Neural Systems for Chinese Ideograph Reading: Categorical and Complexity-Modulated Effects

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Introduction

Ideograms such as Chinese characters are graphical symbols that represent morphemes (meaning) whereas letters of phonetic alphabets such as English that represent phonemes (sound). Unlike phonetic alphabets, in which there are a limited number of fundamental units, written Chinese has more than 80,000 characters. Approximately 3000 characters are needed for basic literacy (e.g. reading a Chinese newspaper) and a well-educated person has memorized in excess of 4000 to 5000 characters. Chinese characters have a wide range of complexity: a character can be composed of a single stroke, while some characters require more than 20 strokes. It is possible that the neural mechanisms of reading in Chinese are strongly modulated by the visual complexity of Chinese characters. In this study, functional MRI was utilized to study neural activity during Chinese character reading with varying degrees of complexity parameterized by stroke number.

Methods

Subjects: Five native Chinese (Mandarin) readers and three control subjects (non-Chinese readers) were studied.
Imaging: Images were acquired on a 3T Siemens Trio MRI Scanner using - TR: 2 s, TE: 30 ms, FOV 192 mm, flip angle 90, and 3 mm cubic voxels. Four runs of 255 scans were acquired per subject.
fMRI Paradigms: A rapid-presentation event-related fMRI (RE-fMRI) design was utilized to identify the neural response to Chinese real or pseudo-character. Each study started with a training run followed by three Chinese character identification runs. During each run, subjects were presented with visual stimuli, each lasting one second. For the training run, instead of characters, x's and o's were displayed. For the Chinese character runs, half of the stimuli were real Chinese characters, while half were pseudo characters which superficially resembled real Chinese characters and were matched for stroke number. It was expected that native Chinese readers would be able to tell the difference between real and pseudo characters, while control subjects would not be able to do so. The complexity of both real and pseudo characters was parametrically modulated through five levels by varying the number of strokes composing a character. Behavioral data were collected via button boxes. The subjects were instructed to push the buttons just after the visual stimuli disappeared to minimize potential interaction with the motor activity.
Data Analysis: fMRI scans were analyzed using SPM2 (1). Scans were slice time corrected, motion corrected, spatially normalized to the MNI template, and spatially smoothed with a 5 mm Gaussian kernel. Data were then pooled across the three runs within-subject, and analyzed with multiple regression. A preliminary (fixed effect) group analysis with the available subjects was also performed. Regressors modeling the primary (zero order) effect of real and pseudo characters were modeled, as were first-order (linear) and second-order polynomial effects of complexity (2).

Results

Individual Results: Primary categorical (zero order) effects of Chinese character reading localized bilaterally in the middle frontal gyri (MFG, BA9) and possibly adjacent precentral guri (BA6) in all native Chinese readers. Even though all native Chinese readers demonstrated robust bilateral MFG activity ($Z>6.95$), three showed more activity on the right whereas the other two showed more on the left. Both control subjects and native Chinese readers showed similar visual and motor cortical activity. While lacking activity in either left or right middle frontal gyri, the motor representation was statistically more significant among the control subjects compared to the Chinese native readers. The average behavioral accuracy among the Chinese native readers was about 85%, compared to 40% in the control group.
Group Results: As expected, the primary (zero order) effects of Chinese character reading localized to the middle frontal gyrus bilaterally (BA9). Furthermore, the Chinese character versus pseudo character contrast showed relative activation in the right middle frontal gyrus (BA10) and the left medial frontal gyrus (BA11). Finally, the stroke number-modulated effects localized to the following regions: 1st order effects – left middle frontal gyrus (BA9), bilateral fusiform gyri (BA9), left inferior frontal gyrus and prefrontal cortical regions (BA46 & 47), right inferior temporal gyrus (BA20) and bilateral visual cortices; 2nd order effects – right supramarginal gyrus (BA40), left superior frontal gyrus (BA10), and right middle temporal gyrus (BA21).

Discussion

A previous study has suggested that the left middle frontal gyrus (BA9) is required for visuospatial analysis in Chinese ideograph reading (3). The current study finds robust bilateral activity of the same region regardless of the complexity of the stimuli. This finding was common across all native Chinese readers, and was confirmed by the preliminary group analysis that showed several cortical regions modulated by complexity through 1st and 2nd order polynomial effects most notably including the left middle frontal gyrus (BA9). The observation that stroke number effected only on the left middle frontal gyrus may support a unique role of this region in Chinese character processing. Additionally, the right middle frontal gyrus (BA10) and the left medial frontal gyrus (BA11) showed a relative activation during the Chinese character condition when compared to the pseudo-character condition. These and other complexity-modulated regions appear to form a cortical network exhibiting both primary (zero order or non-modulated) and parametrically modulated (1st and 2nd order) effects for Chinese ideograph reading.

References

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