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Basic Medicine

Effects of orthographic neighborhood on reading in Chinese*☆

An fMRI study

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Abstract

BACKGROUND: Much research has focused on neighborhood size in alphabetic languages. Results have consistently demonstrated that the neighborhood effect is a stimulating factor in word reading. The present study addressed whether there are neighborhood effects in Chinese character reading.

OBJECTIVE: To investigate whether neighborhood effect exists in Chinese character reading and whether specific brain regions are responsible for it.

DESIGN: An event-related design.

SETTING: Beijing Anzhen Hospital.

PARTICIPANTS: The experiment was conducted at Beijing Anzhen Hospital from October 2004 to December 2004. Undergraduate students, aged 19–24 years, were selected from Beijing Normal University, comprising 13 males and 16 females. Inclusive criteria: ① Neurologically normal and right-handed; ② native-Chinese speakers. All subjects gave informed consent prior to experimentation.

METHODS: ① Behavioral experiment: the experiment utilized a 2 × 2 factorial design. The factors included orthographic neighborhood size (few or many neighbors) and lexical regularity (regular or irregular characters). There was no significant difference between the ratio of regular and irregular characters in each family. The experiment was performed on a notebook PC and was piloted by E-Prime software. A fixation point "+" was presented on the screen for 500 ms, and then the target item was displayed in the same place of the fixation for 2 000 ms. Subjects were asked to read the character aloud quickly and correctly. The target item disappeared once the subject read it. Reaction time (RT) and error ratios were collected and analyzed. ② fMRI study: the study was an event-related design. Each character was presented for 500 ms, and the offset was followed by "+" presented for 1 500 – 26 000 ms. Each duration was divided by 500 exactly. The subject was required to read silently. AFNI software package was used to analyze the fMRI data.

MAIN OUTCOME MEASURES: ① RT and error ratio in behavioral experiment; ② Brain mapping in fMRI study.

RESULTS: Twenty-nine undergraduate students were involved in the result analysis. ① Behavioral experiment results of RT: the main effect of regularity was highly significant for participants (F_1) and items (F_2) [F_1 (1,28) = 135.74, $P < 0.01$; F_2 (1,76) = 49.506, $P < 0.01$], with regular words being responded faster than irregular words. The main effect of N was not significant, but was localized in an uncertain area [F_1 (1,28) = 3.182, $P > 0.05$; F2 not significant]. Moreover, there was an interaction between neighborhood and regularity [F_1 (1,28) = 6.666, $P < 0.05$; F_2 (1,76) = 3.157, $P > 0.05$]. Analyses of simple effect determined that when the characters were irregular, the RT of low neighborhoods was shorter than high neighborhoods. Behavioral experiment results of error ratio: similar analyses were performed on the number of errors in the naming task. ANOVA demonstrated a main effect of regularity [F_1 (1,28) = 10.475，$P < 0.01$; F_2 (1,76) = 4.686, $P < 0.05$], with errors of regular words less than irregular words. The main effect of neighborhoods was not significant. Moreover, there was an interaction between neighborhood and regularity by subjects [F_1 (1,28) = 7.632, $P < 0.05$], but not by items [F_2 (1,76) =3.906, $P > 0.05$]. Analyses of simple effect found that when the characters were regular, the number of errors in high neighborhoods (23%) was greater than in low neighborhoods (11%). ② fMRI results: bilateral fusiforms were sensitive to Chinese character shape. Both neighborhoods effect and regular effect mainly yielded right cerebral hemisphere and bilateral brain area.

CONCLUSION: Neighborhood effect existed in character reading. However, results are contrary to what has been shown in English word reading. The fewer neighborhoods that one character had, the shorter the RT was. The fMRI results demonstrated the neighborhood effect and regular effect primarily stimulated right cerebral hemisphere and the bilateral brain area.

Key Words: fMRI study; character reading; brain area

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INTRODUCTION

Many studies have demonstrated that in alphabetic writing systems, such as English, reading words or pseudo-words with large orthographic neighborhoods (N) results in faster reaction times (RT) than those with low neighborhoods. However, if the task is changed to lexical decision, pseudo-words with higher N value resulted in slower and less accurate "NO" responses. Moreover, some studies have shown that some factors interacted with the N effect, such as frequency and letter position[1].

Holcomb *et al* [2] demonstrated that words and pseudo-words with many orthographic neighbors generated larger N400s than those with relatively fewer neighbors in an Event-related potentials（ERP） lexical decision experiment. Using a divided visual field presentation, some scholars showed N effects in the right, but not in the left, cerebral hemisphere. Based on ERP results and the robust behavioral N effect, Binder *et al* [3] hypothesized it should be possible to find brain activity correlated with N size in a lexical decision task. However, no particular patterns in response to items with many neighbors were determined when compared to items with few neighbors. Using a divided visual field presentation, Lavidor *et al* [4] determined orthographic neighborhood effects in the right, but not in the left, cerebral hemisphere in lexical decision tasks.

To date, there have been no studies focused on the N effect in Chinese language. Because of the lack of letters in Chinese characters, there is no letter-sound rule. However, this does not mean there is no phonological rules in Chinese character reading. A total of 80.5% of Chinese characters are semantic-phonetic compound characters, comprising a semantic and a phonetic component, also known as "radical". For example, "炬" [ju4] includes left and right parts; the left part "火" is a semantic radical and means "fire", the right part "巨" is a phonetic radical and denotes the pronunciation of "炬". In other words, there is information in the Chinese character to imply its phonology.

Furthermore, there are often many Chinese characters that possess the same phonetic radical, such as "炬、距、钜、拒、讵、苣、柜" - the phonetic radical is "巨" for all of these characters. Among these words, only the phoneme of "柜" [gui4] differentiates from other words. In addition, it is also an irregular word. It is obvious that there are orthographic neighbors in Chinese writing system. Nevertheless, there are no grapheme-phoneme correspondences (GPC) in Chinese, only radicals denoting phonology; this is just an association, not a rule. One critical difference exists between rule and association; in English, the non-lexical route (a) uses the entire stimulus to obtain a pronunciation and (b) does not involve reference to a lexicon. When a Chinese reads an unfamiliar character, neither of these factors can be utilized to pronounce the phonetic radical. There are also neighborhoods of Chinese characters, in terms of orthography. The position of phonetic components is kept to the right side of the character. Therefore, the neighbors of one character in Chinese include the characters with the same phonetic radical. The semantic radicals were switched to the left side for the present study.

The aim of the present study was to investigate the N effect in Chinese character reading, and whether special brain regions are responsible for it.

SUBJECTS AND METHODS

Subjects

This study was conducted in Beijing Anzhen Hospital from October to December, 2004. Twenty-nine undergraduate students (13 men and 16 women) from Beijing Normal University participated in the behavioral experiment, and another 13 neurologically normal, right-handed, college students, native-Chinese speakers between 19–24 years of age were scanned. All subjects gave informed consent prior to experimentation and were paid for their participation.

Methods

Behavioral study

Chinese character neighborhoods indicated characters with the same phonetic radical, but a different semantic radical.

The experiment utilized a 2 × 2 factorial design. The factors included orthographic neighborhood size (few and many neighbors) and lexical regularity (regular and irregular characters). The dependent variables were RT and error rates. There were four types of characters in total. Twenty characters comprised each type.

The criterion of selecting characters from the other seven aspects was controlled for as follows:

The structures of the selected characters proceeded from left to right, with phonetic radicals on the right side. The phonetic radicals were simple (integrated) characters, and the family of the each selected character was inconsistent. Each character in our experiment was a word with an independent meaning. All selected characters were not polyphonous, and the number of strokes in each character was not significantly different. Each item had a special phonetic radical; no two characters had the same phonetic radicals. To properly control experimental materials, the proportion of regular and irregular characters in different N size was compared, with no significant difference between few and large neighborhood size.

Procedure: the experiment was performed on a notebook PC and was piloted by E-Prime software. A fixation point "+" was presented on the screen for 500 ms, and then the target item was displayed at the same fixation point for 2 000 ms. Subjects were asked to read the character aloud quickly and correctly. The target item disappeared once the subject read it. Prior to experiment, five simple characters were used to practice.

fMRI study

Image acquisition and scanning: functional scans were obtained by using a single-shot T2*-weighted gradient-echo echo planar imaging (EPI) sequence (20 contiguous axial slices, slice thickness = 5 mm, TR/TE/theta = 2 000 ms/ 60 ms/90 j, FOV = 220 mm, matrix = 64×64). Following functional scanning, a high-resolution structural scan was performed in the same planes as the scan for anatomic localization and co-registration of images across subjects. Structural data were acquired via a T1-weighted 3D volume acquisition obtained using a gradient echo pulse sequence (TR/TE/theta =30 ms/1.17 ms/35 j, FOV =325 mm, Matrix = 192 × 256).

Stimuli: the same stimuli were used as for the behavioral experiment.

Design: the study was an event-related fMRI design. Each character was presented for 500 ms. The offset was followed by "+" presented between 1 500 ms to 26 000 ms, and each duration could be divided by 500 exactly. The subject was required to read silently.

fMRI data analysis: AFNI software package (http://afni.nimh.nih.gov/afni/) was used for image processing and statistical analyses. Images of the first five time points were discarded. The time series were motion-corrected and registered. Functional images were spatially smoothed using Isotropic Gaussian blur with FWHM = 8 mm. The hemodynamic response function (HRF) and multivariate statistics corresponding to each of the four conditions were obtained by deconvolution of the input, using a least squares procedure within a general linear model. Individual images were spatially normalized to the Talairach brain atlas before group analysis. Group analyses were attained through deconvolution of the input data linked to 13 subjects. A random-effects 3 (neighborhood size: high/low)× 2 (regularity: regular/irregular) × 13 (subjects) ANOVA was then performed.

RESULTS

Quantitative analysis of the participants

Results of behavioral study

The mean RT of participants with many neighbors of regular and irregular characters, based on correct responses, were (565 ± 56) and (611 ± 69) ms, respectively. The mean RT of words with few neighbors of regular and irregular characters were (568 ± 63) and (596 ± 70) ms, respectively.

During the initial analyses of naming latency, the analysis of variance was conducted for participants (F_1) and items (F_2), with neighborhood size (big *vs*. small) and character regularity (regular *vs*. irregular) as included factors.

The main effect of regularity was highly significant [F_1 (1,28) = 135.74， $P < 0.001$; F_2 (1,76) = 49.506, $P < 0.001$], with regular words being responded faster than irregular words. The main effect of N was not significant. Moreover, there was an interaction between neighborhood and regularity [F_1 (1,28) = 6.666, $P < 0.05$; F_2 (1,76) = 3.157, $P = 0.08$].

Analyses of simple effect determined no significant difference between words of high or low N when characters were regular; however, the RT for irregular characters was slower for low N than high N.

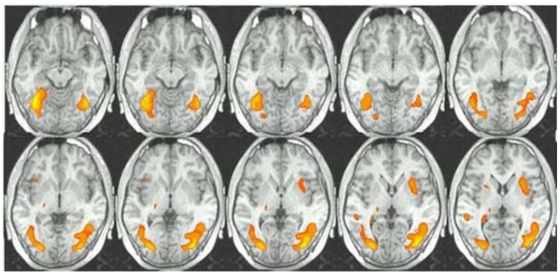
Number of errors: the mean error rates of subjects of regular and irregular characters with many neighbors were 23% and 24%, respectively; however, words of regular and irregular characters with few neighbors were 11% and 33%, respectively. ANOVA displayed a main effect of regularity [F_1 (1,28) = 10.475， $P < 0.01$; F_2 (1,76) = 4.686, $P < 0.05$], with errors of regular words less than irregular words. The main effect of N was not significant. Moreover, there was an interaction between neighborhood and regularity by subjects [F_1 (1,28) = 7.632, $P < 0.05$], but not by items [F_2 (1,76) = 3.906, $P = 0.052$].

There was no significant difference between words with high or low N, when characters were irregular. However, with regular characters, the number of errors was greater in high N than in low N. Regularity was reliable in low N; the number of errors was less when subjects were asked to read regular characters, compared to irregular characters. No regularity appeared when reading characters with many neighborhoods.

fMRI results

Main effects of the four conditions versus fixation: Four conditions that were regular characters in big N (BR) and in small N (SR), irregular characters in big N (BIR) and in small N (SIR) stimulated brain activation, respectively, as shown below (Figures 1− 4).

R L

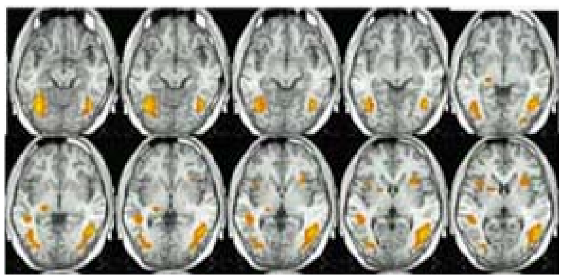


z=−12 to z=6 spacing=2

$Z = 3.498$, $P = 9.7 \times 10^{-4}$

Figure 1 Brain activation maps for regular characters in big neighborhoods as indexed to fixation

R L

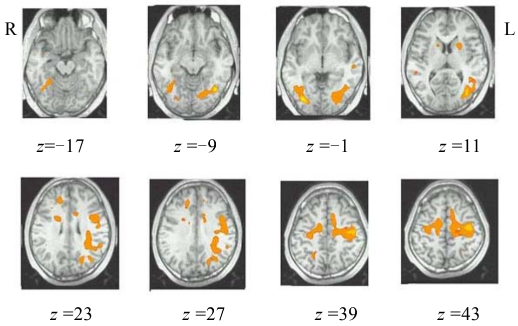


$Z = 3.498$, $P = 9.7 \times 10^{-4}$

Figure 2 Brain activation maps for regular characters in small neighborhoods as indexed to fixation

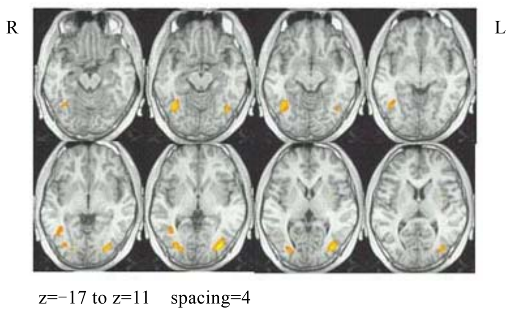
As seen from the maps, four kinds of characters activated neuronal networks with substantial similarity. Bilateral fusiform activation was determined in all four conditions. Regardless of N, bilateral temporal occipital connection regions and left insula were activated with regular characters.

Certain regions were activated differently when irregular characters were read and N size was varied. Particular regions, such as left inferior frontal gyrus, left inferior parietal lobule, left inferior frontal gyrus, bilateral cingulated gyrus, and left precentral gyrus, were activated when irregular characters with high N were read.



Z = 9.217, *P* = 3 × 10^{-11}

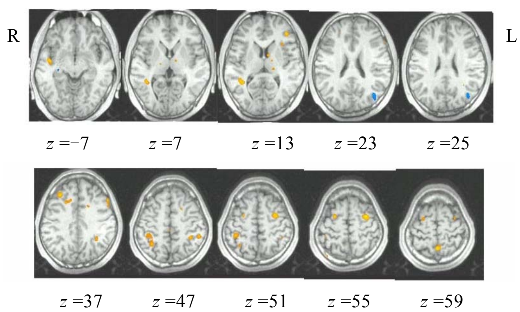
Figure 3 Brain activation maps for irregular characters in big neighborhoods as indexed to fixation



Z=9.217, *P*=3×10^{-11}

Figure 4 Brain activation maps for irregular characters in small neighborhoods as indexed to fixation

Effects revealed by comparisons among the four conditions: The right insula, middle temporal gyrus, superior temporal gyrus, bilateral middle frontal gyrus, inferior parietal lobule, and precuneus were activated more by low N than high N. The left middle temporal gyrus was the only brain region that was stimulated more my high N, compared to low N (Figure 5).



N: neighborhoods

Figure 5 Brain activation maps for low N *vs* high N, red for low N > high N, blue for high N > low N, *Z* = 2.757, *P* < 0.05

No brain region (> 5 voxels) correlated to regular vs. irregular words. The bilateral lingual gyrus, superior temporal gyrus, postcentral gyrus, left insula, and right insula were activated by irregular vs. regular words (Figure 6).

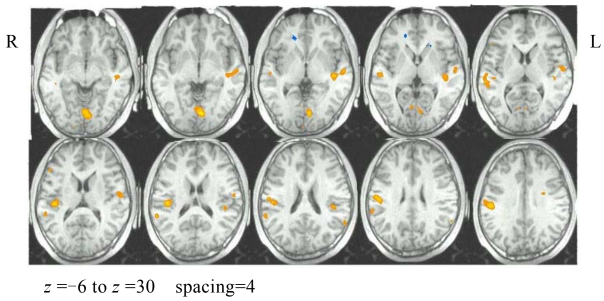


Figure 6 Brain activation maps for irregular characters vs. regular characters, red for irregular > regular, blue for regular > irregular, *Z* = 3.067, *P* = 0.009 8

Figure 6. The right fusiform gyrus/lingual gyrus/ inferior occipital gyrus/parahippocampal gyrus, bilateral middle occipital gyrus/posterior cingulated gyrus/cuneus corresponded to interaction between N size and regularity (Figure 7).

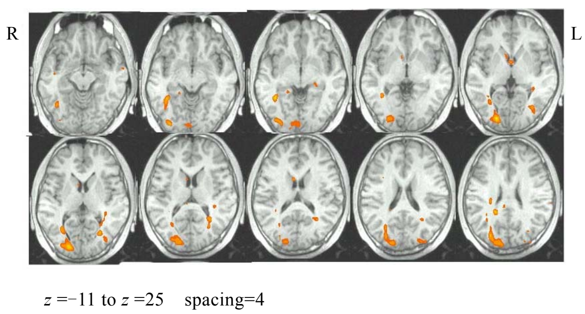


Figure 7 Interaction between neighborhood size and regularity, *Z* = 9.342, *P* < 0.01

DISCUSSION

fMRI main effects of four conditions, as contrasted with fixation - VWFA in Chinese

Compared with fixation, the four tasks showed a common activation pattern that involved the bilateral fusiform. The left mid-fusiform gyrus has been dubbed the “visual word form area” in previous neuropsychological reports[5-6]. Reading Chinese characters activated the left fusiform, which implied that there was a common region between Chinese and alphabetic language reading - “Visual word form area (VWFA)”. However, when reading Chinese, the right fusiform was also significant activated. This brain region presented activation differences between Chinese characters and alphabetic words of visual format, and this embodied the differences produced by orthography. In the present study, all materials were presented visually and all items were real characters, so orthographic processing from the print is evident. Of course, phonology access cannot be excluded in this experiment, but these regions were obviously not relative with the phonological processing of Chinese characters [7]. Fusiform typically relates to orthographic processing. In visual tasks, a typical VWFA was activated and the contralateral site was activated as well.

Effects of neighborhood size and regularity on silent phonological processing of Chinese characters

In general, low N size resulted in greater brain activation than high N size. The right cerebrum and certain regions of the bilateral cerebrum were primarily activated with low N; however, the left middle temporal gyrus was the only brain region that was activated more by high N than low N.

Binder *et al* [3] hypothesized that it should be possible to detect brain activity that correlates with N size. Possible candidates for the N locus could be the right fusiform gyrus or the fusiform gyrus of the contralateral hemisphere. However, a recent fMRI study[8] determined that no brain regions showed a reliable effect of orthographic neighborhood size; however, when the spatial extent threshold was reduced, an area in the ascending posterior segment of the left superior temporal sulcus and in the adjacent angular gyrus showed greater activation for items that had few orthographic neighbors. The authors proposed that the left temporoparietal region is the only brain region that is parametrically modulated by neighborhood size, with relatively greater activity for items with fewer neighbors. In the Chinese language, the present study showed the left cerebral hemisphere was not as active as the right hemisphere, with exception to the left middle temporal gyrus. Moreover, some bilateral cerebral regions might be related specifically to the Chinese writing system. This, however, should be tested with further studies.

On the basis of fMRI data, stimuli that resembled a few words appeared to induce activations greater than stimuli that visually resembled many other characters. A small activation in the left middle temporal gyrus was observed with high N, when compared to low N. We hypothesize that the left middle temporal gyrus responds to many visual orthographic neighbors.

Irregular characters stimulated more bilateral cerebral regions than the regular characters. The behavioral experiments demonstrated processing irregular characters was more difficult than processing regular characters, and naturally the processing of irregular characters stimulated more brain activity. These results indicate Chinese regular effect was showed bilaterally. The present results differ from that reported by Tan *et al* [9], maybe we considered neighborhood N in the present experiment.

The most interesting finding was that some specific regions for interaction were stimulated, such as the right fusiform gyrus, lingual gyrus, inferior occipital gyrus, parahippocampal gyrus, bilateral middle occipital gyrus, and cuneus/cingulated gyrus. Because these regions interact with each other, the interaction between neighborhood size and regularity was manifested in behavior

In general, regardless of the effect or interaction, brain activity takes place primarily in the right cerebral hemisphere Very little activity took place in the left cerebral hemisphere (contralateral hemisphere did not participate).

Conclusions: Bilateral fusiforms were sensitive to the formation of Chinese characters.

The effects of neighborhood size and regularity relied primarily on the right cerebral hemisphere, with some bilateral cerebral regions also showing activation. The present results will require further verification, due to the explorative nature and limitations, such a subjective threshold and a limited number of participants.

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