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Long-term experience with Chinese language shapes the fusiform asymmetry of English reading

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ABSTRACT

Previous studies have suggested differential engagement of the bilateral fusiform gyrus in the processing of Chinese and English. The present study tested the possibility that long-term experience with Chinese language affects the fusiform laterality of English reading by comparing three samples: Chinese speakers, English speakers with Chinese experience, and English speakers without Chinese experience. We found that, when reading words in their respective native language, Chinese and English speakers without Chinese experience differed in functional laterality of the posterior fusiform region (right laterality for Chinese speakers, but left laterality for English speakers). More importantly, compared with English speakers without Chinese experience, English speakers with Chinese experience showed more recruitment of the right posterior fusiform cortex for English words and pseudowords, which is similar to how Chinese speakers processed Chinese. These results suggest that long-term experience with Chinese shapes the fusiform laterality of English reading and have important implications for our understanding of the cross-language influences in terms of neural organization and of the functions of different fusiform subregions in reading.

Introduction

Previous cross-linguistic neuroimaging research has shown significant interactions between the native language and the second language in the brain. On the one hand, the native language can shape the cognitive and neural mechanisms of second language processing (Nakada et al., 2001; Nelson et al., 2009; Tan et al., 2003; Wang et al., 2003); and on the other hand, second language learning affects the neural mechanisms of native language (Mei et al., 2014; Nosarti et al., 2010; Zou et al., 2012). To account for the cross-language influences, Perfetti and colleagues have proposed the assimilation–accommodation hypothesis (Perfetti and Liu, 2005; Perfetti et al., 2007). The assimilation process assumes that the human brain will read a second language as if it is the native language and use the neural network for the native language to support the second language (Cao et al., 2013a; Nelson et al., 2009). The accommodation process assumes that the brain's reading network must adapt to the features of a new writing system in order to accommodate those features that require different reading procedures (Cao et al., 2013b; Liu et al., 2007; Nelson et al., 2009; Zhao et al., 2012).

Chinese–English bilinguals provide a unique opportunity to investigate cross-language influences, because English and Chinese languages differ in several important aspects such as visual appearance and orthographic transparency (Bolger et al., 2005; Chen et al., 2009; Perfetti and Tan, 2013; Tan et al., 2005). Specifically, Chinese characters are composed of intricate strokes packed into a square shape and their phonologies are mainly accessed through whole-word mapping (i.e., addressed phonology), whereas English words are constructed by linear combinations of letters and their phonologies are mainly accessed through grapheme-to-phoneme mapping (i.e., assembled phonology). Given their differences in visual appearance and orthographic transparency, reading Chinese words relative to English words may involve more visuospatial analysis and more whole-word processing, and consequently recruit more regions in the right hemisphere (Mei et al., 2013; Tan et al., 2000). In support of this view, previous studies have reported bilateral (e.g., Guo and Burgund, 2010; Liu et al., 2007; Peng et al., 2004; Tan et al., 2001; Wang et al., 2011; Wu et al., 2012) or even right-lateralized activation (Tan et al., 2000) in the occipitotemporal region for Chinese

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processing. This is in clear contrast to the left-hemispheric dominance in the processing of English words (Cohen et al., 2002; Price, 2012; Vigneau et al., 2005). In a direct comparison between native Chinese and native English speakers, Nelson et al. (2009) confirmed that English speakers showed left-lateralized activation in the occipitotemporal region when reading English words, while Chinese speakers activated the bilateral occipitotemporal region when reading Chinese words.

Given the differences in occipitotemporal laterality between Chinese and English reading, how does Chinese experience affect English reading? To our knowledge, only one study has addressed this question by comparing Chinese–English bilinguals with native English speakers (Nelson et al., 2009). They found that Chinese–English bilinguals activated the bilateral fusiform cortex when processing Chinese and English words. These results supported the idea that long-term experience with Chinese language shapes fusiform laterality of English processing. This pioneering study, however, had three important limitations. First, Nelson et al.'s study included a relatively small sample size (i.e., 11 Chinese–English bilinguals and 6 native English speakers), which might greatly be affected by intersubject variances (Dehaene et al., 1997). Second, their study relied on the comparison between native English readers and native Chinese readers who learned English as a second language, which might have been confounded by factors such as language proficiency and age of acquisition, two factors that have been found to have significant effects on the neural mechanism of reading (e.g., Chee et al., 2001; Hernandez and Li, 2007). One way to control for those two confounding factors is to compare English reading between two groups of native English speakers, those with and those without Chinese experience. Finally, their study did not examine the laterality differences across different subregions in the occipitotemporal cortex. It has been suggested the anterior and posterior parts of the occipitotemporal region are engaged, respectively, in lexico-semantic versus visuo-perceptual processing (e.g., Simons et al., 2003; Xue and Poldrack, 2007), and high-level orthographic versus low-level perceptual processing (e.g., encoding letter shapes) (Vinckier et al., 2007). Consequently, functional asymmetry in the anterior and posterior occipitotemporal regions is sensitive to high-level linguistic (e.g., semantic) and visuospatial factors, respectively (Mei et al., 2013; Seghier and Price, 2011). Consistently, our previous study revealed that functional laterality of Chinese processing varied across different subregions in occipitotemporal cortex — left laterality in the anterior region and bilaterality in the posterior region (Xue et al., 2005). Therefore, it is important to examine fusiform laterality by its subregions.

To overcome the three limitations mentioned above, the present study 1) used a relatively large sample (42 native Chinese speakers, 44 native English speakers with experience with Chinese language, and 45 native English speakers without prior experience with Chinese language) to reduce the confounding effect of intersubject variances, 2) compared native English speakers with and without Chinese experience to avoid the confounding effect of language proficiency and age of acquisition, and 3) split the fusiform gyrus into three subregions (i.e., anterior, middle, and posterior) to examine the effect of Chinese experience on the functional laterality of English reading in different fusiform subregions. To minimize (or avoid) automatic activation of Chinese during English reading, we used an implicit reading task (i.e., a passive viewing task) and included both English words and alphabetic pseudowords, the latter of which were not likely to activate Chinese processing automatically because they had no semantics and hence could not be translated into Chinese words. In this study, we first confirmed the laterality differences between Chinese and English by comparing native Chinese speakers with native English speakers without prior experience with Chinese language. We then examined whether long-term experience with Chinese language shaped the functional asymmetry of English reading in different fusiform subregions by comparing fusiform laterality in English speakers with vs. those without experience with Chinese language.

Methods

Subjects

Eighty-nine native English speakers (34 males, mean age = 20.72 ± 2.02 years old) and 42 native Chinese speakers (21 males; 22.05 ± 1.85 years old) participated in this study. Native English speakers included two groups: those with long-term experience with Chinese language (n = 44) and those without (n = 45). The former group included mostly Chinese Americans who were born in United States but had learned Chinese for at least ten years. Among the latter group of 45 subjects, none had any previous experience with Chinese language or other logographic languages such as Japanese, but 29 of them learned other alphabetic languages (e.g., French, Spanish, German, and etc.) as a second language (typically in high school because of the second-language requirements) and the remaining 16 subjects considered themselves as monolingual English speakers because of their minimal fluency in another language.

The two groups of native English speakers did not differ in nonverbal intelligence (Raven's Advanced Progressive Matrices) (Raven, 1990) and performance on English reading tasks [word identification from the Woodcock Reading Mastery Tests — Revised (WRMT-R) (Woodcock, 1987), phonemic decoding efficiency and sight word efficiency from the Test of Word Reading Efficiency (TOWRE) (Torgesen et al., 1999), rapid object and color naming from the Comprehensive Test of Phonological Processing (CTOPP) (Wagner et al., 1999)] (Table 1).

All subjects had normal or corrected-to-normal vision, had no previous history of neurological or psychiatric disease, and were strongly right-handed as judged by Snyder and Harris's handedness inventory (Snyder and Harris, 1993). Informed written consent was obtained from the participants before the experiment. This study was approved by the IRBs of the University of California, Irvine, the University of Southern California, and Beijing Normal University.

Materials

Sixty English words, 60 alphabetic pseudowords (i.e., letter strings that comply with English orthographic rules, such as *hilk* and *bime*), and 60 Chinese words were used in this study. The English materials were presented in gray-scale with 226 × 151 pixels in size, and the Chinese words were 151 × 151 pixels in size.

All English words were monosyllables. They were selected from the MRC psycholinguistic database: machine usable dictionary, version 2.00

Table 1
Mean scores (and SD) on the reading tests and a nonverbal intelligence test obtained by native English speakers with or without Chinese experience.

	With Chinese experience	Without Chinese experience	*t*	*p*
Word identification	99.39 (4.13)	98.02 (4.16)	1.55	.125
Sight word efficiency	98.32 (6.93)	98.26 (6.85)	0.04	.966
Phonemic decoding efficiency	57.05 (5.41)	55.87 (5.24)	1.03	.304
Rapid object naming	41.20 (6.14)	40.75 (7.71)	0.31	.761
Rapid color naming	37.35 (5.76)	37.38 (5.80)	0.03	.977
Raven's Advanced Progressive Matrices	26.64 (4.42)	25.58 (4.21)	1.16	.250

Note: the scores for rapid object and color naming are amounts of time (second) needed to complete the tests, and the scores for other tests are the number of correct items. Word identification is a subtest of the Woodcock Reading Mastery Tests — Revised (WRMT-R); sight word efficiency and phonemic decoding efficiency are subtests of the Test of Word Reading Efficiency (TOWRE); rapid object and color naming are subtests of the Comprehensive Test of Phonological Processing (CTOPP).