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Neural representations of nouns and verbs in Chinese: an fMRI study

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The neural representation of nouns and verbs has been a focus of many recent neuroimaging and neuropsychological studies. These studies have in general found that in English and other Indo-European languages, verbs are represented in the frontal region (e.g., the left prefrontal cortex) while nouns in the posterior regions (the temporal–occipital regions). There is accumulating evidence, however, that the picture may have been overly simplified. In the present study, we examine the representations of nouns and verbs in Chinese, a language that has unique properties in its grammar and particularly in the structure of nouns and verbs. In an fMRI experiment, subjects viewed a list of disyllabic nouns, verbs, and class-ambiguous words and performed a lexical decision on the target. Results from the experiment indicate that nouns and verbs in Chinese activate a wide range of overlapping brain areas in distributed networks, in both the left and the right hemispheres. The results provide support for the prediction regarding the impact of linguistic typology and language-specific influences on the neural representation of grammatical categories. They are consistent with recent proposals that specific linguistic experience shapes neural systems of reading and speaking and that the language-specific properties of the Chinese grammar affect the representation, processing, and acquisition in this language.

Keywords: Noun; Verb; Chinese; fMRI

Introduction

A central issue in the cognitive neuroscience of language is how the brain represents linguistic categories such as nouns, verbs, and adjectives. Neuropsychological studies of brain-injured patients and neuroimaging studies of normal speakers have both suggested specific brain areas that respond to different linguistic categories, in particular, object names (nouns) and action names (verbs). For example, while Broca's aphasics have significant problems with action/verb naming, Wernicke's aphasics typically experience difficulties in producing nouns (Bates et al., 1991; Caramazza and Hillis, 1991; Miceli et al., 1988; Shapiro and Caramazza, 2003). PET studies reveal that nouns and verbs elicit responses from different regions of the brain: nouns or object names activate the posterior regions (occipitotemporal areas, including the visual cortex) while verbs or action names activate the prefrontal and frontal–temporal regions (e.g., Damasio and Tranel, 1993; Martin et al., 1995; Petersen et al., 1989; Pulvermüller, 1999; Wise et al., 1991).

In a typical PET study of nouns and verbs, subjects are presented with a series of experimental stimuli either visually (e.g., picture of a pencil or the noun *pencil*) or aurally (e.g., the spoken word *pencil*). Their task is to name the stimulus or to generate (silently or overtly) an action word that is associated with the stimulus (e.g., *pencil*→ *write*), the latter being the so-called "verb generation task". Comparisons are made between naming, reading, and verb generation of the stimuli to identify areas with significantly increased regional cerebral blood flow (rCBF) activities. In an earlier study, Petersen et al. (1989) showed that the verb generation task leads to enhanced activities in the left frontal cortex for verbs as compared with activities for nouns. Martin et al. (1995) found that the generation of verbs activates the middle temporal gyrus, the left inferior frontal lobe (Broca's area), and the right cerebellum, while the generation of color words (nouns) activates a region in the ventral temporal lobe. Wise et al. (1991) presented subjects with nouns and verbs binaurally, and found that activations in semantic judgments of noun–noun and verb–noun pairs did not differ, but verb generation produced significantly increased rCBF in Broca's area, the posterior part of the left middle frontal gyrus, and the supplementary motor area. In general, these results suggest that verb generation tends to evoke stronger activities in the left frontal cortex, compared to the generation of nouns.

Several electrophysiological studies also investigated noun–verb differences in the brain. Dehaene (1995) presented subjects with nouns, verbs, and numerals and found that nouns elicited negativity in bilateral temporal regions, whereas verbs elicited left temporal negativity with additional left inferior frontal positivity, and that such category-specific differences emerged between 256 and 280 ms after stimulus onset. Preissl et al. (1995) found ERP differences in the frontal lobes between nouns and verbs as early as 200 ms after stimulus onset. They suggested that the neuronal activities in the motor cortices are due to the strong motor associations elicited by verbs while the activities in the visual cortices due to the strong visual associations elicited by nouns (see Pulvermüller et al., 1996 for similar arguments and findings based on an EEG study). More recently, Federmeier et al. (2000), in a study with nouns, verbs, and class-ambiguous words embedded in

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sentence contexts (e.g., *John wanted the [target word] but* ...), found that verbs elicited a unique left-lateralized, frontal positivity between 200 and 400 ms after stimulus onset, which was not observed for nouns or ambiguous words. Ambiguous words (e.g., *paint*) elicited greater frontal negativity, suggesting that ambiguous words and unambiguous nouns and verbs have distinct neural representations. Largely, the ERP or EEG results are consistent with PET results in showing that the noun–verb differences tend to be related to neural activities in the frontal versus the posterior regions.

One potential problem with these studies (especially the PET studies), as Pulvermüller (1999) points out, is that many generated action words in the "verb generation task" are not necessarily verbs (e.g., nouns that describe movement or action). Pulvermüller found that nouns referring to actions could yield results indistinguishable from those that have been claimed for verbs. Tyler et al. (2001) pointed out other specific problems with the verb generation task; for example, in most such tasks, subjects receive both nouns and verbs in a single trial (with both contributing to the activation), and therefore the task may not tap just verb processing. Shying away from the verb generation task, Perani et al. (1999) used a lexical decision task in which subjects are asked to judge whether a presented stimulus is or is not a legal word of the language. They found that although Italian speakers responded to verbs with significantly more activation, in a wide range of areas, than to nouns, the subjects showed no areas that were more active for nouns than for verbs. The authors attributed this pattern to the fact that the nouns used in their experiment involved tool names that carry overlapping semantic features with verbs.

In addition to Perani et al.'s results (which cast doubt on a clear-cut neural distinction for nouns and verbs), there are other studies that start to challenge the strong hypothesis regarding noun–verb cortical distinctions. Warburton et al. (1996) showed that the retrieval of nouns and verbs in tasks such as verb generation and noun–verb comparison activates widely distributed brain regions: in the left hemisphere, all processes associated with word retrieval produced similar distributions of activations in temporal, parietal, and prefrontal regions for nouns and verbs. The only difference observed was that verbs elicited stronger activations overall, consistent with Perani et al.'s finding. Tyler et al. (2001), in lexical decision and semantic categorization tasks, found that when stimulus words were matched for imageability, frequency, and word length, nouns and verbs both elicited activations in the left prefrontal and inferior temporal cortices, and that words of contrasting imageability (abstract vs. concrete) and frequency (low vs. high) showed no significant differences. These authors interpreted their results as indicating that the conceptual system of lexical knowledge is represented in a distributed and undifferentiated network in which linguistic categories or domain structures are not weighted.

While the above findings are important in unraveling linguistic representations in the brain, they are primarily limited to Indo-European languages. In this study, we test the generality of these findings in Chinese, a language that differs significantly in structure from English and other Western languages. This is particularly interesting in view of the possibility that nouns and verbs do not necessarily evoke distinct cortical activities.

It has been argued that the structural properties of Chinese have major impact on the representation, processing, and learning of this language (Chen et al., 2002; Li et al., 1993, in press; Tan et al., 2003). With respect to grammatical categories, some linguists have gone so far as to argue that grammatical classes like nouns and verbs cannot be properly distinguished as such in Chinese because of the lack of inflectional morphology and the multiple grammatical roles that words can play in this language (Kao, 1990; see also Hu, 1996 for a review of the debates on Chinese lexical classes). In many Indo-European languages, nouns are marked for gender, number, and definiteness, while verbs marked for aspect, tense, and number. In Chinese, most of these grammatical markers for nouns and verbs are absent (with the exception of aspect markers). In addition, many Chinese verbs can occur freely as subjects and nouns as predicates involving no morphological change (Mo and Shan, 1985). Furthermore, Chinese has a large number of class-ambiguous words that can be used as nouns and as verbs (like *paint* in English); unlike their counterparts in English or other languages, these ambiguous words involve no morphological changes when used in the sentence. Linguists call these "words of dual membership",[1] which are related in meaning and identical in pronunciation and orthography. According to one estimate (Guo, 2001), about 17% of the high frequency Chinese words have the dual membership status. Another estimate, specifically on nouns and verbs, indicates that regardless of frequency, between 13% and 29% (depending on test criteria) of Chinese monosyllabic and disyllabic words can be used as nouns and as verbs (Hu, 1996). Although such ambiguous words are also possible in other languages, they may not occur as frequently and may involve morphological changes: for example, most German nouns cannot be used as verbs, and Italian homophonous noun–verb forms often occur with different morphological endings (e.g., *speranza*, "hope"; *sperare*, "to hope").

A natural question to ask is how these language-specific properties affect representations in the brain. Do speakers of typologically different languages have different neural representations for nouns and verbs? One prediction, based on such differences as discussed, would be that nouns and verbs in Chinese do not involve distinct neural representations as they do in English or other languages, due to the lack of grammatical markings on these words and the large number of class-ambiguous noun–verb items. Fiebach et al. (2002) recently found that even in a morphologically rich language like German, nouns and verbs do not elicit different brain responses when grammatical cues are missing; differences arise when grammatical cues are present. However, accounts of nouns and verbs based purely on grammatical considerations are inadequate according to some linguists and psycholinguists: nouns and verbs differ in lexical semantics, lexical co-occurrences, and other cognitive and conceptual dimensions such as imageability and translatability (Gentner, 1981), and hence, Chinese nouns and verbs might also be different in these domains. In addition, there is neuropsychological evidence that Chinese Broca's and Wernicke's patients experience similar difficulties with nouns and verbs as aphasic patients do in other languages (Bates et al., 1991). Such considerations would lead, however, to a prediction that the neural representation of nouns and verbs in Chinese is also subserved by distinct cortical regions.

Our study attempts to test these competing predictions. It contributes to the understanding of lexical category representation in three ways. First, previous imaging studies of nouns and verbs have relied mostly on the use of PET or ERP techniques, while our study uses fMRI to investigate the issue. Second, previous studies

[1] Dual memberships can occur not only between nouns and verbs but also between other grammatical classes in Chinese (see Hu, 1996).

have examined only English and other Western languages, while our study investigates Chinese, a language that has unique properties in its grammar and particularly in the structure of nouns and verbs. Finally, previous studies have mostly examined nouns and verbs alone,[2] while our study tests a class of ambiguous words that can occur both as nouns and as verbs.

Methods

Subjects

Eight native Mandarin Chinese speakers, four males and four females, participated in this fMRI study. They gave informed consent in accordance with guidelines set by the University of Hong Kong and Beijing 306 Hospital. They were all undergraduate students from Beijing Normal University, ranging in age from 19 to 23 years.

All subjects were strongly right-handed as judged by the handedness inventory devised by Snyder and Harris (1993). We adopted nine items from the inventory involving unimanual tasks (i.e., tasks that can be done by only one hand). A 5-point Likert-type scale was used, with "1" representing *exclusive left-hand use* and "5" representing *exclusive right-hand use*. The nine items were writing a letter, drawing a picture, throwing a ball, holding chopsticks, hammering a nail, brushing teeth, cutting with scissors, striking a match, and opening a door. The scores on these items were summed for each subject, with the lowest score, 9, indicating exclusive left-hand use for all tasks, and the highest score, 45, indicating exclusive right-hand use. All subjects had scores higher than 40.

Materials

A total of 68 words were selected as experimental materials presented to subjects visually in a lexical decision task (see Appendix A for the list and their English glosses). The words were selected from the *Dictionary of Grammatical Information of Modern Chinese* (Yu et al., 1998), in which each word is marked for its grammatical properties and functions with examples. These words were divided into three sets, with the noun set and the class-ambiguous set each containing 23 words and the verb set containing 22 words. All test words were disyllabic, that is, made of two characters, given the consideration that the majority of Chinese words (especially class-ambiguous words) are disyllabic (see Hu, 1996 for statistical estimates). All words were of relatively high frequency according to the CMCR corpus (Corpus for Modern Chinese Research; Beijing Language Institute, 1995): mean frequency for nouns was 10 952 in 1.2 million word tokens; for verbs, 10 693; and for ambiguous words, 19 776.[3] An attempt was also made to select words of relatively high imageability, although no imageability norms are available for Chinese words. The visual complexity of the stimuli was controlled by the number of strokes in the two characters (mean number of strokes for nouns was 15.3; for verbs, 15.8; and for ambiguous words, 16.5). A separate set of 66 disyllabic nonwords was also selected to serve as fillers. The nonwords were made by the juxtaposition of two legal characters that do not form legal words. The visual complexity of these nonwords was comparable to that of the word stimuli (mean number of strokes was 16.6).

Apparatus and procedure

The experiment was performed on a 1.9 T GE/Elscint Prestige whole-body MRI scanner (GE/Elscint Ltd., Haifa, Israel). Before fMRI imaging, the subject was visually familiarized with the procedures and the experimental conditions to minimize anxiety and enhance task performance. Visual stimuli were presented to subjects through a projector onto a translucent screen. Subjects viewed the stimuli through a mirror attached to the head coil. A T2*-weighted gradient-echo echo planar imaging (EPI) sequence was used for fMRI scans, with the slice thickness = 6 mm, in-plane resolution = 2.9 $\times$2.9 mm, and TR/TE/θ = 2000 ms/45 ms/90°. The field of view was 373 mm $\times$ 210 mm, and the acquisition matrix was 128 $\times$ 72. Eighteen contiguous axial slices parallel to the AC-PC line covering the whole brain were acquired while the subject performed the task. The high-resolution (1 $\times$ 1 $\times$ 2 mm^3) anatomical brain MR images were acquired using a T1-weighted, 3-D gradient-echo sequence.

Each experimental condition consisted of 23 disyllabic words (22 for the verbs) and 22 nonwords. A block design was used, with three blocks for each experimental condition and nine blocks for the baseline condition. Each block in one experimental condition had 15 trials. In each trial, a word (or nonword) was exposed for 600 ms, followed by a 1400-ms blank screen. Subjects performed a lexical decision task in which they judged whether a visually presented stimulus was a real two-character Chinese word. Subjects indicated a positive response by pressing the key with the index finger of their right (dominant) hand. They were asked to perform the task as quickly and as accurately as possible. A fixation baseline was adopted. In the baseline condition, subjects maintained fixation on a crosshair for 16 s.

Data analysis

Data were preprocessed using SPM99 (http://www.fil.ion.ucl.ac.uk/spm/). Images were corrected for motion across all runs by using sinc interpolation. Structural and functional data were spatially normalized to an EPI template based on the ICBM152 stereotactic space (Cocosco et al., 1997), an approximation of canonical space (Talairach and Tourmoux, 1998), using an average of 152 stereotaxic T1-weighted volumes. Images were resampled into 2 $\times$ 2 $\times$ 2 mm cubic voxels and then spatially smoothed with an isotropic Gaussian kernel (6-mm full width at half-maximum).

Functional images were grouped into the noun, verb, and ambiguous sets. Images from the first 6 s of each condition were excluded from further functional data processing to minimize the transit effects of hemodynamic responses. Activation maps were generated by using a cross-correlation method (Friston et al., 1995), where the activity of each pixel was correlated to a boxcar function that was convolved with the canonical hemodynamic response function. Low-frequency signal components were treated as nuisance covariates. Inter-subject variability in global intensity was corrected by the use of proportional scaling to a common

[2] The only study that has looked at the class-ambiguous words we are aware of is Federmeier et al. (2000), in an ERP study of lexical categories in sentence context, as reviewed above.

[3] The higher frequency for the ambiguous set might be simply because ambiguous words can occur in both the noun contexts and the verb contexts.

mean. Subject-specific linear contrasts for each of the effects of interest were assessed, including (1) noun–baseline, (2) verb–baseline, (3) ambiguous–baseline, (4) noun–verb, and (5) verb–noun. These contrasts were then entered into a second-level analysis treating subjects as a random effect, using a one-sample Student's t test against a contrast value of zero at each voxel. Only activations that fell within clusters of 10 or more contiguous voxels exceeding the uncorrected statistical threshold of $P < 0.001$ were considered significant.

Results

Brain activation fMRI images averaged across the eight subjects for nouns versus fixations, verbs versus fixations, and ambiguous words versus fixations are shown in Fig. 1. Significant areas of activation for these comparisons are summarized in Table 1.

Comparisons of each of the three experimental conditions (nouns, verbs, ambiguous words) with fixations showed brain activities in bilateral inferior prefrontal gyri (BAs 44/45/46),

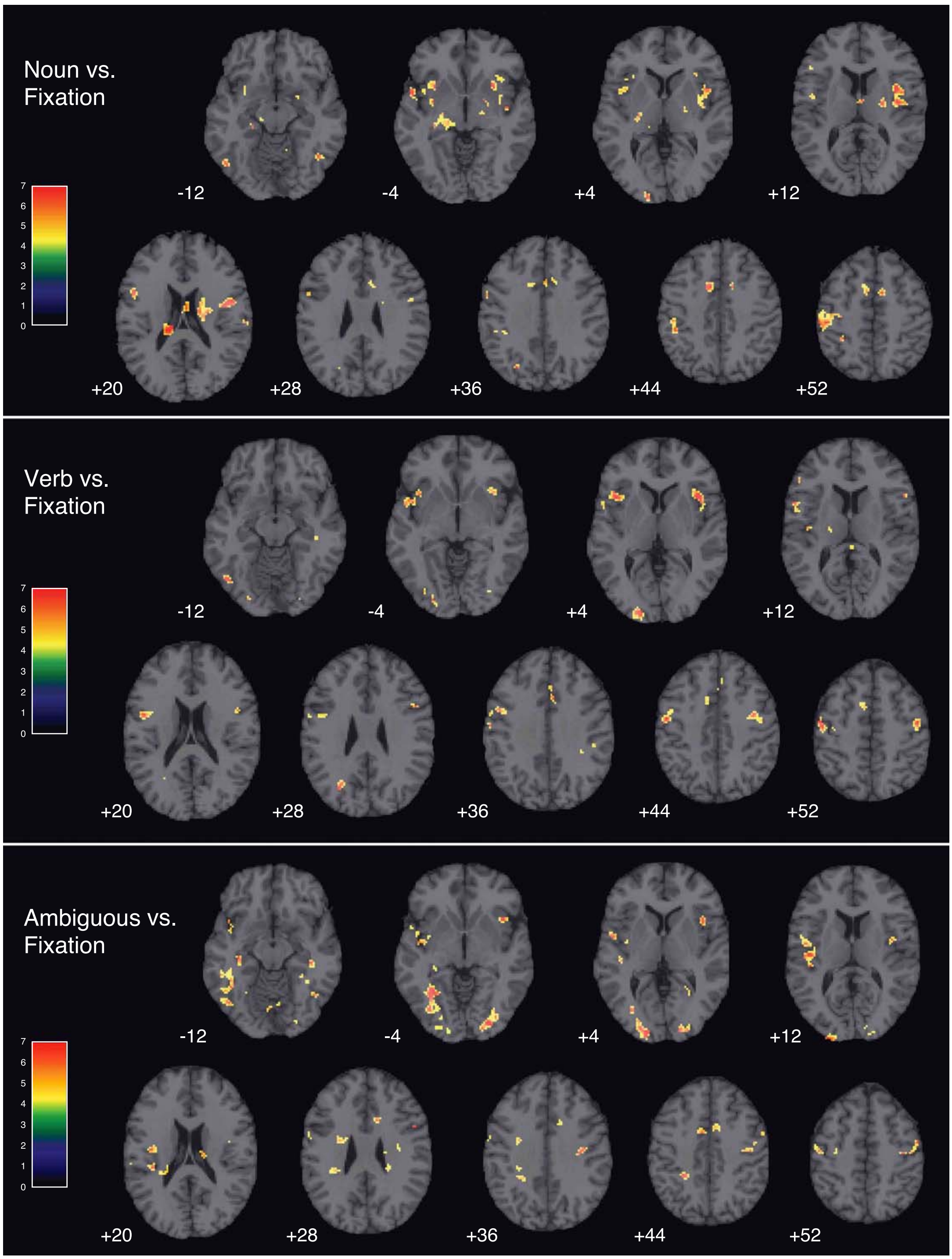

Fig. 1. Averaged brain activations for nouns versus fixations, verbs versus fixations, and class-ambiguous words versus fixations.

Table 1
Stereotactic coordinates, *t* values, and corresponding Brodmann's Areas (BA) for regions showing significant activations

Regions activated	Noun vs. fixation			Verb vs. fixation			Ambiguous vs. fixation		
	BA	Coordinate	*t*	BA	Coordinate	*t*	BA	Coordinate	*t*
Frontal									
L inferior frontal gyrus	44	−50, 11, 20	11.58	46	−50, 32, 11	6.26	44	−59, 5, 22	5.93
	46	−48, 28, 12	5.97						
L postcentral gyrus	2	−48, −23, 45	9.25				43	−40, −9, 17	8.27
L precentral gyrus	4	−36, −15, 54	7.29	4	−50, −7, 50	11.82	6	−28, −2, 31	7.67
				6	−51, −10, 39	8.38			
L insula					−38, 15, −2	7.94			
L Syllvian fissure								−46, −17, 10	10.31
R precentral gyrus	4/6	42, −3, 17	17.79	4	46, −13, 56	9.83	6	38, −12, 34	13.02
							4	40, −13, 47	9.16
R Syllvian fissure		28, 15, −4	8.72		36, 15, −6	11.69		42, 16, −1	10.40
R medial frontal gyrus				6	8, 7, 59	11.54			
R inferior frontal gyrus	45	34, 25, 4	6.61	44	55, 16, 10	7.32	44	50, 11, 23	9.84
				44	48, 11, 23	6.96			
R postcentral gyrus	43	63, −18, 19	6.58						
Temporal									
L mid-superior gyri	22	−51, 8, −2	9.72	21	−40, −5, −20	14.80	22	−53, −26, 14	7.33
L inferior temporal gyri							37	44, −59, −9	6.52
R middle temporal gyri	21	44, −8, −3	7.50				20	40, −26, −12	9.12
Parietal									
L inferior parietal gyrus	40	−44, −33, 44	8.76				40	−26, −37, 41	12.66
		−32, −44, 48	7.65						
R inferior parietal gyrus				40	36, −35, 37	8.35	40	36, −28, 24	7.65
Occipital									
L middle occipital gyrus	37	−50, −65, −9	12.85	19	−48, −66, −8	15.46			
L superior occipital gyri				19	−26, −64, 31	9.30			
L fusiform gyrus	37	−48, −59, −14	9.95	20/37	−38, −28, −15	8.12	37	−40, −24, −17	13.73
L cuneus	18	−16, −95, 10	10.91	18	−18, −91, 6	9.71	18	−16, −93, 8	19.21
L lingual gyrus							19	−26, −57, −4	12.34
R fusiform gyrus				18	26, −82, −11	12.57			
R cuneus							18	18, −89, 4	13.20
R lingual gyrus							18	2, −74, −8	8.67
Other areas									
Cingulate	32	−12, 10, 38	8.96				32	8, 8, 42	6.10
Cingulate	32	14, 12, 38	8.39						
Thalamus		4, −7, 15	14.93		−18, −15, 8	8.67			
Putamen		24, −7, 10	11.48						
Parahippocampal gyrus								30, −41, −6	7.73
Nucleus caudate		16, −9, 21	8.59						
Hippocampus		−22, −28, −9	9.54					−34, −24, −11	9.10
Lenticular nucleus		−30, 13, −2	8.63						
Cerebellum									
		12, −65, −20	24.45		−40, −54, −24	10.32		28, −57, −21	15.07
					26, −57, −22	11.17		18, −47, −16	10.64

bilateral precentral gyri (BAs 4/6), right Sylvian fissure (lateral sulcus), left mid-superior temporal gyrus (BAs 21/22), left fusiform gyrus (BA 37), left cuneus (BA 18), and anterior cingulate cortex. The cerebellum was also involved in the processing of all three types of words.

Significant activations in the postcentral gyrus (sensory cortex), left inferior parietal cortex (BA 40), right middle temporal gyrus, and hippocampus were seen in the processing of nouns and ambiguous words (relative to fixation), and the direct comparison of these two categories of words did not show a reliable difference. In addition, activations in the right occipital cortex (BAs 18, 19) mediated the processing of verbs and ambiguous words, while the reading of nouns was subserved by the putamen and caudate nucleus. However, the only significant activation arising from direct contrasts between either two of the three types of words was in caudate nucleus, which was more strongly activated in the

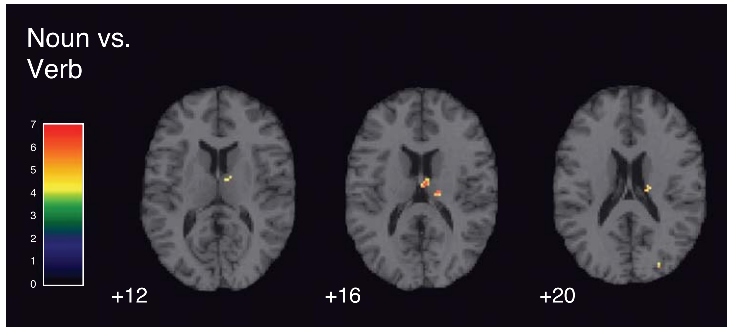

Fig. 2. Averaged brain activations for nouns versus verbs.

noun condition than in the verb condition, as shown in Fig. 2. No other areas showed reliable differences.

Discussion

The results obtained in this study indicate that nouns and verbs in Chinese activate a wide range of areas in the brain. The activations are not confined to specific regions but rather, are distributed in frontal, temporal, parietal, and occipital areas, and in both the left and the right hemispheres. The class-ambiguous words produce generally stronger activations (especially toward the posterior areas of the brain), but there are no significant differences between the ambiguous words and the nouns and verbs. Given that there are no overall significant differences between nouns and verbs, it comes as no surprise that the ambiguous words do not significantly differ from their parent counterparts.

The picture of neural representations of nouns and verbs in Chinese, then, seems to contrast with the popular conviction that there exist distinct cortical regions for these two word types in other languages (see a summary in Pulvermüller, 1999, and our earlier review). In previous imaging studies, speakers of English and other Indo-European languages typically display a strong activation of the frontal cortex for verbs and a strong activation of the temporal–occipital and visual cortices for nouns. These studies also coincide with the neuropsychological evidence that Broca's patients typically have difficulties with verbs, whereas Wernicke's patients have difficulties with nouns (Caramazza and Hillis, 1991; Miceli et al., 1988). Our contrasting data here, on the one hand, are consistent with studies that have started to challenge the noun–verb dissociation hypothesis (e.g., Tyler et al., 2001), and on the other hand, provide support for our hypothesis discussed earlier regarding the impact of linguistic typology and language-specific properties on the neural representation of linguistic categories: the non-distinct brain responses to nouns and verbs might arise as a function of native speakers' experience with the specific linguistic features of the Chinese grammar.

Before we discuss further the neural contributions of the Chinese grammar, it is important to emphasize three patterns from our study that are less obvious in previous imaging studies of nouns and verbs. First, our study indicates that nouns and ambiguous words as well as verbs activate the frontal regions in Chinese, in contrast to previous studies that report frontal activations for verbs only. The activation in the frontal cortex for nouns and ambiguous words might be because many nouns in Chinese can be used as verbs (the denominal verbs, see Chan and Tai, 1994), and that a major portion of the class-ambiguous words were cases whose noun uses were derived from their verb uses, an ongoing process in modern Chinese lexical usage (Hu, 1996). Second, our study indicates a wide range of right-hemispheric as well as left-hemispheric activations, in contrast to the observation that only left-hemisphere is activated for nouns and verbs (exceptions are Martin et al., 1995 and Damasio et al., 1996). The involvement of the right hemisphere in the processing of nouns and verbs might be due to the orthographic features of Chinese characters in reading (Tan et al., 2001a), and in part due to the role that lexical tones play in Chinese word processing, as reported in previous imaging work with Chinese characters (Scott et al., 2003; Tan et al., 2001b). Pulvermüller (1999), because of his ERP data, suggested that right hemispheric activations may be caused by left hemispheric neuronal generators within the inter-hemispheric sulcus (which can be activated during the processing of nouns, as suggested by Martin et al., 1996). Finally, our study indicates that the cerebellum was also involved in the processing of nouns, verbs, and class-ambiguous words in Chinese. The involvement of cerebellum in lexical processing is consistent with recent views that the cerebellum, in addition to its traditionally held functions, may play an important role in cognitive and perceptual operations, for example, semantic association in word generation (Martin et al., 1995; Petersen et al., 1989), sensory acquisition and discrimination (Gao et al., 1996), and semantic discrimination (Xiang et al., 2003).

The caudate nucleus is the only area where significant differences between nouns versus verbs and ambiguous words are observed in Chinese. It is not yet clear what this difference exactly implicates. Abdullaev et al. (1998) argued that the human caudate nucleus and prefrontal cortex share strikingly similar roles in some cognitive and linguistic tasks including lexical decision, semantic categorization, and reading aloud. Given that both nouns and verbs activate the prefrontal cortex for Chinese speakers, it is unclear why only nouns should significantly activate the caudate nucleus, if Abdullaev et al.'s conclusion is correct. Thus, the specific contribution of the caudate nucleus to the processing of Chinese nouns needs to be investigated further in future research.

The differential patterns of brain activations for nouns and verbs have generally been taken as evidence that different linguistic categories are subserved by different neural substrates. Our results indicate that a strong claim about the modularity of linguistic categories cannot be made across typologically different languages. Because of the lack of inflectional morphology and the lack of other grammatical constraints (e.g., nouns can freely serve as predicates and verbs as subjects), linguists have argued that it is not easy to draw sharp lines between nouns and verbs in Chinese as it is in English (see review and discussion in Hu, 1996). In some cases, even derivational morphology is not necessary in Chinese as in other languages to turn a verb into a noun (e.g., *huihua*, "draw"→*huihua*, "drawing") or to turn a noun into a verb (e.g., *weixi*, "threat"→*weixi*, "threaten"). Compounded with the large number of class-ambiguous words, these properties may significantly blur the boundaries between nouns and verbs in Chinese, which have in the past led some linguists even to argue that Chinese words have no fixed status with respect to grammatical classes. Such language-specific properties may have been responsible for the patterns observed in our study.[4] In the psycholinguistic literature, there has been strong evidence that language-specific properties of Chinese affect the representation, on-line processing, and acquisition in this language (see chapters in Li, Tan, Bates, and Tzeng, in press). There has also been mounting evidence that specific linguistic experience shapes neural systems of reading and speaking (Gandour et al., 2003; Tan et al., 2003), consistent with the view that neural structures can develop across the life span in response to the demands of the learning environment (Bates, 1999; Nelson, 1999). Our findings from this study are consistent with such lines of evidence and arguments.

How can we reconcile our fMRI results with the neuropsychological evidence that Chinese aphasic patients still show distinct response patterns in speech production? Bates et al. (1991) found that Broca's aphasics have more difficulty in action naming than object naming, while Wernicke's aphasics show the reverse. On the basis of this result, Bates et al. rejected the morphological and syntactic accounts that ascribe action-naming impairments to the deficit in handling greater morphological load carried by verbs (given that nouns and verbs do not differ in morphological load in Chinese). It would appear that these aphasic data are inconsistent with our fMRI results. However, it is yet unclear how the Chinese aphasic data would directly map to an argument for distinct cortical representations of nouns and verbs, given that the Wernicke's patients in the Bates et al. study were performing at a relatively low level for both nouns and verbs (around 30% correct in naming). In addition, the aphasic study involved the naming of pictures while the current study uses written Chinese characters in a lexical decision task, and hence the two cannot be directly compared.

As we pointed out earlier, some recent studies are challenging the noun–verb dissociation hypothesis even with English-speaking subjects. They suggest that when stimulus characteristics such as word length, frequency, and conceptual complexity are carefully considered in the experiment, the hypothesized distinctions for nouns and verbs either disappear in neural imaging data (Tyler et al., 2001), or remain there in behavioral data because the same characteristics can affect lexical processing in different directions (Szekely et al., in press). Szekely et al. (in press) argue that the hypothesized noun–verb dissociation is an artifact of the many processing dimensions that separate the two word types, including, but not limited to, *age of acquisition* (nouns tend to be acquired earlier than verbs), *word frequency* (high-frequency words result in faster processing speed for nouns but slower speed for verbs), and *conceptual complexity* (mapping from dynamic events to verbs is more variable than from objects to nouns). Moreover, these properties could influence processing modalities in different ways (e.g., stronger for word production, but less clear for word comprehension). Our study is consistent with this line of research, in that we show that any differences (or lack of differences) in the neural representation of nouns and verbs are tied to stimulus characteristics and processing characteristics of the word types in question, in any given language.

It would be useful to repeat and extend our study in several directions in future studies to identify in detail language-specific influences on the neural representation of nouns and verbs. First, it would be interesting to see if similar patterns can be obtained with comparable stimuli and with fMRI methods, in languages in which strong claims about the noun–verb dissociation have been made. Second, it is possible that the lexical decision task used in our study may be less sensitive to word category information than some other tasks, and it would be interesting to test subjects on the same or similar materials with a different task such as grammatical category judgment (e.g., by asking subjects to judge directly whether the presented stimulus is a noun or a verb). For comparison with the results in Bates et al. (1991) and Szekely et al. (in press), we might also use a picture-naming task. Finally, it would be interesting to use the same or similar materials to test second language learners of Chinese whose native language has been claimed to involve distinct neural representations of nouns and verbs. These subjects may be tested at different proficiency levels such that any "developmental" patterns in second language learning may be discerned.

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Appendix A. Nouns, verbs, and class-ambiguous words used in the experiment

Nouns	Verbs	Ambiguous
chanliang (output)	*biancheng* (become)	*bianhua* (change, change)
daolu (road)	*chaoguo* (exceed)	*bianji* (compilation, compile)
dianying (movie)	*chulai* (come)	*daibiao* (representative, represent)
ertong (children)	*danren* (assume)	*daoyan* (director, direct)
fangan (scheme)	*dapo* (break)	*heying* (picture, take a picture)
feiji (airplane)	*dida* (arrive)	*huafei* (expense, spend)
gongzi (salary)	*duode* (acquire)	*huihua* (drawing, draw)
guanggao (poster)	*gaohao* (do well)	*jianyi* (suggestion, suggest)
guanzhong (audience)	*gaosu* (tell)	*jiaoxun* (lesson, teach)

(continued on next page)

[4] One cannot easily use the current study to support the linguistic argument that Chinese words have no grammatical class memberships. Although nouns and verbs in Chinese display significant flexibility in grammatical functions, they may still differ in other important dimensions such as semantics and lexical co-occurrence distributions (Guo, 2001; Li, 2002). Thus, we cannot easily jump from the non-distinct cortical responses to the nonexistence of nouns and verbs in Chinese.

Appendix A (*continued*)

Nouns	Verbs	Ambiguous
gushi (story)	*jiancheng* (build)	*jihua* (plan, plan)
haiguan (customs)	*jiaohuan* (exchange)	*jilu* (record, record)
hetong (contract)	*kandao* (see)	*lingdao* (leader, lead)
jiaoshi (classroom)	*liuxia* (leave)	*mingling* (order, order)
jiemu (blocks)	*qianding* (sign)	*renshi* (understanding, understand)
lüke (tourist)	*quxiao* (cancel)	*tongzhi* (notice, notify)
meitan (coal)	*shuli* (establish)	*weixie* (threat, threaten)
shangchang (market)	*xiajiang* (descend)	*xuyao* (need, need)
shangdian (shop)	*yudao* (meet)	*yaoqiu* (request, require)
shanqu (hills)	*zhidao* (know)	*yingxiang* (influence, affect)
shipin (food)	*zhongzhi* (plant)	*zhishi* (instruction, instruct)
waihui (foreign money)	*zhuazhu* (hold)	*zhubian* (editor, edit)
wenzhang (article)	*zuochu* (make)	*zongjie* (summary, summarize)
zuqiu (soccer)		*zuzhi* (organization, organize)

Chinese words are given in Pinyin in italics, and English glosses in parentheses. Both the noun meaning and the verb meaning are glossed for the class-ambiguous words.

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