Neural Correlates of Nouns and Verbs in Early Bilinguals

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Previous neuroimaging research indicates that English verbs and nouns are represented in frontal and posterior brain regions, respectively. For Chinese monolinguals, however, nouns and verbs are found to be associated with a wide range of overlapping areas without significant differences in neural signatures. This different pattern of findings led us to ask the question of where nouns and verbs of two different languages are represented in various areas in the brain in Chinese–English bilinguals. In this study, we utilized functional magnetic resonance imaging (fMRI) and a lexical decision paradigm involving Chinese and English verbs and nouns to address this question. We found that while Chinese nouns and verbs involved activation of common brain areas, the processing of English verbs engaged many more regions than did the processing of English nouns. Specifically, compared to English nouns, English verb presentation was associated with stronger activation of the left putamen and cerebellum, which are responsible for motor function, suggesting the involvement of the motor system in the processing of English verbs. Our findings are consistent with the theory that neural circuits for linguistic dimensions are weighted and modulated by the characteristics of a language.

Key words: **nouns and verbs; bilingualism; fMRI; reading; language; Chinese–English bilinguals; putamen; cerebellum**

Introduction

How do bilinguals process and organize two languages in the brain? Are the distinctive features of two languages differentially weighted in cortical representations? Research on these questions is important for advancing our understanding of how one brain supports separate languages. While recent brain imaging studies have investigated neural circuits underlying language organization and language selection in bilinguals who speak similar (e.g., both languages are alphabetic) (Crinion *et al.*, 2006; Kim, Relkin, Lee, & Hirsch, 1997; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Mahendra, Plante, Magloire, Milman, & Trouard, 2003; Mechelli *et al.*, 2004; Perani *et al.*, 1998; Price, Green, & Studnitz, 1999; Rodriguez-Fornells, Rotte, Heinze, Nösselt, &

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Münte, 2002; Wartenburger *et al.*, 2003) or different languages (Chee, Tan, & Thiel, 1999; Crinion *et al.*, 2006; Gandour *et al.*, 2007; Liu, Dunlap, Fiez, & Perfetti, 2007; Liu & Perfetti, 2003; Luke, Liu, Wai, Wan, & Tan 2002; Tan *et al.*, 2003; Weber-Fox & Neville, 1996), little is known about whether the linguistic distance between the two languages influences neural signatures in the bilingual brain (Jeong *et al.*, 2007).

In the more extreme case, English and Chinese represent languages that vary in numerous aspects, and these linguistic features of each language may make differential demands on the neural circuitry that supports them. This can be extrapolated from studies of monolinguals in these languages (e.g., Gandour *et al.*, 2000; Siok, Perfetti, Jin, & Tan, 2004; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). In the Chinese and English languages the two writing systems present sharp contrasts in several dimensions, including orthography, phonology, semantics, and grammar. 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 are 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 & 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 (Li, Jin, & Tan, 2004). Although such

ambiguous words are also possible in other languages, they may not occur as frequently and may involve morphological changes.

Past research with English has shown that verbs are represented in the left prefrontal cortex, whereas nouns are stored in the posterior brain systems encompassing temporal-occipital regions. This conclusion is supported by both reports from patients of selective dysfunction of word classes (Baxter & Warrington, 1985; Caramazza & Hillis, 1991; Corina *et al.*, 2005; McCarthy & Warrington, 1985; Miceli, Silveri, Villa, & Caramazza, 1984; Zingeser & Berndt, 1988) as well as by neuroimaging studies conducted in normal adults (Damasio & Tranel, 1993; Hauk & Pulvermüller, 2004; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1989; Pulvermuller, 1999; Shapiro, Moo, & Caramazza, 2006; Wise *et al.*, 1991). However, a recent fMRI study examining monolingual Chinese adults in our own laboratory indicated that Chinese nouns and verbs activate a wide range of overlapping brain areas (without a significantly different network) than those reported in the English studies cited above (Li *et al.*, 2004). Relatively fewer distinctive grammatical features of nouns and verbs at the lexical level are likely to be responsible for this finding, but the question may be addressed more directly by employing bilingual individuals.

Hence, in the current study we asked whether for those Chinese-English bilinguals who have acquired the two languages early in life, nouns and verbs of the Chinese and the English language are processed separately. We used functional magnetic resonance imaging (fMRI) while subjects were asked to perform a lexical decision task on nouns and verbs in both Chinese and English. On the basis of the common neural system theory of early bilingualism (Kim *et al.*, 1997; Klein *et al.*, 1995; Mahendra *et al.*, 2003; Wartenburger et al., 2003), one would predict that the pattern of brain activity evoked by nouns and verbs in the two languages is identical.

Methods

Subjects

We carried out functional magnetic resonance imaging (fMRI) in 11 undergraduate students of the University of Hong Kong, whose ages ranged from 21 to 32 years. They gave informed consent in accordance with guidelines set by the Ethics Committee at the University of Hong Kong. All subjects were early Chinese–English bilinguals who started to learn English and Chinese (Cantonese) at age 3 to age 5 (formally through preschool). All were strongly right-handed as judged by the handedness inventory devised by Snyder and Harris (1993). We used nine items involving tasks typically done by only one hand. A 5-point Liket-type scale was used, with "1" representing exclusive left-hand use, and "5" representing exclusive right-hand use. The 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 the nine 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.

A first- and second-language proficiency questionnaire was devised to obtain measures of self-reported current abilities in English and Chinese for the bilingual subjects (Tan *et al.*, 2003). On average, subjects began reading English at 3 years of age and received a minimum of 16 years of formal training in English throughout primary school, high school, and university in Hong Kong. The questionnaire also contained a rating scale to assess subjects' self-reported language skills in speaking and reading. Item scores ranged from 1 (*not fluent at all*) to 7 (*very fluent*). The average rating scores of fluency in subjects' English were 5.18 (speaking, SD = 0.75), 5.73 (reading, SD = 0.47). Subjects' scores in Chinese were 6.27 (speaking, SD = 0.90) and 6.36 (reading,

SD = 0.92). There was no significant difference between subjects' rating scores in English and Chinese reading ($t = 1.89$, $P = 0.09$), although their ratings in Chinese speaking was significantly superior to that in English speaking ($t = 3.46$, $P < 0.01$). Thus, the subjects' Chinese-speaking performance was better than the English-speaking performance, despite the early age of acquisition of both languages for Hong Kong students, as has previously been reported (Bolton & Luke, 1999; Luke, 1997).

MRI Data Acquisition

The experiment was performed with a 1.5T scanner (Signa Horizon EchoSpeed with version 8.2 software, General Electric Medical Systems, Milwaukee, WI, USA) at the Queen Mary Hospital, University of Hong Kong. All subjects were visually familiarized with the entire procedure and the experimental conditions before the fMRI scans. A T2*-weighted gradient-echo EPI sequence was used, with the slice thickness = 5 mm, in-plane resolution = 4.3 mm × 4.3 mm, and TR/TE/FA = 3000 ms/60 ms/90 degree. Twenty-four contiguous axial slices were acquired to cover the whole brain. One hundred eighty (180) images were acquired in a single run. The anatomic brain MR images ($1.09 \times 1.09 \times 5$ mm^3) were acquired using a T1-weighted, spin-echo sequence.

fMRI Paradigm

There were four types of stimuli, English verbs, English nouns, Chinese verbs, and Chinese nouns. A total of 66 two-character Chinese words and 66 English words were used. Chinese disyllabic (two-character) words had a frequency of occurrence of no less than 23 per million according to the *Modern Chinese Frequency Dictionary* (1986). English words were of relatively high frequency and had a frequency of occurrence no less than 21 per million (Francis & Kucera, 1982). Within the two language categories, the visual complexity

of the stimuli was controlled by the number of strokes in the two characters for Chinese (mean number of strokes for nouns was 20.9, for verbs 19.8), and by the number of letters for English (mean number of letters was 5.9 both for nouns and verbs). Separate sets of 66 disyllabic Chinese pseudowords and English pseudowords were selected to serve as distractors. The Chinese pseudowords were made by the juxtaposition of two legal characters that do not form legal words. English pseudowords were orthographically legal and pronounceable, but had no meanings (e.g., *thove*). The visual complexity of these nonwords was comparable to that of the word stimuli (mean number of strokes was 21.8 for Chinese; mean number of letters was 5.4 for English).

The stimuli were shown through an LCD projector system. Subjects were asked to perform two runs separately, namely, in Chinese and English. Each experimental condition consisted of 33 real words and 33 pseudowords. A block design was used, with three blocks for each experimental condition and six blocks for the baseline condition. Blocks of experimental condition were separated by the baseline condition. Each block in one experimental condition had 22 trials. In each trial, a word (or pseudoword) was exposed for 600 ms, followed by a 1400-ms blank screen. Subjects performed a lexical decision task in which they judged whether or not a visually presented stimulus was a real word. Subjects indicated a positive response by pressing a key with the index finger of their right hand. They were asked to perform the task as quickly and as accurately as possible. A fixation baseline was used, and during this time subjects maintained fixation on a crosshair for 45 seconds.

Data Analysis

Processing of fMRI data was performed using the MATLAB software (Version 6.1; Math Works Inc., Natick, MA, USA) and the SPM99 software package (Wellcome Department of Cognitive Neurology, Institute of Neurology, Queen Square, London, UK). Images were corrected for motion across all runs by using sinc interpolation (Friston *et al.*, 1995). They were then spatially normalized to an EPI template based on the ICBM152 stereotactic space (Cocosco, Kollokian, Kwan, & Evans, 1997), an approximation of canonical space (Talairach & Tournoux, 1988). Images were resampled into $2 \times 2 \times 2$ mm cubic voxels and then spatially smoothed with an isotropic Gaussian kernel (8 mm full width at half-maximum).

Functional images were grouped into English verb, English noun, Chinese verb, and Chinese noun sets. Images from first 6 seconds of each condition were excluded from data processing to minimize the transit effects of hemodynamic responses. Activation maps were generated by using a cross-correction 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. Intersubject variability in global intensity was corrected by the use of proportional scaling to a common mean. Subject-specific linear contrasts for each of the effects of interest were assessed, including noun versus baseline, verb versus baseline, noun versus verb, and verb versus noun, within the same language. 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 fifteen or more contiguous voxels exceeding the uncorrected statistical threshold of $P < 0.005$ were considered significant.

Results

Images of group maps (11 subjects) for nouns versus baseline (fixation) and verbs versus baseline (fixation) in both languages are shown in Figures 1 and 2 and significant areas of
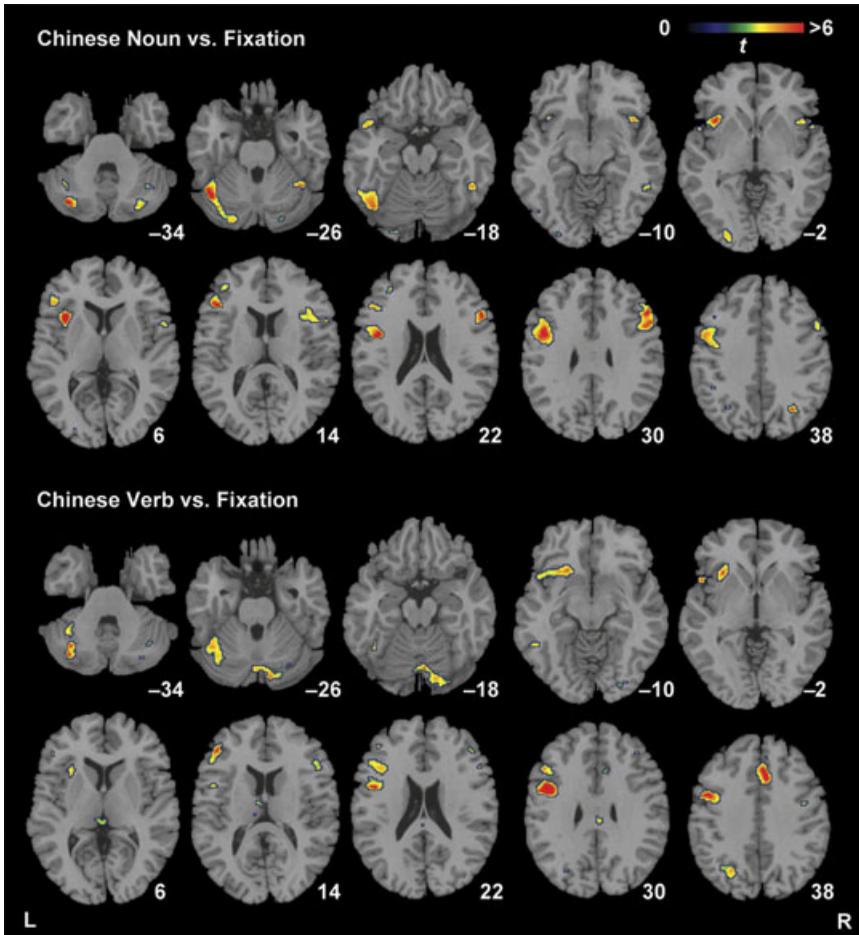
Figure 1. Functional maps: averaged brain activation evoked by lexical decision on Chinese words. The functional maps (*in color*) are overlaid on the corresponding T1 images (*in grayscale*). Planes are axial sections, labeled with the height (mm) relative to the bicommissural line. L = the left hemisphere; R = the right hemisphere.

activation for these comparisons are summarized in Table 1.

Chinese: Chinese nouns and verbs activated a wide range of brain areas, distributed in the frontal, parietal, and occipital areas as well as the cerebellum. Particularly strongly activated by both Chinese nouns and verbs were left middle frontal gyrus (BA 9), left inferior frontal cortex (BAs 44/45/46/47), left medial frontal gyrus (BA 6), left insula, left inferior parietal (BAs 40), left precentral gyrus (BA 4), and bilateral cerebellar regions. Right middle (BAs 9/6) and inferior frontal (BAs 44/45) gyri and left fusiform gyrus also mediated the process-

ing of both kinds of Chinese words. Importantly, a direct comparison of Chinese verbs and nouns did not show significant differences for either direction (i.e., nouns > verbs, or verbs > nouns).

English: Relative to fixation, English nouns and verbs both showed brain activity in left inferior frontal gyrus, left inferior parietal gyrus (BA 40), left medial frontal gyrus, and left cerebellum. Direct comparisons between English verbs and nouns were performed. There was no significant difference for the noun > verb comparison. However, English verbs evoked stronger activation in the left putamen,
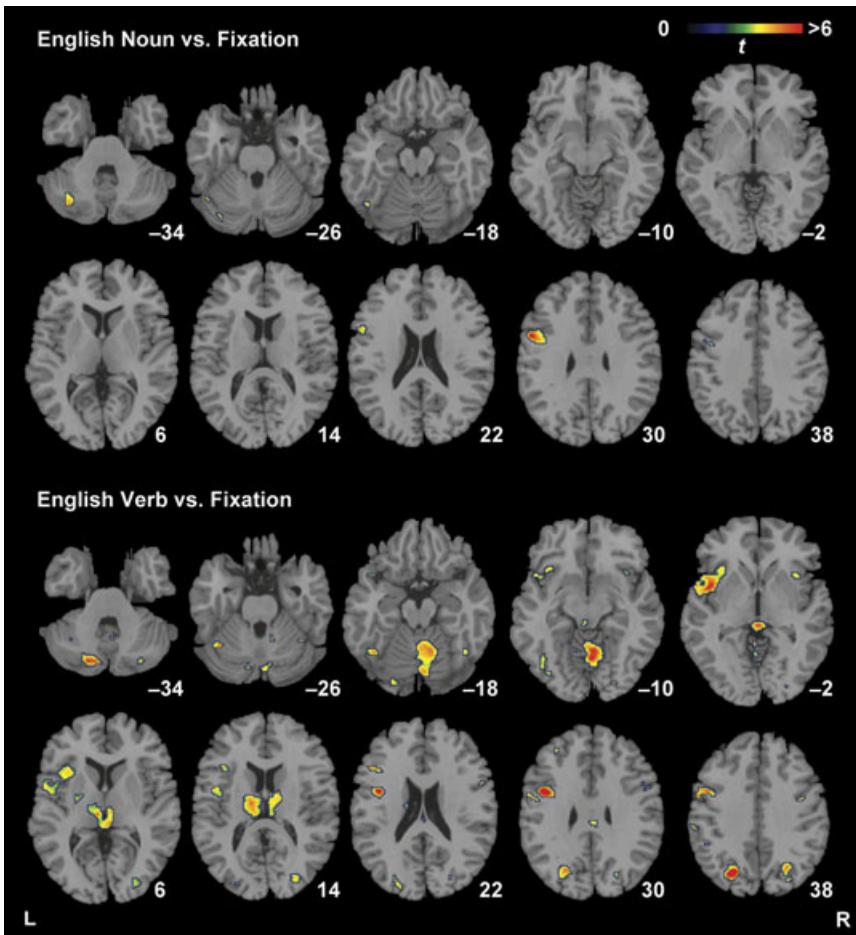
Figure 2. Functional maps: averaged brain activation evoked by lexical decision on English words. The functional maps (*in color*) are overlaid on the corresponding T1 images (*in grayscale*). Planes are axial sections, labeled with the height (mm) relative to the bicommissural line. L = the left hemisphere; R = the right hemisphere.

cerebellum, bilateral medial frontal gyri (BA 6), bilateral precentral gyri (BAs 4 and 6), left fusiform gyrus (BA 37), left precuneus (BA 7), right cuneus (BA 19), and right middle occipital areas (BA 18) (Table 2). Figure 3 illustrates blood-oxygen-level dependent (BOLD) signal changes in two selected regions.

Discussion

This fMRI study used nouns and verbs as stimuli to investigate how bilinguals represent categorical information of words from two different types of written languages. It has demon-strated that, in the early Chinese–English bilinguals' brain, Chinese nouns and verbs showed a largely overlapping pattern of cortical activity. In contrast, English verbs activated more brain regions compared to English nouns. Specifically, the processing of English verbs evoked stronger activities of left putamen, left fusiform gyrus, cerebellum, right cuneus, right middle occipital areas, and supplementary motor area. The recognition of English nouns did not evoke stronger activities in any cortical regions.

Overlapping neural representations for Chinese nouns and verbs may be explained by the ambiguous classification of these two word

TABLE 1. Regions Showing Significant Activations

| Regions activated	Noun versus fixation			Verb versus fixation		
	BA	Coordinate	t	BA	Coordinate	t
Chinese						
Frontal						
L. middle frontal gyrus	9	−45, 18, 32	4.7	9	−43, 20, 27	5.19
	10	−32, 39, 14	4.0			
L. inferior frontal gyrus	45/46	−40, 22, 17	9.50	44	−40, 1, 23	9.34
	44	−40, −5, 21	7.58	46	−41, 32, 10	6.39
				47	−18, 16, −10	5.25
L. medial frontal gyrus	6/8	−4, −1, 54	5.29	6	−3, 14, 55	10.82
L. insula	−	−32, 10, 4	8.55	−	−45, 10, −3	5.76
L. precentral gyrus	4	−34, −11, 45	3.75	4	−27, −9, 50	4.64
R. middle frontal gyrus	9	48, 21, 30	5.80	46	40, 34, 21	4.87
R. inferior frontal gyrus	44	45, 18, 24	6.80	45	41, 24, 15	3.95
R. medial frontal gyrus				8	1, 20, 47	14.49
R. insula	−	38, 10, −5	5.57			
R. precentral gyrus				6	38, −5, 35	3.58
Temporal						
L. superior temporal gyrus	38	−43, 8, −16	4.60			
Parietal						
L. inferior parietal gyrus	40	−43, −48, 38	7.56	40	−38, −54, 44	4.69
				40/7	−34, −46, 50	5.95
L. precuneus	19	−25, −65, 39	6.65	19	−24, −67, 42	9.50
Occipital						
L. inferior occipital gyrus	18	−22, −91, −3	5.22			
L. fusiform gyrus	37	−50, −55, −16	3.25	37	−45, −52, −10	4.11
R.. superior occipital gyrus	19	27, −65, 32	7.14			
Other areas						
Cingulate				32	3, 22, 40	16.14
Thalamas				−	−8, −23, 7	4.57
Cerebellum	−	−32, −75, −34	6.78	−	−32, −75, −34	5.88
		36, −52, −24	7.40		4, −73, −18	5.38
English						
Frontal						
L. superior frontal gyrus				9	−29, 37, 28	3.95
L. inferior frontal gyrus	44	−47, 3, 26	6.05	44	−40, 1, 28	10.23
				45	−36, −1, 19	7.77
L. medial frontal gyrus	6	−3, 10, 50	4.69	6	−1, −9, 56	4.74
L. precentral gyrus				4	−29, −15, 43	4.57
L. putamen				−	−30, −15, −2	5.91
R. inferior frontal gyrus				44	48, 4, 23	4.23
R. medial frontal gyrus				6	3, 1, 49	6.93
R. precentral gyrus				6	36, −5, 33	3.96
Parietal						
L. inferior parietal gyrus	40	−43, −44, 47	4.00	40	−41, −48, 40	4.26
Occipital						
L. superior occipital gyrus				19	−22, −73, 31	12.9
L. fusiform gyrus				19/37	−36, −67, −14	5.67
L. precuneus				7	−22, −71, 42	4.49
L. cuneus				18	−20, −89, 13	4.94
R. middle occipital gyrus				18	22, −77, 19	4.52
				19	26, −83, 8	4.36
R. inferior occipital gyrus				18	24, −91, −3	3.51
R. fusiform gyrus				37	40, −60, −17	4.65
R. cuneus				19	22, −75, 36	9.31
R. precuneus				19	26, −67, 37	6.81
Cerebellum	−	−31, −73, −34	4.59	−	−13, −81, −33	5.96
		−40, −63, −28	3.83		3, −63, −9	6.53
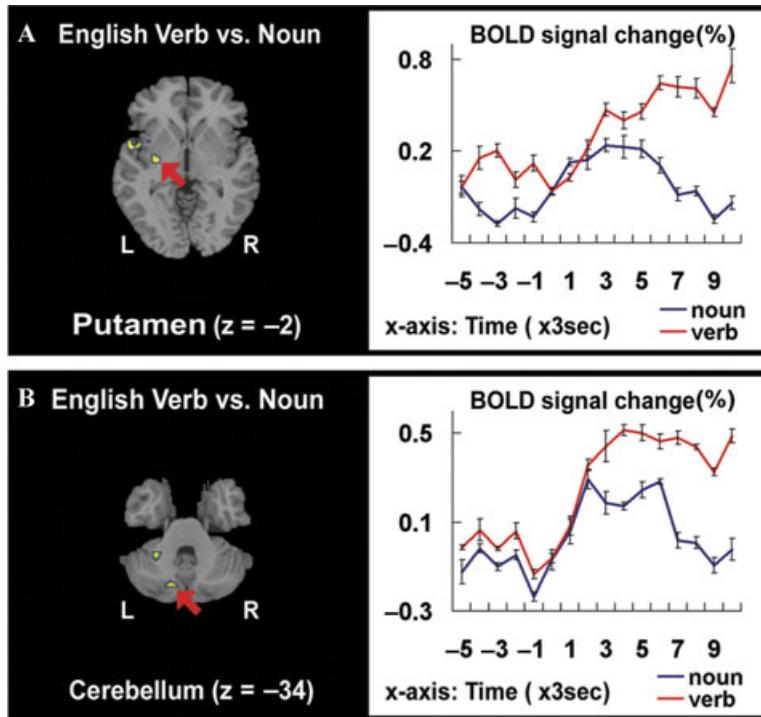
Figure 3. Selected brain regions showing activation differences between English verbs and English nouns. Presented are time course and activation maps in left putamen (**A**) and cerebellum (**B**).

TABLE 2. Regions Showing Significant Activations for English Verbs Compared with English Nouns

Regions activated	English verb versus noun		
	BA	Coordinate	*t*
Frontal			
L. medial frontal gyrus	6	−20, −5, 58	4.34
L. precentral gyrus	4/6	−40, −1, 14	5.83
L. putamen	–	−30, −14, −2	3.55
R. medial frontal gyrus	6	15, −7, 54	3.52
R. precentral gyrus	4	24, −19, 45	4.42
Occipital			
L. fusiform gyrus	37	−31, −23, −16	4.85
L. precuneus	7	−3, −63, 44	7.87
		−4, −71, 40	7.36
R. middle occipital gyrus	18	24, −81, 10	3.69
R. cuneus	19	4, −69, 37	10.41
Cerebellum	–	−15, −73, −34	5.70

types in Chinese (Li *et al.*, 2004). Hu (1996) suggested that a major portion of the class-ambiguous words were cases whose noun uses were derived from their verb uses, and many nouns in Chinese can be used as verbs (Chan & Tai, 1994). While word classes could hardly be distinguished from each other in Chinese, one can much more easily draw a line to separate English nouns and verbs. In the present study, using fixation as a baseline, English nouns and verbs showed similar patterns of activation in left inferior frontal cortex and left medial frontal gyrus. Importantly, more brain activity was found for English verbs relative to nouns in the left insula, left putamen, left fusiform gyrus, left cerebellum, supplementary motor area (SMA), and right visual cortex. The present pattern of results from our bilingual subjects seems at odds with previous studies with native English speakers, which showed distinct sites for noun processing (Martin *et al.*, 1995; Pulvermuller, 1999; Shapiro *et al.*, 2006), except for one report by Perani and colleagues (1999) who showed that no areas were more active for nouns than for verbs. Thus, verbs seem to be an extremely

complex word category, as argued by Pinker (1989).

The involvement of the cerebellum in lexical processing of English verbs is consistent with the recent views that the cerebellum, in addition to its traditionally held motor functions, may play a crucial role in cognitive operations such as sensory acquisition and discrimination (Gao *et al.*, 1996), semantic association in word generation tasks (Martin *et al.*, 1995; Petersen *et al.*, 1989), semantic discrimination (Xiang *et al.*, 2003), verbal learning (Fiez & Raichle, 1997) and reading (Ben-Yehuda & Fiez, this volume). Hypothetically, cerebellar activation for English action words may arise from the action and movement valence denoted by verbs. The strong activity in processing English verbs was also seen in left putamen/insula, and SMA, regions known to formulate motor programming and coordinate speech articulation (Dronkers, 1996; Price, 2000; Wise, Greene, Büchel, & Scott, 1999; Xu *et al.*, 2001), suggesting their particular role in mediating motor-related functions of verbs. Left fusiform gyrus, right cuneus, and left precuneus all exhibited stronger activation in the processing of English verbs. Their function remains to be investigated.

Conclusions

The present findings lend support to the proposal that under specific conditions bilingual learners may deal with word-categorical information of the two languages separately. Specifically, when word class is an important semantic/syntactic marker of language development, such as in English, early bilinguals are able to acquire such category-specific information swiftly. This can be the case even when the other of the two native languages, Chinese, is impoverished in providing morphological devices to distinguish nouns and verbs and does not manifest the same neuronal differentiation. Thus, the bilingual brain is highly plastic in that it handles two language systems in ways that reflect their different design principles.

Conflicts of Interest

The authors declare no conflicts of interest.

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