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Research Report

Speaking words in two languages with one brain:
Neural overlap and dissociation

Hongyan Liu\textsuperscript{a}, Zhiguo Hu\textsuperscript{b}, Taomei Guo\textsuperscript{a,}*, Danling Peng\textsuperscript{a}

\textsuperscript{a}State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, 100875, PR China
\textsuperscript{b}Laboratory for Higher Brain Function, Institute of Psychology, Chinese Academy of Sciences, Beijing, PR China

Article history:
Accepted 11 December 2009

ARTICLE INFO

ABSTRACT

The present study investigated the neural overlap and dissociation underlying overt word production in the first language (L1) and second language (L2). Twenty-four Chinese–English bilinguals named pictures in either L1 or L2 while being scanned with functional magnetic resonance imaging (fMRI). When comparing picture naming in L2 to naming in L1, increased activity in the left inferior frontal gyrus, bilateral supplementary motor areas (SMA), left precentral gyrus, left lingual gyrus, left cuneus, bilateral putamen, bilateral globus pallidus, bilateral caudate and bilateral cerebellum were observed. This suggested that word production in L2 is less automatic and needs to recruit more neural resources for lexical retrieval, articulatory processing and cognitive control than in L1. In contrast, picture naming in L1 relative to picture naming in L2 revealed increased activity in the right putamen and right globus pallidus probably due to different phonological features between Chinese and English. In addition, the conjunction analysis, for the first time, revealed the common neural correlates underlying picture naming in L1 and L2.

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Keywords: Bilingualism, Word production, Neural basis, fMRI

1. Introduction

As the world is becoming a global village, more and more people are able to use more than one language. These people are termed bilinguals. Research interest in bilingualism has increased in recent years. One of the important issues is whether a common neural system is shared by word production in a second language (L2) and in a first language (L1), or whether there are specific brain areas dedicated to word production in each of bilinguals’ two languages. New neural imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) make it possible to answer these questions.

Some research demonstrated that there is a neural overlap underlying word production in L2 and L1. In a PET study with English–French bilinguals, Klein et al. (1994) found largely overlapping brain areas for English (L1) and French (L2) with only one exception that the left putamen was found selectively activated during word repetition in L2 relative to word repetition in L1. These results were replicated in a word generation task with English–French bilinguals (Klein et al., 1995). Some other studies also observed that there was no neural difference between L1 and L2 in a word generation task (Chee et al., 1999), a verb generation task (Klein et al., 1999; Pu et al., 2001) with Chinese–English bilinguals, and a picture naming task with Spanish–English bilinguals (Hernandez et al., 2000).
Overall, these studies suggested a common neural system for word production in L1 and L2. On the other hand, some other studies found that word production in L2 exhibited more frontal activation compared to word production in L1. In an fMRI study using a word generation task, Yetkin et al. (1996) found that less fluent language showed greater activation in the left frontal lobe. Vingerhoets et al. (2003) further showed an increased activation in the frontal cortex including Broca’s area in foreign language compared to L1 in both verbal fluency task and picture naming task. Another two recent studies (De Bleser et al., 2003; Hernandez and Meschyanet, 2006) using the picture naming task also demonstrated that response increases in L2 production relative to L1 production were found in the prefrontal cortex. In the PET study by De Bleser et al. (2003), Dutch–French bilinguals were asked to covertly name pictures in each language. They found increased activations in L2 relative to L1 in two areas of the inferior frontal gyrus, BA47 and BA44. In a recent fMRI study, Hernandez and Meschyanet (2006) found that the Spanish–English bilinguals exhibited increased activation in the right insula, the anterior cingulate gyrus, the dorsolateral prefrontal cortex, and the left fusiform gyrus during covertly picture naming in L2 relative to picture naming in L1. The increased activation of prefrontal regions with naming in L2 than L1 was generally considered to be due to more efforts for lexical retrieval and post-lexical processing for L2 (for a review, see Indefrey, 2006).

Inconsistent results across studies may be related to the age of acquisition or proficiency of a second language (e.g., Indefrey, 2006). It is possible that difference between word production in L2 and word production in L1 is larger in unbalanced bilinguals than in balanced bilinguals as it is less automatic for the former to producing words in L2. Specifically, less proficient L2 of unbalanced bilinguals may need to recruit more neural resources to retrieve lexical information or to overcome interference from the dominant native language (for reviews, see Abutalebi & Green, 2007; Rodríguez-Fornells et al., 2006). Furthermore, the above mentioned studies on bilingual word production mainly used a covert naming task in order to reduce head motion, but some studies on monolingual speech production found that covert naming may actually underestimate the magnitude of neural activity due to interference (Barch et al., 1999) or motor activity (Palmer et al., 2001). It is hence reasonable to infer that the difference between word production in L1 and L2 may also be underestimated when using a covert naming task. In fact, some ERP (event-related potential) studies on bilingual language processing began to adopt the overt naming task (e.g., Christoffels et al., 2007; Verhoef et al., 2009).

Therefore, the present study aims to examine the neural basis underlying word production in L1 and L2 with unbalanced bilinguals by using an overt picture naming task. To minimize movement artifacts caused by overt naming, an event-related design was adopted (Huang et al., 2001). Based on direct comparison between L1 and L2, we aim to demonstrate potential difference in the neural correlates of word production in L1 and L2. In addition, although some previous studies suggested that there is a neural overlap in L1 and L2 production, these studies did not clearly specify which areas are involved in the common neural network. It has been shown that the cognitive conjunction analysis is a good new approach to measure the neural commonality between two or more tasks (Price & Friston, 1997; Price et al., 1997). Therefore, the present study also attempts to use this method to examine the common neural basis underlying word production in L1 and L2.

2. Results

2.1. Behavioral results

Table 1 - Brain activation for direct comparisons between naming in Chinese (L1) and naming in English (L2).

<table>
<thead>
<tr>
<th>BA</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
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<td>44, 45, 48</td>
<td>−48</td>
<td>38</td>
<td>16</td>
</tr>
<tr>
<td>L SMA</td>
<td>6, 32</td>
<td>−2</td>
<td>6</td>
<td>52</td>
</tr>
<tr>
<td>L precentral gyrus</td>
<td>44</td>
<td>−54</td>
<td>10</td>
<td>32</td>
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<tr>
<td>L lingual gyrus</td>
<td>17</td>
<td>−8</td>
<td>64</td>
<td>8</td>
</tr>
<tr>
<td>L cuneus</td>
<td>18</td>
<td>−6</td>
<td>74</td>
<td>18</td>
</tr>
<tr>
<td>L putamen/Globus pallidus/Caudate</td>
<td>−14</td>
<td>6</td>
<td>−4</td>
<td>8.12</td>
</tr>
<tr>
<td>R putamen/Globus pallidus/Caudate</td>
<td>12</td>
<td>8</td>
<td>−6</td>
<td>5.59</td>
</tr>
<tr>
<td>L cerebellum</td>
<td>−6</td>
<td>−74</td>
<td>18</td>
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<tr>
<td>R cerebellum</td>
<td>34</td>
<td>−48</td>
<td>−32</td>
<td></td>
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<tr>
<td>Chinese vs. English</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R putamen/Globus pallidus</td>
<td>30</td>
<td>−10</td>
<td>−4</td>
<td>5.04</td>
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</table>

Note: Height threshold, P<0.001, uncorrected, spatial extent threshold, 20 voxels. The x, y, and z values in MNI coordinates. Abbreviations: L, left hemisphere; R, right hemisphere; BA, Brodmann’s area; SMA, supplementary motor area.
Conjunctions were found in a widespread array of regions in both left and right hemispheres. Specifically, the conjunction effects were associated with several frontal areas, including the bilateral inferior frontal gyri, bilateral middle frontal gyri, bilateral supplementary motor areas (SMAs), bilateral cingulate gyri, left precentral gyrus and bilateral insula. In temporal regions, significant increased activity was observed in the right superior temporal gyrus, right middle temporal gyrus and bilateral inferior temporal gyri. In occipital and parietal regions, activations included bilateral superior occipital gyri, bilateral middle occipital gyri, bilateral inferior occipital gyri, bilateral cuneus, left lingual gyrus, bilateral fusiform gyri, bilateral superior parietal lobule, left inferior parietal lobule, bilateral postcentral gyri and right angular gyrus. Other activations were also exhibited in the bilateral thalamus, bilateral putamen, bilateral globus pallidus and bilateral cerebella. The regions activated by naming in both languages without difference in magnitude were illustrated in Table 2 and Fig. 3.

3. Discussion

Using an event-related fMRI design, the present study examined the difference and similarity in the neural basis underlying overt word production in L1 and L2 with unbalanced Chinese–English bilinguals. The neural dissociation was investigated by directly comparing naming in L2 with naming in L1. Compared to naming pictures in L1, naming pictures in L2 revealed increased activation in the left inferior frontal gyrus (LIFG), bilateral SMAs, left precentral gyrus, left lingual gyrus, left
Within the LIFG was observed. The BA 44 and BA 45 have been traditionally termed as the Broca’s area, which is involved in phonological processing (Pugh et al., 1996; Paulesu et al., 1997; Gabrieli et al., 1998; Martin and Chao, 2001; Poldrack et al., 2001), semantic processing (Wagner et al., 2001; Roskies et al., 1999), verbal motor planning and articulation (Hillis et al., 2004). The present finding is also in accordance with the meta-analysis of neuroimaging studies by Indefrey (2006), which showed a stronger activation in the left frontal inferior gyrus for L2 processing compared with L1. This further suggested that, compared with naming in L1, naming in L2 needs to recruit more neural resources for lexical retrieval and post-lexical processing (for a review, see Indefrey, 2006).

### Table 2 – Conjunctions between brain activations for naming in Chinese (L1) and naming in English (L2).

<table>
<thead>
<tr>
<th>Region</th>
<th>BA</th>
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<th></th>
<th></th>
<th>t-value</th>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Middle frontal gyrus</td>
<td>6, 46</td>
<td></td>
<td>-32</td>
<td>56</td>
<td>28</td>
<td>4.17</td>
<td>53</td>
<td>-5</td>
<td>54</td>
<td>7.53</td>
</tr>
<tr>
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<td>44, 45, 47, 48</td>
<td></td>
<td>-36</td>
<td>22</td>
<td>-4</td>
<td>6.65</td>
<td>33</td>
<td>28</td>
<td>-4</td>
<td>4.39</td>
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<td>6, 8, 24, 32</td>
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<td>16</td>
<td>46</td>
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<td>4</td>
<td>14</td>
<td>48</td>
<td>9.41</td>
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<td>Cingulate gyrus/Medial frontal</td>
<td>6, 8, 24, 32</td>
<td>-4</td>
<td>17</td>
<td>44</td>
<td>9.78</td>
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<td>17</td>
<td>46</td>
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<tr>
<td>Precentral gyrus</td>
<td>3, 4, 6, 43, 44, 48</td>
<td>-51</td>
<td>-5</td>
<td>28</td>
<td>8.28</td>
<td>56</td>
<td>-4</td>
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<td>0</td>
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<td>32</td>
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<tr>
<td>Superior temporal gyrus</td>
<td>21, 22, 38, 42, 48</td>
<td>-56</td>
<td>10</td>
<td>-3</td>
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<td>9.22</td>
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<td>Occipital lobe</td>
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<td>-81</td>
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<tr>
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<td>-22</td>
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<tr>
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<td>-69</td>
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<td>-16</td>
<td>6</td>
<td>6.11</td>
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<tr>
<td>Caudate</td>
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<td>8</td>
<td>3.89</td>
<td>21</td>
<td>8</td>
<td>8</td>
<td>2.89</td>
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<td></td>
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<tr>
<td>Putamen/Globus pallidus</td>
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<td>6</td>
<td>2</td>
<td>5.89</td>
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<tr>
<td>Cerebellum</td>
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<td>-68</td>
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<td>-56</td>
<td>-20</td>
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Note: Height threshold, P<0.001, uncorrected, spatial extent threshold, 20 voxels. The x, y, and z values are in MNI coordinates. Abbreviations: L, left hemisphere; R, right hemisphere; BA, Brodmann’s area; SMA, supplementary motor area.

Fig. 3 – Brain maps illustrating the conjunction effect between naming in Chinese and naming in English.
Another possible explanation for the increased activation of the LIFG in naming in L2 relative to L1 is that the region is associated with overcoming interference between the two languages. Although participants in the present study were not required to do a language switching task, given that they were unbalanced bilinguals, they may need to inhibit the activation of L1 when speaking words in L2 by recruiting typical “executive function” brain areas (e.g., Abutalebi & Green, 2007). The dorsolateral prefrontal cortex and inferior frontal lobe are known to be involved in general executive function and have been found to be active in language switching or inhibition control (e.g., Hernandez et al., 2000, 2001; Rodriguez-Fornells et al., 2005; for a review, see Rodriguez-Fornells et al., 2006).

The current study also revealed increased activity in brain areas related to motor processing for word production in L2 compared to word production in L1, including the bilateral SMAs, left precentral gyrus. The precentral gyrus and SMA are considered as premotor areas. Both of them have projections to the primary motor cortex, raising the possibility that activation in these regions may be related to phonological or phonetic encoding and execution of complex articulatory processing in language production (Braun et al., 2001; Dronkers, 1996; Wise et al., 1999). As word production in L2 is less automatic, it may thus recruit these areas for verbal planning or articulatory processing, resulting in the enhanced activation of the SMA, precentral gyrus. Increased activation of bilateral cerebella in naming in L2 provided further evidence for the above claim, as the cerebellum is mainly involved in articulatory processing of speech production (Ackermann et al., 1997, 1998).

Increasing activity was also found in the bilateral putamen, bilateral globus pallidus, and bilateral caudate when comparing naming in L2 with naming in L1. These areas are a part of the basal ganglia, which is one of the largest subcortical structures in the human forebrain, and has influences on motor behavior and cognition (Graybiel, 2000). This area plays a role in the planning and execution of actions (Elsinger et al., 2006; Monchi et al., 2006), and speech motor control (for a review, see Alm, 2004). Also, it may be involved in modulation of articulatory or phonological output representations (Booth et al., 2007) and may be a part of a procedural system that is involved in the assembly of phonemes into higher order structures such as words (Ullman, 2001). The increased activation of these areas, especially the left basal ganglia, may be due to the fact that bilinguals need to inhibit the interference from L1 during lexical selection in producing words in L2 (e.g., Abutalebi et al., 2008; for a review, see Abutalebi and Green, 2007) as bilinguals’ two languages are activated in parallel especially when they produce words in the less dominant language (e.g., Guo and Peng, 2006).

Taken together, the present study showed that several brain regions related to articulo-motor processing (i.e., the SMA, precentral gyrus, putamen, and cerebellum) and cognitive control (i.e., the LIFG and left basal ganglia) were involved in naming in L2 relative to naming in L1. These findings were different from the results of most previous studies (e.g., Chee et al., 1999), which did not find activation in these areas when participants were asked to name pictures covertly. One possible reason is that an overt naming task was adopted in the present study, which was considered to be more appropriate to investigate the neural basis in language production (Barch et al., 1999; Palmer et al., 2001). Another possible reason is that late unbalanced bilinguals were recruited in the present study. It is quite possible that less activation of these areas, especially the areas related to cognitive control, may be observed as bilinguals become proficient in their L2 or acquire their L2 in their early age, as is the case of some previous studies (e.g., Hernandez et al., 2001; Klein et al., 1994, 1995).

Further studies thus need to examine these possibilities to test which factor is more related to neural difference in word production in L2 compared to word production in L1.

Furthermore, the current study found that, compared with naming in L2, naming in L1 exhibited more activation in the right basal ganglia including the right putamen and right globus pallidus, but there was dissociation of involvement in the right basal ganglia in naming in L1 and L2. Specifically, naming in L1, compared to naming in L2, showed more activation of the posterior putamen (see Fig. 2A). In contrast, naming in L2, compared to naming in L1, showed more activation of the anterior putamen and caudate (see Fig. 2B). This suggests that different parts of the putamen may be associated with different levels of speech motor control, as naming in L1 is more automatic than in L2. This is in line with the findings of Jueptner and Weiller (1998), which showed that, during new learning, the dorsolateral prefrontal cortex and striatum (caudate nucleus and anterior putamen) were activated, while the automatic movements are associated with the sensorimotor cortex and posterior putamen. However, previous studies with other types of bilinguals (Klein et al., 1994, 1995; Yetkin et al., 1996; De Bleser et al., 2003; Hernandez and Meschyan, 2006; but see Vingerhoets et al., 2003) did not show any difference when comparing L1 with L2. The basal ganglia has connections with the inferior frontal gyrus and lateral temporal cortex which have been implicated in phonological processing, and may be involved in cortical initiation of phonological representations in these structures (Booth et al., 2007; Houk, 2005). As Chinese language and English language use different scripts, and pronunciations of Chinese words are determined by consonants and vowels together with tones (Liu et al., 2006), word production in Chinese and word production in English may involve coordination of different parts of articulators, which may lead to activation of different parts of the basal ganglia. One might argue that previous studies with Chinese-English bilinguals (e.g., Pu et al., 2001; Chee et al., 1999) also did not reveal any significant activation when comparing naming in L1 with naming in L2. This may be due to the fact that these studies used a covert word generation task, which may underestimate the motor difference between L1 and L2 (Barch et al., 1999; Palmer et al., 2001). However, the relationship between phonological and articulatory processing and neural activity of different parts of the right basal ganglia still needs further investigation.

Finally, the neural overlap of word production in L2 and L1 was identified by using the conjunction analysis (Price & Friston, 1997; Price et al., 1997). Activation was observed in a widespread bilateral network in the frontal, temporal, parietal and occipital cortex as well as in the cerebella and limbic system. The activation pattern is generally consistent with findings in previous studies that showed largely neural overlap in word production in L1 and L2 (Klein et al., 1994, 1995).
Eighty line drawings selected from the Snodgrass and Vanderwart (1980) were used as stimuli. Ten of them were used for the practice session. A plus sign ‘+’ presented on a white screen was used as the baseline. The ratio of pictures and baselines is 5:4. Pictures were presented on either a red or blue background, and the background colors were counter-balanced across languages.

Each picture or plus sign ‘+’ was presented for 1000 ms, and was replaced by a blank screen of 2000 ms. During the experimental trials, participants were asked to name pictures verbally. If they could not produce a response, they were instructed to say ‘no’ in an appropriate language. During the baseline trials (i.e., ‘+’ followed by a blank), they were asked to passively view the screen. The event-related design was used to minimize the movement related artifacts. The presentation of experimental trials (i.e., pictures) and baseline trials was randomized.

Participants named pictures in L1 or L2 in two different runs. Each run contains 126 trials. The order of the two runs was counterbalanced across subjects. A short break was provided between runs. Behavioral data were then collected outside of the scanner 1 month later. Different from previous studies using the picture naming task, the participants were not pre-trained with pictures’ name in order to avoid practice effect. All the instructions were given in Chinese language by the experimenter.

4. Experimental procedures

4.1. Participants

Twenty-four college students (twelve male and twelve female) with a mean age of 21.8 years (SD=2.15) participated in the experiment. They were Chinese-English bilinguals who began to learn English when they were about 12 years old. All of them were right-handed with normal or corrected to normal vision. None of them had any history of neurological or psychiatric disorders. According to their self-rating scores in reading, writing, speaking, and listening on a 10-point scale (1=poor, 10=excellent), their Chinese was rated as medium (8.21 vs. 5.87), F(1,23)=80.11, P<0.001. Written informed consent was obtained from all participants following a protocol approved by the State Key Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University.

4.2. Stimuli and procedure

Image processing and statistical analyses were performed using SPM2 (Wellcome Department of Cognitive Neurology, London, UK) in conjunction with the ArtRepair software (Mazaika, Whitfield-Gabrieli, Reiss, & Glover, 2007) implemented in Matlab. Preprocessing included slice-time correction and an optimized motion correction routine (see below for details) to treat the possible movement related artifacts due to the overt naming task. Images were then normalized to the Montreal Neurological Institute (MNI, Montreal, Canada) echo planar imaging reference brain with a 2x2x2 mm³ spatial resolution. All functional images were smoothed with a cubic Gaussian filter of 8 mm full-width at half-maximum.

To quantify the effect of subject movement on the quality of our data, we inspected the data using the ArtRepair toolbox for SPM2 (Mazaika et al., 2007) and examined the realignment parameters provided by the SPMP motion correction procedure. We were particularly interested in scan-to-scan (incremental) motion during the task (e.g., Barch et al., 1999), i.e., the change in position between images and its immediately
preceeding image. We also inspected the movement parameters for extreme movements by considering absolute movements (the displacement of a scan with respect to the realignment reference scan of the time series, i.e., in our case, the first image in the time series). The criteria for inclusion were that a subject would not show absolute motion greater than the voxel size and incremental motion greater than 1 mm. All subjects met the absolute motion inclusion criteria. However, one subject did not meet the incremental motion inclusion criteria. Since there were only 4 volumes with incremental motion greater than 1 mm, the data of the subject were still remained in the following analysis after repaired with the ArtRepair. Individual volumes showing rapid inter-TR movement of greater than 0.5 mm were excluded via interpolation of the two nearest non-removed volumes. Consequently, approximately 0.48% of total volumes for 24 subjects were corrected. Interpolated volumes were then partially deweighted when first-level models were calculated on the repaired images (Mazaika et al., 2007).

The General Linear Model was used to estimate the condition effect with canonical HRF as reference function for each subject. The data were globally scaled and high-pass-filtered at 128 s. Individual results were acquired by defining four effects of interest for each subject (i.e., naming in L1 minus baseline, naming in L2 minus baseline, naming in L1 minus naming in L2, and naming in L2 minus naming in L1). Group-averaged effects were computed with a second-level random-effect model. Effects of interest were calculated for the direct contrast between naming in L1 and L2, i.e., naming in L1 minus naming in L2 and naming in L2 minus naming in L1. The results were then masked by the corresponding contrast between the first experimental condition and baseline (i.e., naming in L1 minus baseline, naming in L2 minus baseline, respectively, the height threshold of the mask contrast was P<0.01, uncorrected). Only clusters with more than 20 voxels activated above the threshold of P<0.01 (uncorrected) were considered as significant. Reported voxels correspond to the standardized MNI coordinate space.

Furthermore, we conducted a conjunction analysis (Price & Friston, 1997; Price et al., 1997) to reveal the common neural basis for word production in L1 and L2. A modification of the procedure described by Price and Friston (1997) was used and is the same procedure used in some previous studies (Braun et al., 2001; Corina et al., 2003; San Jose-Robertson et al., 2004). Conjunctions are defined as common areas of activation in a set of task pairs (e.g., naming in L1 minus baseline and naming in L2 minus baseline). Interactions i.e. significant differences between the individual pairwise contrasts (e.g., naming in L1 minus baseline versus naming in L2 minus baseline), are eliminated from the conjunction map (for this purpose, significant interactions were defined conservatively as voxels with a threshold of P<0.01, uncorrected). The resultant conjunction map was further masked so that only voxels in which significant activations were detected in both of the individual pairwise contrasts (P<0.001, uncorrected) were retained. Therefore, the conjunction map reported in the present study should be interpreted as simply depicting, in a more conservative, Boolean sense, common activations (naming in L1 minus baseline and naming in L2 minus baseline) that do not significantly differ in magnitude.

Acknowledgments

The research was supported by the National Natural Science Foundation of China (30600179) to Taomrei Guo and Program for Changjiang Scholars and Innovative Research Team in University (PCSIRT). We thank the two reviewers for their valuable comments for an earlier version of the manuscript, and Wenping You, Jingjing Guo, Min Chen, and Xiujun Li for their help with collecting data.

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