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Orthographic transparency modulates the functional asymmetry in the fusiform cortex: An artificial language training study

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ABSTRACT

The laterality difference in the occipitotemporal region between Chinese (bilaterality) and alphabetic languages (left laterality) has been attributed to their difference in visual appearance. However, these languages also differ in orthographic transparency. To disentangle the effect of orthographic transparency from visual appearance, we trained subjects to read the same artificial script either as an alphabetic (i.e., transparent orthography) or a logographic (i.e., nontransparent orthography) language. Consistent with our previous results, both types of phonological training enhanced activations in the left fusiform gyrus. More interestingly, the laterality in the fusiform gyrus (especially the posterior region) was modulated by the orthographic transparency of the artificial script (more left-lateralized activation after alphabetic training than after logographic training). These results provide an alternative account (i.e., orthographic transparency) for the laterality difference between Chinese and alphabetic languages, and may have important implications for the role of the fusiform in reading.

1. Introduction

A longstanding question in the neurobiology of language is whether there are specific neural networks for different language systems (e.g., Chen, Xue, Mei, Chen, & Dong, 2009; Paulesu, Démonet, et al., 2001; Paulesu, McCrory, et al., 2000; Siok, Perfetti, Jin, & Tan, 2004; Tan, Laird, Li, & Fox, 2005). One way to address this question is to use the contrast of logographic (e.g., Chinese) and alphabetic (e.g., English) languages, because of their dramatic differences in visual appearance (Bolger, Perfetti, & Schneider, 2005; Perfetti et al., 2007). Chinese characters possess a number of intricate strokes that are packed into a square shape, whereas alphabetic languages have linear combinations of letters. Based on this difference, researchers have hypothesized that, compared with alphabetic languages, reading Chinese characters might involve more visuospatial analysis, and consequently recruit more regions in the right hemisphere (Liu, Dunlap, Fiez, & Perfetti, 2007; Tan et al., 2000).

Neuroimaging studies on the processing of Chinese characters are generally consistent with this hypothesis. Specifically, within the typical reading network, previous studies have generally revealed left-lateralized frontal activations for both logographic and alphabetic languages (e.g., Bolger et al., 2005; Chee, Tan, & Thiel, 1999; Chee et al., 2000; Chen, Fu, Iversen, Smith, & Matthews, 2002; Xue, Dong, Jin, & Chen, 2004). However, in the occipitotemporal cortex, many studies on Chinese characters have reported bilateral (e.g., Liu et al., 2007; Tan et al., 2001) or even right-lateralized activations (Tan et al., 2000). The finding of greater involvement of the right occipitotemporal region in the processing of Chinese characters was further confirmed by many other studies (e.g., Bolger et al., 2005; Guo & Burgund, 2010; Kuo et al., 2001, 2003, 2004; Peng et al., 2003, 2004; Tan et al., 2005; Wang, Yang, Shu, & Zevin, 2011), although several studies showed left-lateralized activations in the middle fusiform when comparing Chinese characters with other objects, such as an artificial script (Liu et al., 2008), faces (Bai, Shi, Jiang, He, & Weng, 2011), and common objects (Mei et al., 2010). Using a voxel-wise direct comparison method that provided higher spatial resolution, we found that the functional laterality of Chinese processing varies across different regions in the fusiform gyrus, i.e., bilaterality in the posterior fusiform cortex and left laterality in the anterior fusiform cortex (Xue et al., 2005). This is in clear contrast to the left-hemisphere dominance in the processing of alphabetic languages (Cohen et al., 2002; Price, Wise, & Frackowiak, 1996; Vigneau, Jobard, Mazoyer, & Tzourio-Mazoyer, 2005).

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Currently, the prevailing explanation for this laterality difference in the occipitotemporal region is that more visuospatial analysis is needed for processing Chinese characters compared with alphabetic writings (Liu et al., 2007; Tan et al., 2000). However, in addition to visual appearance, Chinese and alphabetic languages also differ significantly in orthographic transparency (Chen et al., 2009; Perfetti et al., 2007). Alphabetic languages typically use letter-phoneme mapping and reading in alphabetic languages can be achieved through grapheme-to-phoneme correspondence (GPC) rules, although there are variations between shallow (e.g., Italian) and deep orthographies (e.g., English). In contrast, Chinese is a nontransparent orthography: there is no letter-phoneme mapping in Chinese. Although most of them have a phonetic radical that can provide clues to the pronunciation, only a small proportion of Chinese characters sound the same as their phonetic radicals. Thus, reading Chinese characters mainly relies on the association of whole characters and sounds (Liu et al., 2007; Tan et al., 2005).

Since Chinese (or other logographic languages) and alphabetic languages differ in both visual appearance and orthographic transparency, studies relying on the contrast between them have difficulties in testing whether their differences in orthographic transparency can account for the different laterality patterns in the occipitotemporal region. One way to tease apart the effect of orthographic transparency from visual appearance is to use the artificial language training paradigm, which allows researchers to manipulate the unit size of orthography-to-phonology mapping (i.e., orthographic transparency) while controlling for visual appearance (i.e., using the same set of words). In a recent ERP study, Yoncheva, Blau, Maurer, and McCandliss (2010) trained two groups of subjects to read an artificial script (letter-like figures) either as an alphabetic or logographic (i.e., non-alphabetic) language for about 20 min. ERP recordings during a reading verification task (visual–auditory matching) after training showed a left-lateralized N170 response in the alphabetic condition, but a right-lateralized response in the logographic condition. This result suggests an important role of orthographic transparency in shaping the laterality in the occipitotemporal region in reading tasks.

Due to the limited spatial resolution of ERP, it is however unclear from Yoncheva et al. (2010) whether subregions in the occipitotemporal cortex are differentially modulated by the script's orthographic transparency. Several studies have suggested that the anterior and posterior parts of the occipitotemporal region are engaged in lexico-semantic and visuo-perceptual processing, respectively (Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Xue & Poldrack, 2007). Our previous studies have revealed that, although bilaterality in the middle fusiform was found for novel logographic characters, i.e., Korean Hangul (Xue, Chen, Jin, & Dong, 2006a), processing familiar logographic characters such as Chinese showed bilaterality in the posterior regions but left laterality in the middle and anterior fusiform cortex (Xue et al., 2005, 2006a). Consistent with this idea, one recent study has suggested that the functional asymmetry in the anterior and posterior fusiform cortex was determined by semantic and visuospatial factors, respectively (Seghier & Price, 2011).

Disentangling effects of orthographic transparency and visual appearance on the laterality patterns would also provide important clues to the functional role of the left occipitotemporal region in reading. There are currently two prevailing perspectives. The visual word form area (VWFA) perspective (Cohen & Dehaene, 2004; Cohen et al., 2002) has proposed that the left mid-fusiform is specialized in processing abstract visual word forms. It predicts no effect of orthographic transparency on fusiform laterality if the visual forms are the same. In contrast, the interactive perspective (Price & Devlin, 2011) posits that the VWFA integrates low-level visuospatial features with higher level associations (e.g., phonology and semantics), and its activity emerges from the interaction between bottom-up sensory inputs and top-down predictions. In supporting the interactive perspective, our previous artificial language training result has clearly isolated the role of phonological association in modulating fusiform activity (Xue, Chen, Jin, & Dong, 2006b). The present study aimed at extending this line of research by examining how different phonological access routes, as determined by orthographic transparency, would differentially modulate fusiform activity.

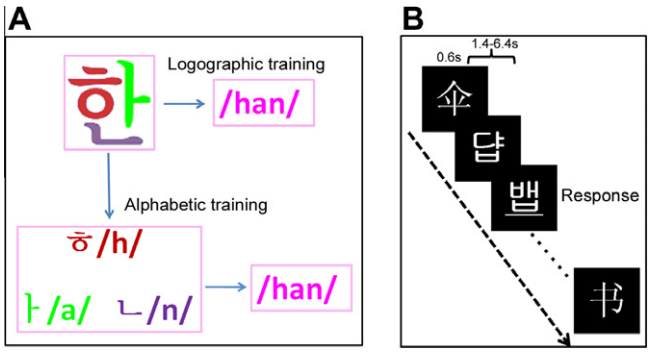

Fig. 1. Experiment design and examples of the stimuli. The artificial language was created by adopting the visual forms and sounds of 60 Korean Hangul characters. Two matched groups of subjects received alphabetic and logographic training (A) for 8 days (1 h per day). Before and after training, subjects were scanned when performing a perceptual task (B), in which subjects were asked to respond to the underlined words.

To examine the effect of orthographic transparency on occipitotemporal laterality in reading, the present study used (1) fMRI technology, with a higher spatial resolution, to examine the effect of orthographic transparency in different subregions in the occipitotemporal cortex, (2) a perceptual task (i.e., underline detection, see Fig. 1), administered both before and after training, to control potential laterality differences before training, and (3) a longer training period (8 days, 1 h per day) than Yoncheva et al.'s study (20 min) to reach a higher level of reading automaticity. The artificial language used in our study was created based on the visual forms and sounds of 60 Korean Hangul characters (see Fig. 1A for examples) because the design principle of Korean Hangul, i.e., logographic visual appearance but alphabetic orthography, is ideal for our purposes. We trained two matched groups of subjects to read the artificial language either as an alphabetic (letter-to-phoneme mapping) or a logographic (word-to-sound mapping) language. Training-related changes in neural activity were compared between the two training conditions to examine whether occipitotemporal laterality was modulated by the script's orthographic transparency, and in which subregions such modulation effect occurred.

2. Materials and methods

2.1. Subjects

Forty-four Chinese college students (23 males; mean age = 22.04 ± 1.82 years old, with a range from 19 to 25 years) participated in this study. They were divided into two groups to receive either alphabetic or logographic training. The two groups were matched on age, gender (12 males and 10 females in the logographic group; 11 males and 11 females in the alphabetic group), nonverbal intelligence, and performance on Chinese reading tasks (see Table 1). All subjects had normal or corrected-to-normal vision, with no previous history of neurological or psychiatric disease and no previous experience with Korean, and were strongly