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Brain Response is Shaped by Language Experience: Evidence from an fMRI Study on Beginning Second Language Learners *

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Abstract Functional MRI was used to explore the role of language experience in shaping the neural substrates of phonological processing. Twelve Chinese children who had very limited exposure to second language (L2), i.e., English, were scanned while they were performing visually presented rhyme judgment tasks in their two languages. We found that the phonological processing of subjects' native language and their newly obtained L2 elicited overlapping activation in the left inferior frontal region. More important, thought the L2 tasks were more difficult and thus caused more intensive activation in bilateral parietal lobule, the Broca's area was less intensively activated in the L2 tasks. These results confirm and extend the view that the involvement of Broca's area in phonological processing is gradually increased as a function of language experience.

Key words fMRI; bilingual; phonology; language proficiency; language experience.

1 Introduction

Existing functional imaging studies have consistently indicated that the neural basis for phonological processing is located in the left inferior frontal lobe [LIFG] (i.e., the putative Broca's area), which differs remarkably from that for music and other nonverbal materials processing[1~4]. One interesting question thus related is how the so-call language area is developed as a function of language experience. On the one hand, it is found that this region is equally involved in high proficient bilinguals' first language (L1) and second language (L2)[5]. On the other hand, increasing evidence indicates that foreigners with no experience of that language show no or less significant activation in this area as compared to native speakers[6~9], some even show rightward activation. For example, when subjects were asked to judge the pitch patterns of Thai lexical tone, only Thai group showed significant activation in the left frontal operculum, while Chinese and English group showed significant activation in the right homologues[6,7]. Following studies with Chinese-English comparison also found LIFG activation only appeared on Chinese speakers when the two groups of participants were processing Chinese tone[8,9].

Studies on less proficient bilingual provide a unique opportunity to further our understanding on the role of language experience in shaping the neural architecture. For example, several studies on low proficient bilinguals found that some brain areas, such as the left inferior frontal gyrus and the left inferior parieto-occipital area were activated only for the native language, which suggests that the neural specialization for native language is shaped by early and extensive exposure[10,11], and the amount of exposure is a critical factor that affects the formation of the neural representation of a second language[12,13].

These findings, however, are not out of dispute. Some studies, by using tasks as working memory[14], semantic decision[15,16], and sentence comprehension[17], have found that the processing of one's less proficient second language would share the same neural network of their native language. In particular,

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Xue et al. (2004)[14] found considerable degree of overlap when non-fluent Chinese-English bilinguals were performing phonological working memory task in their two languages. In addition, the English task, which was more difficulty, caused larger volume of activation in several brain regions sustaining verbal working memory, including the Broca's area and the parietal lobule. These results, together with that from several other studies[15, 17], consistently suggest that non-fluent bilinguals' two languages are implements by overlapping neural network which is modulated by computational demand, or task difficulty.

To address this discrepancy, several factors should be taken into consideration. First, in these studies, subjects were at various degree of second language proficiency. Xue et al.[16] suggested that with the increase of L2 proficiency, the neural contrast between L1 and L2 might show nonlinear changes. Second, the tasks adopted by these studies are also highly varied. Some of these studies used whole-language tasks, such as sentence comprehension, which make it difficult to disentangle the factors that contribute to the observed difference. Third, in Perani and his colleagues' studies[10], subtractive method was commonly used. This would be more likely to get qualitative but not quantitative between-language and between-group contrast[14]. Finally, there is clear evidence which shows obvious individual difference in the neural organization of L2, especially for non-fluent bilinguals[11], which may be caused by learning method, age and time of L2 exposure[11, 18]. As a result, it is important to control these factors and minimize individual difference.

The present study aimed at exploring the neural circuits underlying phonological processing of non-fluent bilinguals' second language *. In particular, we were to answer the following progressional questions: (1) whether the phonological processing of low proficient bilingual's L2 is also left-dominated, (2) if the answer for question one is yes, whether nonfluent bilinguals would or not show overlapping activation in the Broca's area while processing two languages, and (3) if the answer for question two is also yes, whether the processing of L2 would elicit stronger or weaker activation in the left inferior frontal gyrus as compared to the processing of L1. In this fMRI study, visual-presented rhyme judgment task was designed to tap the phonological process while avoid introducing syntactic component. During data processing, in addition to group-averaged result for each language task related to baseline, quantitative comparisons on the activation intensity in the pre-selected ROIs were also performed based on the individual results. In order to minimize the individual difference, primary school students who had very limited L2 exposure were recruited. They had very similar learning experience and consisted of a homogeneous group.

2　Materials and Methods

2.1　Subjects

Twelve right-handed children (6 male, mean age = 11) were included in this experiment. Informed consent was obtained from both the children and their parents in accordance with guidelines set by the MRI center at the Beijing 306 Hospital. All the subjects were selected from a preliminary school. They accepted English training exclusively at school since grade three (about 8 years old). As their chance to learn and practice English was very limited (only about two hours per week), they could only recognize about 400 English words after two years study.

2.2　Material and behavioral performance

Eighty English words and eighty Chinese characters were adopted from subjects' textbook to ensure their familiarity with the stimuli. Each type of stimuli was organized into 40 pairs with half of similar rhyme and half not. The fMRI design in this study was very similar to study that we reported before[16]. In brief, block design was used in this study with fixation as baseline. The experimental blocks are arranged in a sequence of CEECECCE (C: Chinese; E: English) to counterbalance the practice and fatigue effect. The duration for experiment block and control block is 30s and 21s, respectively. Stimuli were timed by DMDX software and presented by a projector onto a translucent screen. Subjects viewed the stimuli through a mirror attached to the head coil. During the experimental condition, each pair of stimuli was presented for 2500ms, followed by a blank screen for 500ms. Subjects were asked to judge whether the two words rhymed or not. They indicated a positive response by pressing the key corresponding to the index finger of their right hand and a negative response by pressing the key corresponding to the index finger of the left hand. In the control block, fixation cross was presented and subjects were asked to only silently fixate on the crosshair.

2.3 Apparatus and procedure

We used a 2.0 T GE/Elscint Prestige whole-body MRI scanner (Elscint Ltd., Haifa, Israel) at the MRI center of Beijing 306 Hospital to do the scan. For functional imaging scan, a single-shot T2*-weighted gradient-echo, EPI sequence was used with the following parameters: TR/TE/θ= 3000ms/60ms/90°, FOV = 375×210mm, matrix = 128×72, slice thickness = 6mm. Twenty contiguous axial slices were acquired to cover the whole brain. During the total scanning time of 6 min, 48 s, 136 images were collected for each slice. The anatomical MRI was acquired using a T1-weighted, three-dimensional, gradient-echo pulse-sequence. The parameters for this sequence were: TR/TE/θ = 25ms/6ms/28°, FOV = 220×220mm, matrix = 220×220, slice thickness = 2mm.

2.4 Data analysis

Statistical parametric mapping (SPM 99, Wellcome Department of Cognitive Neurology, London, UK) implemented in Matlab (Mathworks Inc. Sherborn, Mass., USA) was used to do the imaging data analysis. All functional images were smoothed with a cubic Gaussian filter of 8 mm. General linear model was used to estimate the condition effect of individual subject[19]. Two effects of interests (L1 vs. Baseline, L2 vs. Baseline) were defined for each subject with the relevant parameter estimates. Group analysis was performed using a random-effect model. For group effects, clusters which had more than 5 voxels (135mm^3) activated above a threshold of $p < 0.001$ (Uncorrected) were considered as significantly activated.

Ten ROIs were defined based on the Automatic Anatomic Labeling map (AAL map) developed by Tzourio-Mazoyer et al.[20], including the three subregions of inferior frontal gyrus (triangular pars, opercular pars and orbital pars) and their right homologous, bilateral insula and bilateral inferior parietal lobule. ROI-based intensity was calculated for each subject under each task in each ROI. Non-parametric test (wilcoxon) was used to compare the difference between Chinese task and English task in each ROI.

3 Results

3.1 Behavior data

The behavior data indicated the subjects were more accurate and faster in Chinese task than in English (Reaction time/Correct ration: Chinese, 1662ms/85%; English, 1797ms/72%), and the differences ($p < 0.05$). were all significant as revealed by paired T-test.

3.2 Imaging data

3.2.1 Group data Significant activation of Chinese and English rhyme judgment tasks relative to the baseline task were shown in Fig.1 and the stereotaxic coordinates were summarized in Table. 1. For Chinese task, the foci of activation were in left inferior frontal lobe (BA45/47), right inferior orbitofrontal area (BA47), bilateral SMA (BA6), cingulate area (BA31/32), lingual gyrus (BA17/18) and fusiform gyrus (BA19). Significant activation could also be found in right insular (BA13), left supramarginal gyrus (BA40) and bilateral cerebellum. For English task, the left inferior frontal (BA45/47), bilateral insula (BA13), SMA (BA6) and the left cingulate areas (BA24/31) were active. Bilateral lingual gyrus (BA17/18), fusiform gyrus (BA19) and cerebellum were also significantly activated. In addition, a wide range of bilateral parietal region was also activated, and the center-of-mass were located in bilateral postcentral parietal lobule (BA2/43), and left supramarginal gyrus (BA40).

3.2.2 ROI results As showed in Fig.2, the ROI-based intensity analysis indicated that Chinese task caused more intensive activation in all the three ROIs located in the left inferior frontal gyrus, including the the left opercular pars ($z = 2.434$, $p < 0.015$), left triangular pars ($z = -1.961$, $p < 0.05$), and the left orbital pars ($z = -1.961$, $p < 0.05$) while the English task caused more intensive activation in the bilateral supramarginal regions (Left: $z = -2.277$, $p < 0.023$; Right: $z = -2.051$, $p < 0.04$). No difference was found in the right inferior frontal gyrus and bilateral insula.

4 Discussion

Recent neuroimaging and neurophychological studies have implicated the inferior frontal gyrus (LIFG) is involved in both semantic and phonological processing, with the posterior portion (i.e., pars triangularis and pars opercularis, BA44/45) more involved in phonological processing and the anterior portion (i.e., orbital area, BA45/47) more involved in semantic task[2,3,21,22]. The present study found significant activation in the Broca's area when very low proficient L2 learners were performing phonological task with visual present words in their two languages, which adds evidence to the view that the left inferior frontal gyrus is in charge of phonological processing of word[22], and also extends this finding to participants' very low proficient second language. In addition, the overlapping activation for L1 and L2 found in this study further confirms our previous finding that there is a common neural network for subjects' two language at least at single-word level even when they are at very low L2 proficient[16].

Table 1 Significant activation for Chinese and English rhyme judgment relative to fixation.

Region (BA)	Chinese minus fixation				English minus fixation			
	x	y	z	Z score	x	y	z	Z score
L Inferior Frontal Gyrus (47)	-30	23	-11	4.79	-27	20	-6	4.60
R Inferior Frontal Gyrus (47)	30	23	-11	4.44	30	37	-9	3.58
L Inferior Frontal Gyrus (45)	-42	19	21	4.59	-42	16	21	4.12
L Insula (13)	-27	0	-5	4.32	-27	-8	22	3.34
R Insula (13)	36	20	2	5.22	39	-22	23	4.33
L Precentral Gyrus (6)	-36	2	36	3.51	-36	2	36	3.89
R Middle Frontal Gyrus (6)	-	-	-	-	30	-3	47	3.39
L Cingulate Gyrus (32)	-6	16	38	4.96	-	-	-	-
L Cingulate Gyrus (31)	-24	-48	36	4.14	-24	-51	36	4.19
L Cingulate Gyrus (24)	-	-	-	-	-24	-13	39	3.88
R Cingulate Gyrus (32)	9	25	32	5	-	-	-	-
R Cingulate Gyrus (31)	21	-42	38	3.37	-	-	-	-
L Supramarginal Gyrus (40)	-24	-48	35	4.13	-36	-36	32	5.45
L Postcentral Gyrus (43)	-	-	-	-	-48	-14	17	3.47
R Postcentral Gyrus (2)	-	-	-	-	45	-24	37	3.79
L Fusiform Gyrus (19)	-36	-68	-12	5.32	-36	-68	-12	4.97
L Lingual Gyrus (18/17)	-21	-82	-1	5.59	-21	-90	-3	5.01
R Lingual Gyrus (17)	21	-88	-3	5.16	18	-91	-6	4.47
R Fusiform Gyrus (19)	36	-76	-9	4.63	33	-79	-11	4.28
L cerebellum	-27	-30	35	4.48	-6	-62	-22	4.25
R cerebellum	33	-56	-20	4.81	33	-59	-22	5.04

Note. The number in the parentheses indicated the number of Broadmann area. R = right, L = left.

More importantly, we found the intensity of Left inferior frontal activation was significant weaker in subjects' second language than in their native one. This result definitely cannot be contributed to task difficulty, by which we may expect a stronger activation. Rather, according to existed findings on the functional fraction of LIFG in language processing[2, 22], we think the less intensive activation in the left inferior orbital area between Chinese and English may be attributed to less degree of automatic semantic activation of L2 during phonological processing, as subject is less proficient at English. While for the difference in the pars opercularis and pars triangularis, we think this may reflect the prominent impact of language experience in shaping the neural representation of the phonology of a new language.

Existing studies found that fluent bilinguals would show significant activation in the Broca's area when they were processing their second language[5\]], while individuals totally new to a second language showed no activation in this area[6~9]. In line with these findings, our results suggest the neural substrates for the phonological processing of second language is gradually shaped by language exposure. In addition, congruent result was acquired by adopting visual instead of auditory stimulus, which suggests that the impact of language experience is irrelevant to task requirement, such as perception or production.

In our previous studies on bilingual phonological processing with a 2-back working memory paradigm, we found significant more strong activation for subjects' less proficient second language, i.e., Eng-

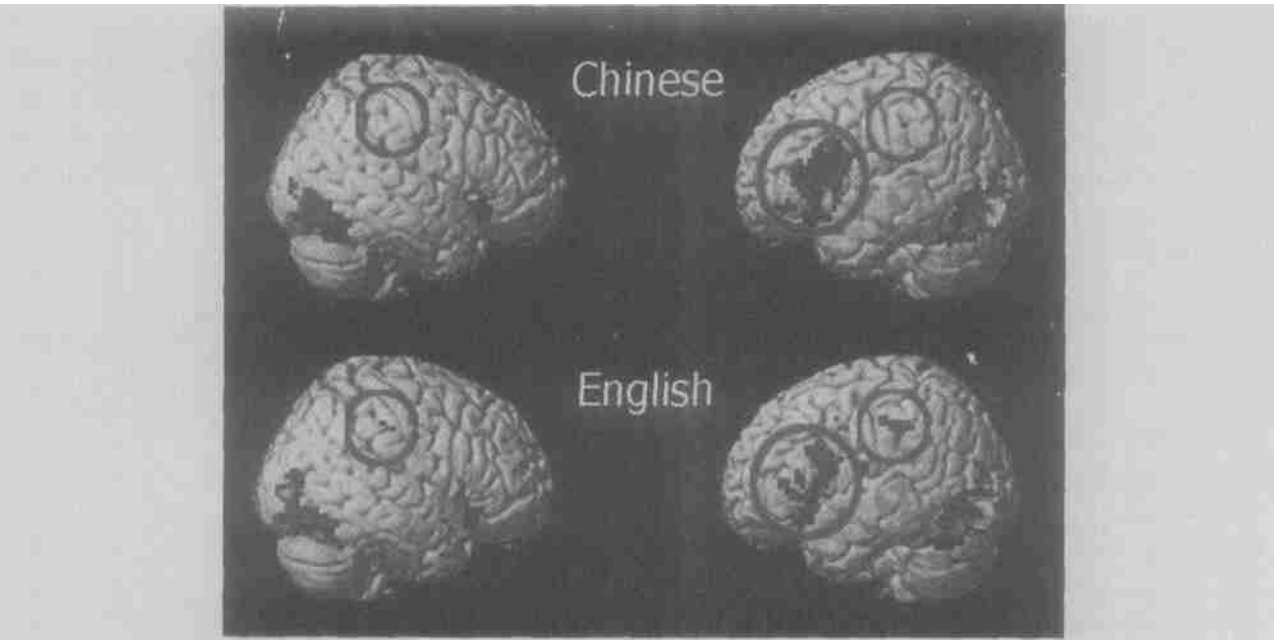

Fig. 1 Group-averaged results for the rhyme judgment task of Chinese (upper) and English (Lower) relative to their controls are shown as t statistic map. Significant difference between Chinese and English task are found in the left inferior frontal gyrus (large circle) and bilateral inferior parietal lobule (small circle). Stereotaxic coordinates are summarized in Table 1 and quantitative comparison between the two tasks is shown in Fig. 2.

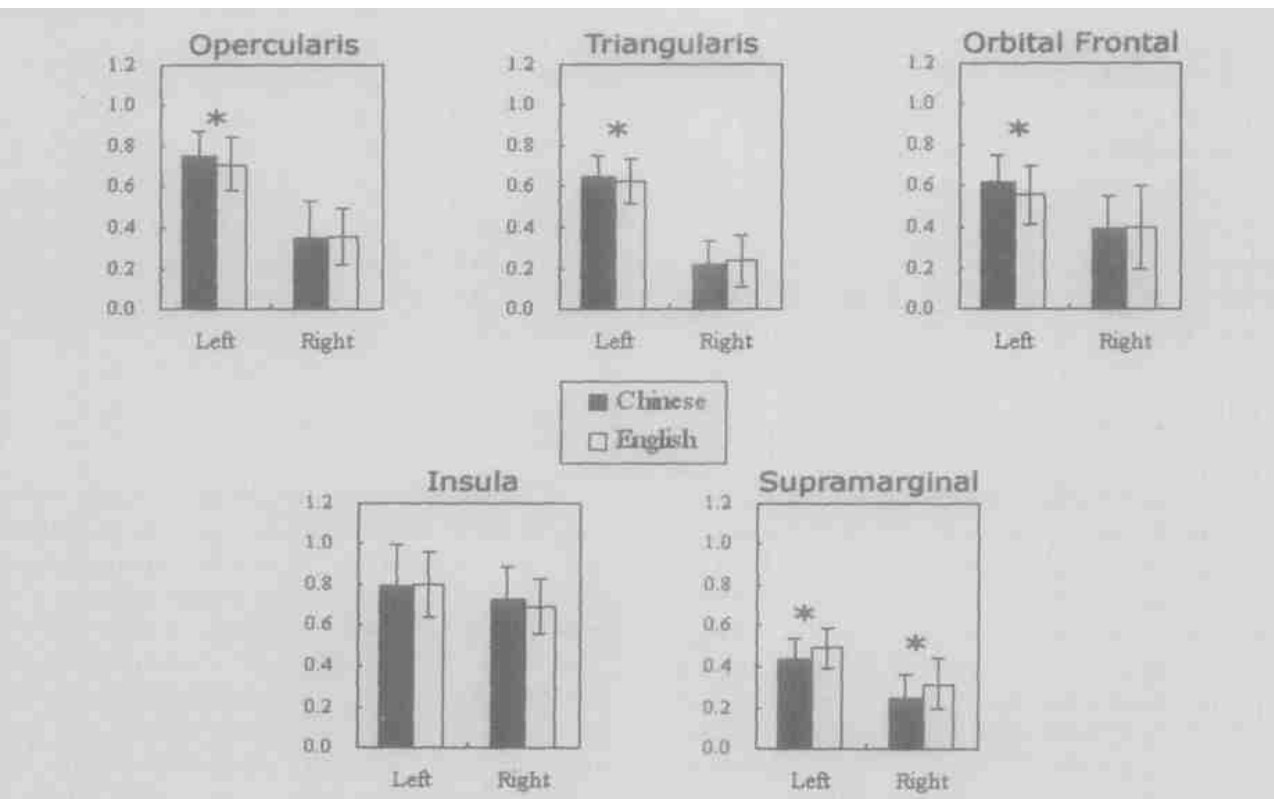

Fig. 2 ROI based intensity comparison between Chinese and English task in the prior defined ten ROIs. The bar represents the mean intensity and the T shape for the standard deviation. Significant differences ($p < 0.05$) revealed by non-parametric test (wilcoxon) are marked with black star.

lish[14]. This finding suggests that it is less likely that the processing of English inherently needs less frontal activation than the processing of Chinese. On the contrary, the neural contrast of Chinese and English found on the beginning English learner would be largely contributed to the language experience, but not the language itself. The language experience hypothesis might also help to resolve the discrepancy in the two studies. In the present studies, subjects were at very low second language proficient, while in that study, the participants were college students and had middle fluent grasp of English. If further studies convinced our hypothesis, we may expect increased activation in the Broca's area as subjects become increasing fluent at their second language.

Nevertheless, the present finding didn't exclude the task difficulty effect in this area on very low proficient bilinguals, which may be counteracted by effect of language experience because the later factor is dominant in the present study. Actually, we did find task difficulty effect in the present study. The more intensive activation in bilateral superior parietal lobule is consistent with our two previous studies on non-fluent bilinguals with semantic decision task[16] and working memory task[14], respectively. According to the popular cognitive-neural model of verbal working memory, the parietal lobule is involved in the temporal storage of phonological representation[23,24]. During rhyme judgment task, verbal information of the paired words converted from visual stimulus must keep active in working memory for further processing. In the present study, the English words usually comprised two or more syllables while Chinese characters contained only one, and subjects were less familiar with English words. As a result, more cognitive and neural resource was required to keep the phonology of English words in working memory. Another reason may simply be that L2 tasks needed more attention orientation, which would cause more computation in the parietal lobule[25].

The present study supports Perani and his colleagues' major point that for certain bilingual function, e.g., phonology processing, the neural representation of the second language is gradually shaped with the increase L2 exposure[10,12,13]. Nevertheless, we didn't find any significant brain region that was solely activated by L1, but not by L2. Apart from the obvious differences in material, and cognitive task, another possible reason may lie in how the data was analyzed and interpreted. The direct subtraction between the activation maps of two language tasks would be more easily lead to a qualitative conclusion. By only looking at the group average pattern with a predefined threshold, the selection of subject may also be important due to the obvious individual difference. Further studies are definitely required to clarify these issues.

In summary, the important point of the present study is that it provides strong evidence indicating there is overlapping brain circuit for bilinguals' two languages even when they are at the beginning stage of second language learning, and language experience plays an important role in shaping the neural response when performing a language task. The neural representation of some linguistic components, such as the phonology, may gradually develop as a function of language exposure. This may have potentially importantly implication for English learning and teaching.

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语言经验对大脑激活的影响:来自第二语言初学者的证据

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摘 要 研究采用功能磁共振成像技术考察语言经验在塑造大脑激活模式中的作用。12 名只有很少英语学习经验因而熟练程度很低的小学儿童参与了实验。结果发现, 在视觉呈现的押韵判断任务中, 英文任务和中文任务共同激活了左侧额下回负责语音加工的脑区。更重要的是, 虽然英文任务更难, 也更多地激活了双侧的顶叶区域, 但是它在额叶诱发的激活强度显著低于中文。这个结果进一步说明第二语言的语音皮层表征是随着学习经验的增加而逐渐发展起来的。

关键词 功能磁共振成像, 双语, 语音, 语言熟练程度, 语言经验。
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