	*/qie1ge1/*	Cut	等级	*/deng3ji2/*	Grade	虚构	*/xv1gou4/*	Makeup
项链	*/xiang4lian4/*	Necklace	砍伐	*/kan3fa2/*	Chop	档次	*/dang4ci4/*	Level	编造	*/bian1zao4/*	Fabricate
光盘	*/guang1pan2/*	CD	亲吻	*/qin1wen3/*	Kiss	信誉	*/xin4yu4/*	Credit	抨击	*/peng1ji1/*	Attack
磁带	*/ci2dai4/*	Tape	拥抱	*/yong1bao4/*	Hug	名声	*/ming2sheng1/*	Reputation	批驳	*/pi1bo2/*	Refute
被窝	*/bei4wo1/*	Quilt	清洗	*/qing1xi3/*	Clean	生机	*/sheng1ji1/*	Vitality	保持	*/bao3chi2/*	Preserve
床单	*/chuang2dan1/*	Bedsheet	扫除	*/sao3chu2/*	Tidy up	朝气	*/zhao1qi4/*	Youthful spirit	维护	*/wei2hu4/*	Maintain
话筒	*/hua4tong3/*	Microphone	旋转	*/xuan2zhuan3/*	Spin	财力	*/cai2li4/*	Wealth	□劝	*/gui1quan4/*	Advise
耳机	*/er3ji1/*	Earphone	环绕	*/huan2rao4/*	Circle	身家	*/shen1jia1/*	Asset	引导	*/yin3dao3/*	Guide
子弹	*/zi3dan4/*	Bullet	嘱咐	*/zhu3fu4/*	Enjoin	言辞	*/yan2ci2/*	Diction	放任	*/fang4ren4/*	Indulgent
匕首	*/bi4shou3/*	Dagger	叮咛	*/ding1ning2/*	Urge	文笔	*/wen2bi3/*	Writing style	纵容	*/zong4rong2/*	Indulge
路标	*/lu4biao1/*	Road sign	背诵	*/bei4song4/*	Recite	成就	*/cheng2jiu4/*	Accomplishment	进取	*/jin4qu3/*	Proactive
地图	*/di4tu2/*	Map	阅读	*/yue4du2/*	Read	业绩	*/ye4ji4/*	Achievement	拼搏	*/pin1bo2/*	Struggle
海浪	*/hai3lang4/*	Ocean wave	摆动	*/bai3dong4/*	Sway	友谊	*/you3yi2/*	Friendship	钦佩	*/qin1pei4/*	Admire
波涛	*/bo1tao1/*	Billow	摇曳	*/yao2ye4/*	Joggle	情义	*/qing2yi4/*	Brotherhood	崇拜	*/chong2bai4/*	Adore
地铁	*/di4tie3/*	Subway	追逐	*/zhui1zhu2/*	Chase	程序	*/cheng2xu4/*	Procedure	思念	*/si1nian4/*	Miss
车票	*/che1piao4/*	Ticket	□跑	*/ben1pao3/*	Run	模式		身	项	*/baDoubtoggle*	

(*continued*)

High-ima			

References

Bates, E., Chen, S., Tzeng, O., Li, P., Opie, M., 1991. The noun–verb problem in Chinese aphasia. Brain Lang. 41, 203–233.

Baxter, D.M., Warrington, E.K., 1985. Category-specific phonological dysgraphia. Neuropsychologia 23, 653–666.

Beauchamp, M.S., Lee, K.E., Haxby, J.V., Martin, A., 2003. fMRI responses to video and pointlight displays of moving humans and manipulable objects. J. Cogn. Neurosci. 15, 991–1001.

Bedny, M., Thompson-Schill, S.L., 2006. Neuroanatomically separable effects of imageability and grammatical class during single-word comprehension. Brain Lang. 98, 127–139.

Bedny, M., Caramazza, A., Grossman, E., Pascual-Leone, A., Saxe, R., 2008. Concepts are more than percepts: the case of action verbs. J. Neurosci. 28, 11347–11353.

Berlingeri, M., Crepaldi, D., Roberti, R., Scialfa, G., Luzzatti, C., Paulesu, E., 2008. Nouns and verbs in the brain: grammatical class and task specific effects as revealed by fMRI. Cogn. Neuropsychol. 25, 528–558.

Bi, Y., Han, Z., Shu, H., Caramazza, A., 2007. Nouns, verbs, objects, actions, and the animate/inanimate effect. Cogn. Neuropsychol. 24, 485–504.

Bird, H., Howard, D., Franklin, S., 2000. Why is a verb like an inanimate object? Grammatical category and semantic category deficits. Brain Lang. 72, 246–309.

Bogka, N., Masterson, J., Druks, J., Fragioudaki, M., Chatziprokopiou, E.S., 2003. Object and action picture naming in English and Greek. Eur. J. Cogn. Psychol. 15, 371–403.

Burton, M., Krebs-Noble, D., Gullapalli, R., Berndt, R., 2009. Functional neuroimaging of grammatical class: ambiguous and unambiguous nouns and verbs. Cogn. Neuropsychol. 26, 148–171.

Caramazza, A., 1994. Parallels and divergences in the acquisition and dissolution of language. Philos. Trans. R. Soc. Lond. B 346, 121–127.

Caramazza, A., Hillis, A.E., 1991. Lexical organization of nouns and verbs in the brain. Nature 349, 788–790.

Chao, L.L., Haxby, J.V., Martin, A., 1999. Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. Nat. Neurosci. 2, 913–919.

Chomsky, N., 1965. Aspects of the Theory of Syntax. MIT Press, Boston, MA.

Coltheart, M., Patterson, K.E., Marshall, J.C., 1980. Deep Dyslexia. Routledge, London.

Crepaldi, D., Berlingeri, M., Paulesu, E., Luzzatti, C., 2010. A place for nouns and a place for verbs? A critical review of neurocognitive data on grammatical-class effects. Brain Lang. 116, 33–49.

Damasio, A., Tranel, D., 1993. Nouns and verbs are retrieved with differentially distributed neural systems. Proc. Natl Acad. Sci. U. S. A. 90, 4957–4960.

Daniele, A., Giustolisi, L., Silveri, M.C., Colosimo, C., Gainotti, G., 1994. Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs. Neuropsychologia 32, 1325–1341.

Davis, M.H., Meunier, F., Marslen-Wilson, W.D., 2004. Neural responses to morphological, syntactic, and semantic properties of single words: an fMRI study. Brain Lang. 89, 439–449.

Federmeier, K.D., Segal, J.B., Lombozo, T., Kutas, M., 2000. Brain responses to nouns, verbs and class-ambiguous words in context. Brain 123, 2552–2566.

Fiebach, C.J., Schlesewsky, M., Lohmann, G., 2005. Revisiting the role of Broca's area in sentence processing: syntactic integration versus syntactic working memory. Hum. Brain Mapp. 24, 79–91.

Finch, S.P., Chater, N., 1992. Bootstrapping syntactic categories. Proceedings of the 14th Annual Conference of the Cognitive Science Society of America. Lawrence Erlbaum Associates, Hillsdale, NJ.

Fisher, R.A., 1973. Statistical Methods for Research Workers. Hafner, New York.

Franklin, S., Howard, D., Patterson, K., 1994. Abstract word meaning deafness. Cogn. Neuropsychol. 11, 1–34.

Frawley, W., 1992. Linguistic Semantics. Lawrence Erlbaum, Hillsdale, NJ.

Gainotti, G., Silveri, M.C., Daniele, A., Giustolisi, L., 1995. Neuroanatomical correlates of category-specific semantic disorders: a critical survey. Memory 3, 247–264.

Grimshaw, J., 1981. Form, function, and the language acquisition device. In: Baker, C.L., McCarthy, J.J. (Eds.), The Logical Problem of Language Acquisition. MIT Press, Cambridge, MA, pp. 183–210.

Kable, J.W., Lease-Spellmeyer, J., Chatterjee, A., 2002. Neural substrates of action event knowledge. J. Cogn. Neurosci. 14, 795–805.

Laiacona, M., Caramazza, A., 2004. The noun/verb dissociation in language production: varieties of causes. Cogn. Neuropsychol. 21, 103–123.

Langacker, R.W., 1999. Grammar and Conceptualization. Walter De Gruyter, Berlin, Germany.

Laudanna, A., Voghera, M., 2002. Nouns and verbs as grammatical classes in the lexicon. Riv. Linguist. 14, 9–26.

Li, C., Thompson, S., 1981. Mandarin Chinese: A Functional Reference Grammar. Univ. of California Press, Berkeley.

Li, P., Jin, Z., Tan, L.H., 2004. Neural representations of nouns and verbs in Chinese: an fMRI study. Neuroimage 21, 1533–1541.

Lin, N., Guo, Q., Han, Z., Bi, Y., 2010. Motor knowledge is one dimension for concept organization: Further evidence from a Chinese semantic dementia case. Brain Lang. doi:10.1016/j.bandl.2010.07.001.

Longe, O., Randall, B., Stamatakis, E.A., Tyler, L.K., 2007. Grammatical categories in the brain: the role of morphological structure. Cereb. Cortex 17, 1812–1820.

Martin, A., Haxby, J.V., Lalonde, F.M., Wiggs, C.L., Ungerleider, L.G., 1995. Discrete cortical regions associated with knowledge of color and knowledge of action. Science 270, 102–105.

McCarthy, R., Warrington, E.W., 1985. Category-specificity in an agrammatic patient: the relative impairment of verb retrieval and comprehension. Neuropsychologia 23, 709–727.

Miceli, G., Caramazza, A., 1988. Dissociation of inflectional and derivational morphology. Brain Lang. 35, 24–65.

Miceli, G., Silveri, M.C., Nocentini, U., Caramazza, A., 1988. Patterns of dissociation in comprehension and production of nouns and verbs. Aphasiology 1 (2), 351–358.

Mohamed, M.A., Yousem, D.M., Tekes, A., Browner, N., Calhoun, V.D., 2004. Correlation between the amplitude of cortical activation and reaction time: a functional MRI study. AJR Am. J. Roentgenol. 183, 759–765.

Nickels, L., Howard, D., 1995. Aphasic naming—what matters? Neuropsychologia 33, 1281–1303.

Noppeney, U., Price, C.J., 2004. Retrieval of abstract semantics. Neuroimage 22, 164–170.

Noppeney, U., Josephs, O., Kiebel, S., Friston, K.J., Price, C.J., 2005. Action selectivity in parietal and temporal cortex. Cogn. Brain Res. 25, 641–649.

Owen, A.M., McMillan, K.M., Laird, A.R., Bullmore, E.T., 2005. N-back working memory paradigm: a meta-analysis of normative functional neuroimaging studies. Hum. Brain Mapp. 25, 46–59.

Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9, 97–113.

Palti, D., Ben-Shachar, M., Hendler, T., Hadar, U., 2007. The cortical correlates of grammatical category differences: an fMRI study of nouns and verbs. Hum. Brain Mapp. 28, 303–314.

Paulesu, E., Frith, C.D., Frackowiak, R.S.J., 1993. The neural correlates of the verbal component of working memory. Nature 362, 342–345.

Penny, W., Henson, R., 2006. Hierarchical models. In: Penny, W., Friston, K.J., Ashburner, J.T., Kiebel, S.J., Nichols, T.E. (Eds.), Statistical Parametric Mapping: the Analysis of Functional Brain Images. Academic Press, New York, pp. 148–155.

Phillips, J.A., Noppeney, U., Humphreys, G.W., Price, C.J., 2002. Can segregation within the semantic system account for category-specific deficits? Brain 125, 2067–2080.

Pinker, S., 1982. A theory of the acquisition of lexical interpretive grammars. In: Bresnan, J. (Ed.), The Mental Representation of Grammatical Relations. MIT Press, Cambridge, MA.

Pinker, S., 1984. Language Learnability and Language Development. Harvard University Press, Cambridge, MA.

Pinker, S., 1994. The Language Instinct. HarperCollins, New York.

Rapp, B., Caramazza, A., 1993. On the distinction between deficits of access and storage: a question of theory. Cogn. Neuropsychol. 10, 113–141.
Redington, M., Chater, N., Finch, S., 1998. Distributional information: a powerful cue for acquiring syntactic categories. Cogn. Sci. 22, 435–469.
Robins, R.H., 1952. Noun and verb in universal grammar. Language 28, 289–298.
Sabsevitz, D.S., Medler, D.A., Seidenberg, M., Binder, J.R., 2005. Modulation of the semantic system by word imageability. Neuroimage 27, 188–200.
Saccuman, M.C., Cappa, S.F., Bates, E.A., Arevalo, A., Rosa, P.D., Danna, M., Perani, D., 2006. The impact of semantic reference on word class: an fMRI study of action and object naming. Neuroimage 32, 1865–1878.
Sahin, N.T., Pinker, S., Halgren, E., 2006. Abstract grammatical processing of nouns and verbs in Broca's area: evidence from fMRI. Cortex 42, 540–562.
Shapiro, K., Caramazza, A., 2003. Grammatical processing of nouns and verbs in the left frontal cortex. Neuropsychologia 41, 1189–1198.
Shapiro, K., Shelton, J., Caramazza, A., 2000. Grammatical class in lexical production and morphological processing: evidence from a case of fluent aphasia. Cogn. Neuropsychol. 17, 665–682.
Shapiro, K., Moo, L.R., Caramazza, A., 2006. Cortical signatures of noun and verb production. Proc. Natl Acad. Sci. U. S. A. 103, 1644–1649.
Shu, H.L., Huang, J.P., Sun, D.J., Li, D.J., Xing, H.B., 1997. Introduction to language corpus system of modern Chinese study. In: Hu, M.Y. (Ed.), Paper Collection for the Fifth World Chinese Teaching Symposium. Peking University Publisher, Beijing.
Siri, S., Tettamanti, M., Cappa, S., Della Rosa, P., Saccuman, C., Scifo, P., Vigliocco, G., 2008. The neural substrate of naming events: effects of processing demands but not of grammatical class. Cereb. Cortex 18, 171–177.
Slotnick, S.D., Schacter, D., 2004. A sensory signature that distinguishes true from false memories. Nat. Neurosci. 7, 664–672.
Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arevalo, A.L., Vargha, A., Bates, E., 2005. Timed action and object naming. Cortex 41 (1), 7–25.
Tomasello, M., 2000. Do young children have adult syntactic competence? Cognition 74, 209–253.
Tranel, D., Martin, C., Damasio, H., Grabowski, T.J., Hichwa, R., 2005. Effects of noun–verb homonymy on the neural correlates of naming concrete entities and actions. Brain Lang. 92, 288–299.
Tsapkini, K., Jarema, G., Kehayia, E., 2002. A morphological processing deficit in verbs but not in nouns: a case study in a highly inflected language. J. Neurolinguist. 15,665