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Lexical representation of nouns and verbs in the late bilingual brain

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A B S T R A C T

Neuropsychological and neuroimaging studies of English and other Western languages suggest that basic lexical categories such as nouns and verbs are represented in different brain circuits. By contrast, research from Chinese indicates overlapping brain regions for nouns and verbs. How does a bilingual brain support the representation and organization of nouns and verbs from typologically distinct languages such as Chinese and English? In this fMRI study we examined the neural representations of nouns and verbs in late Chinese–English bilinguals. Results indicate that the late bilinguals, not surprisingly, showed no significant differences in brain activation for nouns versus verbs in Chinese. Surprisingly, they also showed little neural differentiation of nouns and verbs in English, suggesting the use of native language mechanisms for the processing of second language stimuli.

1. Introduction

How is lexical knowledge organized in the brain? Are words from different lexical categories (e.g., nouns and verbs) represented in segregated neural networks or in a common, shared network? A large number of studies in the literature have been devoted to address these questions (see Crepaldi, Berlingeri, Paulesu, & Luzzatti, 2011; Vigliocco, Vinson, Druks, & Cappa, 2011 for two recent integrative reviews). Early neuropsychological studies found that patients with lesions in the left temporal lobe and associated areas exhibit processing difficulties with nouns, whereas patients with injuries in

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the left frontal lobe are significantly impaired in processing verbs (Caramazza & Hillis, 1991; Damasio & Tranel, 1993). Neuroimaging studies with a variety of methods (e.g., ERP, PET, fMRI) and tasks (e.g., word generation, semantic judgment, picture naming, lexical decision) have suggested that verbs tend to generate activations in the prefrontal and frontal regions, while nouns elicit greater neural responses in the middle and posterior temporal regions for English (e.g., Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1989; Shapiro, Moo, & Caramazza, 2006), German (Koenig & Lehmann, 1996), Dutch (Kellen, Wijers, Hovius, Mulder, & Mulder, 2002), Italian (Perani et al., 1999), and Japanese (Yokoyama et al., 2006). These frontal-vs.-temporal dissociations, however, were not observed in Chinese (Li, Jin, & Tan, 2004), a language that differs significantly in lexical and grammatical structures from the Indo-European languages examined in the above-mentioned studies.

So far it is unclear whether the observed differences in neural patterns are due to morpho-syntactic properties of nouns versus verbs as grammatical categories, or due to semantic-conceptual properties with which nouns and verbs are differentially associated (see Vigliocco et al., 2011 for discussion). It is also unclear, given the emerging inconsistent data in the literature, whether the neural circuits underlying nouns and verbs can be spatially segregated with existing neuroimaging technologies (see Crepaldi et al., 2011 for discussion). It is clear, however, that different tasks or procedures used in the reported studies place different processing demands on aspects of nouns and verbs that may have contributed to the observed differences or lack of differences thereof, as pointed out by Crepaldi et al. (2011): lexical decision, picture naming, semantic judgment, and word generation tasks that have been used in the literature tap into very different levels of processing (lexical, syntactic, semantic) and therefore not surprisingly generate task-specific patterns of neural responses in different studies.

Despite a large number of studies that have examined nouns and verbs in the monolingual context, only a few studies have looked at the neural representations of lexical categories in bilingual speakers. Chan et al. (2008) investigated early Chinese–English bilinguals who grew up in Hong Kong. Because of the typological differences between Chinese and English, these bilinguals provided a unique opportunity to study the question of how different languages might be represented in the same brain. For example, nouns and verbs are marked by grammatical morphology in English (number, person, and tense markers) and other Western languages. However, no inflectional morphology exists in Chinese so different lexical classes are indistinguishable in form (Kao, 1990). Such cross-language differences have clear implications for language processing and neural representation (see chapters in Li, Bates, Tan, & Tzeng, 2006 for reviews). In their fMRI study, Chan et al. (2008) showed that the early bilinguals responded differently to nouns and verbs in the two languages (L1 Chinese and L2 English): consistent with findings from monolingual Chinese speakers (Li et al., 2004), when bilinguals were presented with nouns and verbs in Chinese, they showed no significantly different patterns in brain activation for the two lexical categories; when presented with nouns and verbs in English, however, their neural responses were significantly different, involving stronger brain activations in a set of motor and sensory areas (e.g., left putamen, cerebellum, and the right visual cortex) for verbs than for nouns. These findings suggest that the early bilingual brain might be sensitive to language-specific properties of each target language, and that the neural patterns of activation may be modulated by specific linguistic experiences to the same extent as in the monolingual brain (Li et al., 2004).

A recent fMRI study by Willms et al. (2011) tested proficient Spanish–English bilinguals and reported different results from Chan et al. (2008). Their bilingual participants showed greater neural responses for verbs than for nouns in both languages in a morpho-phonological alternation task, and the neural patterns of response in L1 (Spanish) were very similar to those in L2 (English). The findings from this study are also consistent with data from Hernández, Costa, Sebastián-Gallés, Juncadella, and Reñé (2007) who tested a Catalan–Spanish bilingual patient suffering from Primary Progressive Aphasia. The bilingual patient showed worse performance in naming verbs than nouns, and this pattern held for both L1 (Catalan) and L2 (Spanish). On the basis of these data from Catalan–Spanish and Spanish–English bilinguals, Hernández et al. (2007) and Willms et al. (2011) argued that there is language-invariant cortical organization with respect to lexical knowledge in highly proficient bilingual speakers, with nouns versus verbs being an important grammatical organizing principle.

The discrepancy in the neural processing of nouns and verbs between Chinese–English bilinguals (Chan et al., 2008) and Catalan–Spanish or Spanish–English bilinguals (Hernández et al., 2007; Willms et al., 2011) may be explained by the fact that Chinese and English were significantly different from one another whereas Catalan and Spanish and Spanish and English share a high degree of similarity in grammatical system. Previous research has indicated that when similar linguistic features are shared across the bilingual's two languages, these features tend to be processed more similarly than linguistically dissimilar features in the bilingual brain (Tokowicz & MacWhinney, 2005). Thus, it is not surprising that Catalan–Spanish or Spanish–English bilinguals would distinguish nouns and verbs in similar ways for both languages because the two types of words are marked similarly by grammatical morphology in the two languages. By contrast, grammatical morphology is completely absent in Chinese but not in English, and therefore the neural representations of nouns and verbs are reflected in different ways for the two languages of a Chinese–English bilingual.

The evidence so far suggests (1) an important role of cross-language similarity, and also (2) a potential role of age of acquisition (AoA), both contributing to modulate neural patterns of lexical representation in bilinguals. In the three studies reviewed above (Chan et al., 2008; Hernández et al., 2007; Willms et al., 2011) all the participants were early proficient bilinguals, and their neural specifications of nouns and verbs in L1 and L2 seem to be established as those in monolinguals speaking that language (though perhaps not with exactly the same patterns; see Grosjean, 1989). But will late bilinguals show patterns different from early bilinguals in noun and verb processing? Will they rely on cognitive and neural mechanisms associated with L1 for the processing of L2, even if L1 and L2 differ significantly from one another, such as Chinese and English? Or is the development of neural representation in L2 independent of that in L1, even when L1 is well established in late bilinguals?

To answer these questions, we set out to test a group of late Chinese–English bilinguals. The differential neural patterns observed in Chan et al. (2008) might reflect the bilinguals' long-term linguistic experiences with the two languages. Previous behavioral and imaging research has identified age of acquisition (AoA) as a powerful predictor of L2 performance (see Hernandez & Li, 2007; Wartenburger et al., 2003 for review), and grammatical category as an area in which late Chinese–English bilinguals consistently show difficulty (Chen, Shu, Liu, Zhao & Li, 2007). Given the AoA effects observed, one hypothesis would be that early versus late learners show different processing patterns and neural responses, such that the late learners may rely more on L1 processing mechanisms to handle the L2 (Hernandez, Li, & MacWhinney, 2005). On the other hand, if neural sensitivity to L2-specific characteristics is developed rapidly, as some bilingual ERP data have suggested (McLaughlin, Osterhout, & Kim, 2004), one could hypothesize that both early and late bilinguals would show language-specific neural responses and hence different brain activation patterns for the L1 versus the L2.

2. Method

2.1. Participants

Seventeen college students (eight females and nine males; mean age = 21.78 years, ranging from 19 years to 28 years) from the Capital Normal University, China, participated in the study. All were native Chinese speakers who began to learn English around the age of 12. A language proficiency questionnaire (Li, Sepanski, & Zhao, 2008) was used to measure self-reported Chinese and English abilities in the bilinguals. They were asked to rate their language skills in speaking and reading on a scale of 1 (*not fluent at all*) to 7 (*very fluent*). They all reported 7 for their Chinese speaking and reading skills. Self-reported mean scores for English speaking and reading were 4.41 (SD = .80) and 4.26 (SD = .90), respectively. Significant differences were obtained between the participants' Chinese and English rating scores (all $t > 1$, $Ps < .001$). All participants were right-handed according to the handedness questionnaire of Snyder and Harris (1993). Prior to scanning, the participants gave informed consent according to the protocols approved by the Ethics Committees of the Chinese Academy of Sciences and of the University of Hong Kong.

2.2. Design and procedure

An fMRI block design was used for our study. The Chinese and English stimuli were presented in separate sessions. During the functional scan sessions for each language, participants made lexical decisions to words (nouns, N and verbs, V) or nonwords in either Chinese or English. The use of a lexical decision task was based on the paradigm adopted in our previous studies for consistency and comparison (Chan et al., 2008; Li et al., 2004), and on the consideration that among the various tasks used in noun–verb imaging studies, lexical decision is the one task that has generated relatively consistent distinct patterns of response for nouns versus verbs (see Crepaldi et al., 2011 for a detailed review). In the experiment, all Chinese stimuli were composed of two-character disyllabic words. The nonwords were made up by the juxtaposition of two legal characters that do not form legal words for Chinese, and by the construction of pseudowords that are orthographically legal and pronounceable but meaningless for English. In the baseline condition (A), the participants pressed the buttons to indicate the direction of arrows (left vs. right). Each trial consisted of a stimulus word of 600 ms, followed by a blank of 1400 ms. Participants pressed the right button with their right thumbs for “yes” responses (words or right-going arrow) and pressed the left button with their left thumbs for “no” responses (nonwords or left-going arrows). Each block (N, V, or A) contained 12 trials and the blocks were counterbalanced according to a Latin Square design. All the language stimuli were matched in visual complexity and frequency: mean number of strokes for Chinese disyllabic words was 15, and mean number of letters for English words was 6, for both nouns and verbs. Chinese words had a mean frequency of occurrence no fewer than 14 per million according to the Modern Chinese Frequency Dictionary (Wang, 1986), while the English words had a mean frequency of occurrence no fewer than 28 per million according to the subtitle lexical frequency norms (Brysbaert, 2009; http://subtlexus.lexique.org/).

2.3. MRI acquisition

A Siemens Magnetom Trio 3-T MRI scanner at the Chinese Academy of Sciences was used for the present study. A T2-weighted gradient-echo EPI sequence was used for acquiring the fMRI images, with the following parameters: TR $=$ 2000 ms; TE $=$ 30 ms; FA $= 90^{\circ}$; matrix size $= 64 \times 64$. Functional images were reconstructed from 32 axial slices, with the thickness of each slice being 4 mm. A set of high-resolution anatomical images ($1 \times 1 \times 1$ mm^3) was also acquired with a T1-weighted, 3D gradient-echo sequence.

2.4. fMRI data analysis

Functional images obtained for each participant were analyzed with SPM8 (http://www.fil.ion.ucl.ac.uk/spm/software/spm8/) running under Matlab 7.7 (MathWorks, Natick, MA). The first three images from each language session were discarded to minimize the transit effects of hemodynamic responses. The remaining images were first realigned for motion correction, and then spatially normalized to an EPI template based on the ICBM152 stereotactic space (Cocosco, Kollokian, Kwan, & Evan, 1997). After that, images were smoothed with an isotropic Gaussian kernel (6 mm full width at half-maximum [FWHM]) to increase the signal-to-noise ratio. For each participant, functional images were grouped into four sets: Chinese Noun (CN), Chinese Verb (CV), English Noun (EN), and English Verb (EV). Individual contrast images between experimental conditions (N/V) and baseline condition (A) were assessed for each language, and effects across languages and word types were tested by a within-subjects ANOVA on language (C. vs. E) and word type (N vs. V). The ANOVA was implemented as a full factorial analysis in SPM8, and the four cells of the 2×2 design (CN, CV, EN, EV) were filled using contrast images for each condition versus the baseline condition (A). The ANOVA results were subjected to a voxel-level threshold of $p < .05$ FDR (Genovese, Lazar, & Nichols, 2002) and an extent threshold of minimum of 36 voxels. Direct contrasts between the N and V conditions in each language were performed with a paired samples t-test at a significance level of $p < .05$ FDR using the initial comparisons (N vs. A; V vs. A) as masks. All the statistical maps were superimposed on the high-resolution, normalized, T1-weighted, SPM8 structural template image for viewing, and the MNI coordinates from SPM8 are reported below.

3. Results

3.1. Behavioral data

Fig. 1 presents the behavioral data from the experiment. Data from one participant were excluded from further analyses due to the participant's poor behavioral performance (accuracy below chance level). As can be seen from Fig. 1a, it took the participants significantly less time to process L1 (Chinese) than to process L2 (English), $F(1, 15) = 7.871$, $p < .05$: average RTs for Chinese nouns and verbs were 606.1 ms (SD = 60.8) and 618.8 ms (SD = 65.5), respectively, whereas those for English nouns and verbs were 644.6 ms (SD = 78.5) and 651.18 ms (SD = 82.6), respectively. The participants were also significantly more accurate in lexical decision in Chinese than in English, $F(1, 15) = 39.845$, $p < .001$: mean lexical decision accuracy was 84.64% (SD = .11) for nouns and 83.72% (SD = .12) for verbs in Chinese, and 58.98% (SD = .16) for nouns and 69.27% (SD = .13) for verbs in English. Paired samples *t*-tests showed no significant differences in RT between nouns and verbs for either language. However, *t*-tests on accuracy data showed a significant difference between nouns and verbs in English, with more errors for nouns than for verbs, $t(15) = 4.762$, $p < .001$; no such significant difference was observed for Chinese, as shown in Fig. 1b.

3.2. fMRI data

3.2.1. Effects of language

The ANOVA analysis revealed a main effect of language (Chinese and English) only, but no main effect of word type (Nouns and Verbs). In particular, the processing of English words compared with that of Chinese words generated significantly greater brain activation in the right middle frontal gyrus (BA 9), insula, angular gyrus (BA 39) and bilateral superior parietal lobes (Fig. 2c). The reverse comparison, that is, L1 (Chinese) versus L2 (English), generated no significantly greater neural responses. Neither the main effect of word type nor the interaction between language and word type reached statistical significance. Table 1 summarizes the brain regions that are significantly activated in the bilingual participants' L2 processing compared with their L1 processing, collapsing across word type conditions.

3.2.2. Effects of word type

Brain activation pattern for the processing of nouns was quite similar with that for the processing of verbs in Chinese (Fig. 2a). Both conditions evoked strong neural activities in bilateral superior frontal cortex (BA 6), middle frontal gyri (BAs 9/46) and inferior frontal areas (BAs 44/45/47). Bilateral parietal lobes, left fusiform gyrus (BA 19) and left cuneus gyrus (BA 18) were also highly activated for both

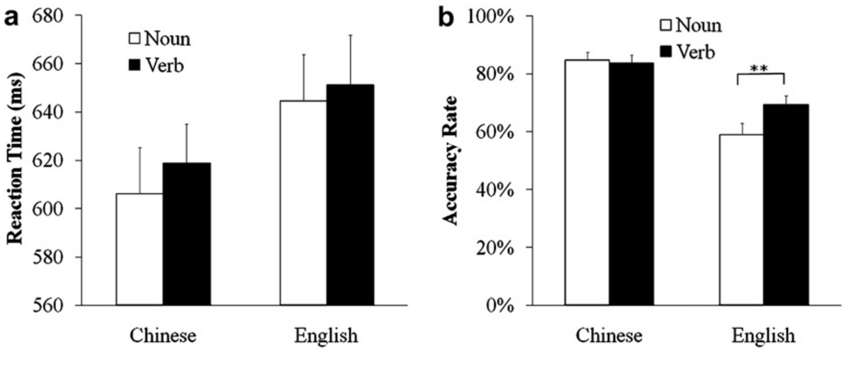

Fig. 1. Behavioral performance (a: RT and b: percent accuracy) for nouns and verbs in Chinese versus English. Paired samples *t*-tests showed no significant differences in RT between nouns and verbs for either language, but showed a significant difference in accuracy rate between nouns and verbs in English ($p < .001$; see ** in 1b) though not in Chinese.

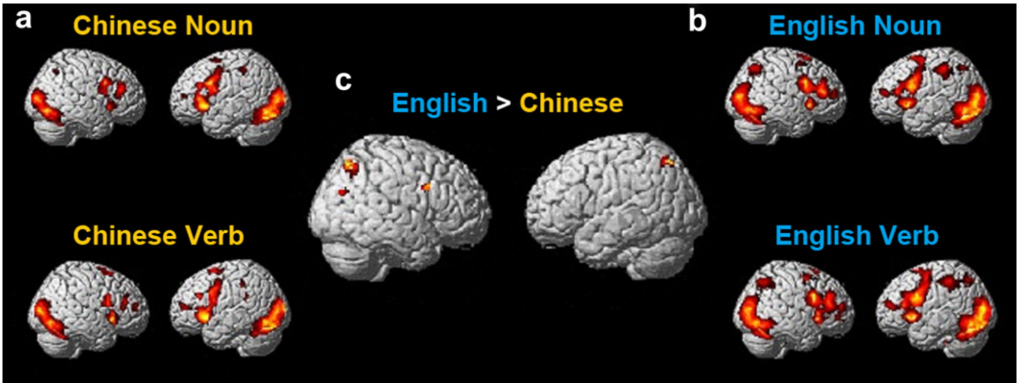

Fig. 2. Surface 3D images display brain regions that responded more strongly in the Chinese (a) and the English (b) lexical decision task compared with the arrow judgment task. Collapsing over word types (nouns and verbs), right middle frontal gyrus, insula, bilateral superior parietal lobes and right angular gyrus showed significantly greater neural responses in the English conditions than in the Chinese conditions, as seen in (c).

conditions. When directly compared, the Chinese noun condition generated stronger activation in the posterior parietal lobe (BAs 7/40) and bilateral cerebellum, whereas the Chinese verb condition showed stronger activation in the right fusiform gyrus. However, none of these activation differences between nouns and verbs reached statistical significance (FDR, $p < .05$).

Processing of English nouns and verbs elicited brain activations in a more widely distributed network, which was similar to, but more symmetrical than, that for Chinese nouns and verbs. As illustrated in Fig. 2b, significant activations were found, for both English noun and verb conditions (compared with the baseline task), in bilateral superior frontal gyri (BA 6), middle frontal gyri (BAs 9/46), inferior frontal cortex (BAs 44/45/47), insula, bilateral posterior parietal regions (BAs 7/40), right angular gyrus (BA 39), left fusiform gyrus, bilateral caudate nucleus and left thalamus. There were more activity in the left middle temporal gyrus for nouns and more activity in the right middle frontal gyrus for verbs, but these differences did not reach statistical significance (FDR, $p < .05$).

4. Discussion

In this study we examined neural representations of nouns and verbs in late Chinese–English bilinguals. Previous research that investigates how nouns and verbs are represented in the brain has focused primarily on Indo–European languages, and on monolingual speakers rather than bilingual speakers (see Crepaldi et al, 2011; Vigliocco et al., 2011 for reviews). Among the neuroimaging studies

Table 1
Significant brain activations in the processing of English (L2) versus Chinese (L1)[a]

Regions activated	BA	Cluster size	Coordinate			*T*
			x	*y*	*z*	
Frontal						
R middle frontal gyrus	9	52	46	10	32	4.47
R insula		54	24	22	4	4.59
Parietal						
L superior parietal lobe	7	151	−22	−70	54	5.33
R superior parietal lobe	7	341	28	−68	54	6.77
R angular gyrus	39	170	34	−72	26	4.89

[a] Note: areas of significant activation are based on direct comparison between L2 activation vs. L1 activation across noun and verb conditions.

that have used the lexical decision task to study nouns and verbs, some revealed noun–verb differences (e.g., Fujimaki et al., 1999; Perani et al., 1999; Tyler, Russel, Fadili, & Moss, 2001) while others indicated no differences (Li et al., 2004; Yokoyama et al., 2006). Such discrepancies may be explained at least partly by the cross-linguistic differences that exist between the various languages studied. The neuroscience of language literature has repeatedly shown that cross-language similarity (or cross-language overlap or distance) plays a significant role in modulating cognitive and neural patterns of response in bilinguals. Cross-language overlap refers to the common features shared by the two languages of the bilingual. Larger cross-language overlap could lead to greater overlap in brain regions during processing, whereas smaller overlap could be associated with more distinct neural response patterns in the bilingual's two languages (see Li & Tokowicz, 2011; Tokowicz & MacWhinney, 2005).[1]

Our study, by examining the neural correlates associated with nouns and verbs in both L1 (Chinese) and L2 (English), reveals how language-specific lexical categories from distinct languages may be organized in the bilingual brain. Our behavioral data indicate that late bilinguals display no significant differences in processing nouns and verbs (but see the frequency effect discussed in Footnote 2). Our fMRI data show that the bilinguals recruit largely overlapping neural networks for processing nouns and verbs, in both L1 and L2, although they rely on a more widely distributed neural system in L2 than in L1, including some subcortical regions. This wider network contribution may reflect their more effortful processing in the second language, as compared with the processing of their native language (see Perani & Abutalebi, 2005 for review). Our data contrast with previous studies in Indo-European languages that have shown noun–verb differences on the one hand, and on the other hand, with the Chan et al. study (2008) in which early bilinguals showed significant neural differentiations between L1 and L2 in both brain activation regions and activation time courses.

The overlapping networks for nouns and verbs in Chinese are consistent with our previous study of monolingual speakers of Chinese (Li et al., 2004), and also consistent with the Chinese patterns from early Chinese–English bilingual speakers (Chan et al., 2008). What differs between the current study and the Chan et al. study (2008) is that while Chan and colleagues found significant differences for the processing of nouns and verbs in English (but not in Chinese), our study showed no such differences in either English or Chinese. The absence of noun–verb differences in Chinese in all these studies may be attributed to the language user's specific linguistic experiences; that is, the lack of grammatical morphology and the high degree of noun-verb ambiguity in Chinese might lead to the speaker's insensitivity to noun–verb differences and consequently non-differentiated neural representation for nouns versus verbs (see Li et al., 2004, for more detailed analysis). A similar absence of difference for English in our bilingual participants, however, may be accounted for by reference to the AoA effect in light of Chan et al.'s finding (2008). In other words, the late Chinese–English bilinguals in our study, as opposed to the early bilinguals in Chan et al.'s study (2008), may be applying the neural mechanism for Chinese (L1) to the processing of English (L2) and hence also show no neural sensitivity to nouns versus verbs in English.

Successful learning of a second language involves significant time and efforts on the part of the learner, and late bilingual speakers often show difficulties in L2 phonology, grammar, and lexicon even after many years of second language experiences. Our data from late bilinguals with intermediate-to-high proficiency indicate that linguistic experiences with one's native language can shape the neural representation of a second language, and that late bilinguals, as opposed to early bilinguals, often rely on cognitive and neural mechanisms associated with L1 when they process L2. It is also clear from our behavioral and fMRI data that lexical processing in the L1 is much faster and more accurate than lexical processing in the L2. The data illustrated in Fig. 2 speak particularly to the effect that the processing of English nouns and verbs by our Chinese–English bilinguals might reflect more effortful linguistic processing in the L2, given the stronger brain activity in the right cortical and subcortical areas (see also Parker Jones, in press for a recent analysis), including the insula that are implicated in cognitive and

[1] The recent Willms et al. (2011) fMRI study of Spanish–English bilinguals suggested 'language-invariant' cortical organization with respect to the noun-verb distinction in bilinguals. However, they also acknowledged that even if the neural circuits were identical for Spanish and English, these languages are relatively close in phylogeny, and "are similar in grammatical and semantic structure when jointly compared to languages like Hungarian, Basque, Chinese, or Kiswahili".

motor control of speech production and articulation (Ackermann & Riecker, 2004). However, there are encouraging signs in our data that with more linguistic exposures and improved language proficiency, our late bilingual learners may be able to develop sensitivity to noun-verb differences in L2, as shown by the (statistically non-significant) pattern that English nouns elicited more activity in the left middle temporal gyrus whereas English verbs more activity in the right middle frontal cortex. In addition, we also see that the response accuracy data from our participants showed some differentiation of English nouns and verbs (higher accuracy for verbs than for nouns).[2] Future research is needed to explore the potential segregation of L2 lexical representation by the use of late bilinguals with distinct proficiency profiles, at low versus high proficiency levels, so that we can further identify the distinct and joint contributions of linguistic experiences, age of acquisition, and proficiency in shaping the bilingual's neural representation of languages.

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[2] This difference, however, might be due to the relative frequency of verbs versus nouns in our stimuli: the mean word frequency for English verbs and nouns used in our stimuli were 34.65 and 28.16, respectively, according to the subtitle lexical frequency norms (Brysbaert, 2009; http://subtlexus.lexique.org/).

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