

COGNITIVE NEUROSCIENCE

Neural correlates of the orthographic neighborhood size effect in Chinese

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Abstract

Word recognition research with alphabetical scripts has revealed a facilitatory neighborhood size effect, whereby naming of words with more orthographic neighbors is faster than that of words with fewer neighbors. Preliminary behavioral evidence in Chinese revealed both facilitatory and inhibitory neighborhood size effects, depending on whether there are higher-frequency neighbors (HFNs) than the target. This functional magnetic resonance imaging study examined the neural substrates of the neighborhood size effect with silent naming. Neighborhood size and the HFN factor were factorially manipulated. Behavioral results replicated previous findings showing that larger neighborhood size facilitated naming in the absence of HFNs, but inhibited naming in their presence. Imaging results identified greater activation in the left middle frontal gyrus for small than larger neighborhood size, and bilateral inferior frontal activations for the with-HFN condition as compared with the without-HFN condition. Critically, there was an interaction in the right middle occipital gyrus showing greater activation for large than for small neighborhood size in the absence of HFNs but no neighborhood size effect in their presence. The results support a proposal that, in addition to a facilitatory contribution from orthographic activation of neighborhoods, naming is also affected by whether there are higher-frequency neighbors, particularly in scripts with deep orthography, where orthographically similar words can be pronounced very differently.

Introduction

A recent line of research in word recognition examines how the number of a word's neighbors affects its naming. In alphabetic writing systems, neighborhood size refers to the number of words that can be generated by changing one letter while keeping all other letters unchanged (Coltheart *et al.*, 1977).

The neighborhood size effect can be predicted from popular word reading models. For example, according to the multiple read-out model (Grainger & Jacobs, 1996), word recognition is determined by whether the level of lexical activation exceeds a specific threshold. For words with a relatively high level of baseline activation, such as high-frequency words, their presentation would quickly activate associated lexical representations, leading to successful lexical activation. However, when the lexical activations are not strong enough to cross the threshold, activations from neighborhood words or other candidate words will then be used to produce an integrated global activation, facilitating the retrieval of the target word representations. Similar inferences can be made from the dual-route model of reading (Coltheart *et al.*, 2001). In this model, naming is proposed to proceed along the lexical pathway going from orthography to semantic representations and then to phonological activation, or along the sub-lexical pathway using the orthography-to-phonology (O-P) conver-

sion. On the assumption that information flows in a cascade manner from one processing stage to the next, the model also expects activations from words similar to the target word to affect its naming.

A more specific question concerns the mechanisms by which word naming is affected by processing of its neighbors. One major observation from previous studies is that large neighborhood size facilitates naming performance; this is referred to as the neighborhood size effect (Laxon *et al.*, 1988; Andrews, 1989, 1992; Grainger & Segui, 1990). Andrews (1989, 1992) and Peereman & Content (1995) show that such facilitation is particularly prominent in the naming of low-frequency words. Grainger *et al.* (1989) suggested that the neighborhood size effect results from redundant information at the sub-lexical level. That is, in alphabetical scripts, words with larger family sizes tend to have bigrams that appear more frequently in other words, and such high-frequency bigrams can speed phonological processing. For example, the word 'seat' has a relatively large family size, and it contains bigrams, namely se, ea and at, that often appear in other four-letter words. In comparison, the word 'size' has a relatively small family size; its bigrams, for example, iz or ze, seldom appear in other words (Andrews, 1992). However, when bigram frequency was controlled, Andrews (1992) still observed the facilitatory neighborhood size effect, leading to the rejection of the explanation of Grainger *et al.* (1989).

Peereman & Content (1995) argued that Andrews (1992) controlled typical bigrams but not uncommon bigrams, and therefore the effects of sub-lexical redundant information cannot be completely excluded.

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They adopted a different approach to study how the neighborhood size effect is affected by the way in which a word is presented. With some empirical support, they assumed that when target words are presented along with pseudowords, participants will adopt a processing strategy relying more on the sub-lexical route; that is, they will perform naming based on O-P conversion rules. In contrast, when target words are presented together with real words, participants will tend to use the lexical route. They found that the neighborhood size effect was significantly larger in the latter case than in the former, suggesting that the effect occurs primarily through the lexical route, reflecting processing at the lexical as opposed to the sub-lexical level. In particular, Peereman & Content (1995) suggested that phonological activation of neighbors speeds up naming of the target word. Similarly, Grainger (1990) suggested that large neighborhood size words involve more common O-P conversion rules that facilitate phonological activation of the target words.

Most relevant to our interests, in a further analysis Grainger *et al.* (1989) found that among the English word stimuli used by Andrews (1989), more than 90% had neighbors of higher frequency than the target word. They speculated that the neighborhood size effect was caused by the inclusion of these higher-frequency neighbors (HFNs). Indeed, Grainger (1990) found that, in French, the presence of HFNs facilitated naming even when neighborhood size was held constant. Providing more direct support, Carreiras *et al.* (1997) used Spanish, and found that the neighborhood size effect was present only when there were HFNs. Sears *et al.* (2006), however, failed to find any effect of neighborhood frequency in English sentence reading. The different results may be attributed to language characteristics. One speculation is that Spanish and French are both of shallow orthography, and members of the same orthographic neighborhood tend to be phonological neighbors, speeding up phonological activation of the target word. In comparison, English has deep orthography, so that some orthographic neighbors may be similar to the target word in phonology and others may be different, resulting in the null effect.

To enable better comparison across different languages, our group first examined the neighborhood effects in the non-alphabetical Chinese, known to have even deeper orthography than English (Bi *et al.*, 2006). More than 80% of Chinese characters are compound characters, consisting of a phonetic radical and a semantic radical. An orthographic neighborhood in Chinese can consist of the same phonetic radical. For example, 璜 (huang2, upholster), 簧 (huang2, reed), 磺 (huang2, sulfur) and 横 (heng2, across) are in one neighborhood, all sharing the same phonetic radical 黄 (huang2, yellow). Surprisingly, in contrast to the Spanish and French studies (Grainger, 1990; Carreiras *et al.*, 1997), we found an inhibitory neighborhood effect; that is, words with larger neighborhood size were named more slowly than words with smaller neighborhood size.

With better designs, more recent evidence from our group established the modulation of the neighborhood size effect by the presence of HFNs. For the example above, suppose that the frequencies for the four members 璜, 簧, 磺 and 横 are 2.3, 2.4, 2.9 and 3.0 (occurrences per million), respectively. For the third character, 磺, there is an HFN, 横; the last character, 横, is of the highest frequency in the family and therefore does not have an HFN. When the target words did not have HFNs, the neighborhood size effect was facilitatory, as observed in the alphabetical languages. However, replicating Bi *et al.* (2006), when the target words did have HFNs, the neighborhood size effect was found to be inhibitory. We (Li *et al.*, under review) attributed this inhibitory neighborhood size effect to the deep orthography of Chinese – orthographic neighbors in Chinese tend to have different pronunciations. That is, we hypothesized that,

because of their higher frequencies and their different pronunciations, the phonology of the HFNs becomes activated rapidly (McClelland & Elman, 1986), competing and interfering with extraction of the target word's phonology. In line with this proposal, our data also showed that such an interference effect depends on how easily the target word phonology is accessed. When the target words are consistent and regular, their phonology is accessed faster than that of inconsistent and irregular words, allowing them to be free from interference from the HFRs.

Briefly, the behavioral evidence obtained so far suggests a possible mechanism of the neighborhood effect in Chinese character naming involving both orthographic and phonological representations. The present study was intended to test this hypothesis with neural imaging evidence. There has been limited research revealing the neural activities underlying neighborhood effects, all with lexical decision tasks. Holcomb *et al.* (2002) and Braun *et al.* (2006) used ERPs, and showed that words in large neighborhoods produced greater N400 amplitudes, suggesting greater lexical-semantic global activation. Brain imaging studies by Binder *et al.* (2003) and Fiebach *et al.* (2007) suggested an opposite conclusion, as words without neighbors were found to elicit greater activation than those with many neighbors in the left middle temporal gyrus, suggesting that the former are processed at a deeper semantic level. Apparently, more empirical data on the neural substrates underlying the neighborhood size effect are needed for effective theoretical integration. One important point is to adopt a naming task as opposed to a lexical decision task, as the latter may not require complete phonological access (Balota & Chumbley, 1984; Andrews, 1992).

Using a naming task, we manipulated both neighborhood size and the HFN factor in a factorial design. We conducted whole brain analysis to identify brain regions whose activation would be modulated by either factor or their interaction. We especially examined regions previously known to be involved in phonological and orthographic processing in Chinese, including the left inferior frontal gyrus (IFG) (Pugh *et al.*, 1996; Herbster *et al.*, 1997; Rumsey *et al.*, 1997; Luo & Niki, 2000; Bitan *et al.*, 2005, 2006), the left middle frontal gyrus (Bolger *et al.*, 2005; Tan *et al.*, 2005), and the right occipital gyrus (Tan *et al.*, 2000, 2001).

Materials and methods

Participants

Thirty participants (15 males, mean age 23.4 years, range 22–24 years) participated in the behavioral session of the experiment. Among them, 14 (eight males, mean age 24.1 years, range 21–25 years) participated in the functional magnetic resonance imaging (fMRI) session. All were Mandarin-speaking native Chinese graduate students. The study was approved by the ethics committee of the Institute of Psychology, Chinese Academy of Sciences, China. Written consent was obtained from each participant.

Design and stimuli

A within-subject 2×2 factorial design was used, with the neighborhood size factor being 'small vs. large', and the HFN factor being 'with HFNs vs. without HFNs'. The stimuli included 56 Chinese characters, 14 for each of the four conditions. Following Bi *et al.* (2006), the orthographic neighborhoods of a character refer to the characters sharing its phonetic radical. As described in Li & Kang (1993), the characters were selected so that there were 2–8 neighbors for the small size, and 10–16 neighbors for the large size.

For a target character without HFNs, none of its neighbors was of a higher frequency than the character itself. For a target character with HFNs, at least one of its neighbor characters was of a higher frequency. The mean number of HFNs was 3.2 (range, 1–4; standard deviation, 1.13), and there was no significant difference between conditions. The characters were also selected so that the pronunciation of the target characters was always different from that of their HFNs. Also, the frequency of the highest character within each neighborhood family was controlled and comparable across all conditions. Correct pronunciation depends on how frequently a character occurs in daily life. It is possible that participants may tend to pronounce the characters on the basis of the radicals if they do not know the characters well. To discourage the adoption of such a strategy, all characters used had been tested in a pilot study involving a separate group of participants from the same subject population to ensure that these characters are common characters, familiar to the participants, and can be readily named.

As there was behavioral evidence from Li *et al.* (under review) that the neighborhood size effect was most prominent for irregular, inconsistent characters, here we only used irregular characters with a low level of consistency. By definition, a Chinese character is regular if it is pronounced the same as its phonetic radical, ignoring tone, and irregular otherwise. Consistency level was calculated by dividing the number of characters sharing the same pronunciation within a neighborhood by the neighborhood size (Fang *et al.*, 1986). For example, in the neighborhood including the phonetic radical 及 (ji2, and), the neighbors are 圾 (ji1, garbage), 汲 (ji2, draw), 极 (ji2, terribly), 笈 (ji2, book), 岌 (ji2, danger), 级 (ji2, class), 吸 (xi1, absorb), and 鞅 (sa3, shoes) ($N = 8$). There are six neighbors with the same pronunciation, ji2, producing a consistency level of $ji2$ of $6/8 = 0.75$. In this study, the consistency level for all stimuli was lower than 0.4. All characters were of left–right structure with the phonetic radical on the right side, and these radicals were always simple characters. None of the characters was a polyphone. All stimuli selected had different phonetic radicals. Character frequency, consistency and stroke number were controlled across conditions, as shown in Table 1.

Behavioral procedure

Stimuli were presented using E-PRIME 2.0 PROFESSIONAL on a Dell laptop computer, at a viewing distance of 50 cm, subtending a visual angle of approximately $2.5^\circ \times 2.5^\circ$. The characters were presented in a randomized order, each for 2000 ms. In the interval between the presentation of two characters, a fixation cross was displayed for 500 s. Participants were tested individually and asked to read the characters aloud to activate the voice-key as accurately and quickly as possible. The voice-key was connected between the SRBOX and the computer to record reaction times. The character disappeared upon

TABLE 1. Stimulus characteristics and mean response times for all conditions

Condition	W-HFN-L	W-HFN-S	W/o-HFN-L	W/o-HFN-S
Frequency	13	12	14	15
Neighborhood size	12.6	5.7	12.9	5.5
Consistency level	0.28	0.3	0.3	0.32
Response time (ms)	646 (83)	668 (76)	678 (83)	661 (85)

W, with; W/o, without; S, small neighborhood size; L, large neighborhood size. Frequency values are occurrences per million. Standard deviations are in parentheses.

response, or at the end of the 2000-ms response window. Reaction times longer than 2000 ms were excluded from analysis.

fMRI procedure

For the imaging session, the behavioral task and procedure were the same as in the behavioral session, with the same interstimulus interval, except that participants were instructed to read the characters silently as soon as each was presented. Hemodynamic responses were acquired using a 3T Siemens Trio MR system (Siemens, Germany). Participants were instructed to remain still inside the scanner. Three-dimensional anatomical images with high spatial resolution were also acquired using a Siemens magnetization-prepared rapid acquisition gradient echo sequence. A blood oxygen level-dependent (BOLD)-sensitive gradient echo-plane imaging sequence was acquired (30 contiguous axial slices, 1.33 mm thick; relaxation time, 2000 ms; echo time, 30 ms; matrix, 64×64 ; field of view, 200 mm).

Imaging data analysis

Image processing and statistical analyses were conducted using the AFNI software package (Cox, 1996; Cox & Hyde, 1997; <http://afni.nimh.nih.gov/afni/>). Slice timing correction, motion correction and temporal filtering of functional images were performed on each individual dataset. The magnetization-prepared rapid acquisition gradient echo anatomical scan was then normalized to the Talairach space (Talairach and Tournoux, 1988). The Talairach-aligned dataset was spatially smoothed using a 6-mm full-width half-maximum Gaussian kernel. General linear models were used for single-subject analysis with deconvolution analysis, producing the hemodynamic response function for each of the four conditions. A group mask was created to remove voxels falling outside the brain, made by multiplying masks from each participant to include only voxels with valid signals for all participants.

Random effect group analysis was performed with three-way ANOVAs, including neighborhood size and the HFN factors as fixed effects, and participant as a random effect. Monte Carlo simulations with AFNI's ALPHASIM program were used to set the voxel-wise intensity threshold at $P < 0.001$ and the cluster size threshold at 12 contiguous voxels (voxel size: $3 \times 3 \times 3 \text{ mm}^3$) for a corrected significance level of $P < 0.05$.

Results

Behavioral performance

Incorrect responses (225 trials, 12.5% of the total trial number) and trials with response latencies < 400 ms or > 1200 ms (30 trials, 1.67% of the total trial number) were excluded from the response time analysis. The mean response times and error rates for all conditions are shown in Table 2. A 2×2 repeated-measures ANOVA was performed on the response time data, and revealed a significant main effect for the HFN factor ($F_{1,29} = 7.04$, $P < 0.02$). Participants responded more slowly to characters with HFNs than to characters without HFNs. The main effect of neighborhood size was non-significant ($F_{1,29} = 0.19$, $P > 0.5$). There was a significant interaction between neighborhood size and neighborhood frequency ($F_{1,29} = 5.52$, $P < 0.03$). *Post hoc* analyses showed a significant inhibitory neighborhood size effect for the with-HFN condition, but a significant facilitatory neighborhood size effect for the without-HFN condition. The same ANOVA on error rates did not reveal any significant effects.

TABLE 2. Summary information for brain activations revealed in three comparisons

Comparison	Anatomical region	BA	X	Y	Z	Volume (mm ³)	Statistics
S > L	L middle frontal gyrus	45	-30	31	20	1651	3.70
W-HFN > W/o-HFN	L inferior frontal gyrus	46/47	-39	38	4	424	3.03
	R inferior frontal gyrus	47	33	32	4	408	3.04
(W-HFN-S > W-HFN-L) > (W/o-HFN-S > W/o-HFN-L)	R middle occipital gyrus	19	45	-68	25	2415	17.59

W, with; W/o, without; S, small neighborhood size; L, large neighborhood size; L, left; R, right; BA, Brodmann's area. X, Y and Z are coordinates in Talairach space. Statistics are *t*-values for the first two effects (degrees of freedom = 13), and *F*-values for the third. Significance level set at $P < 0.05$, corrected for multiple comparisons.

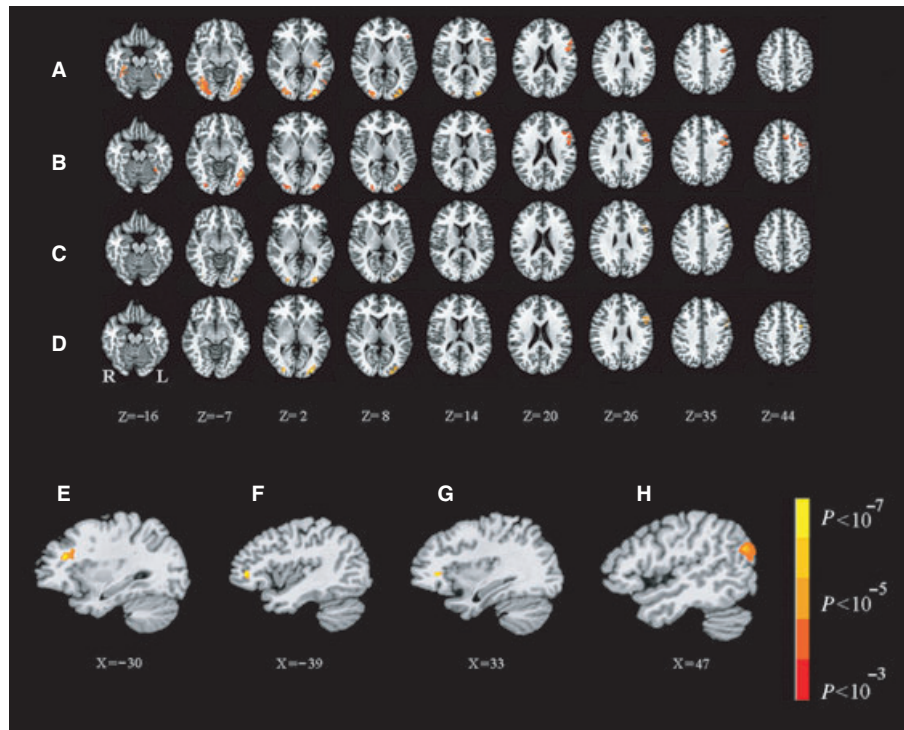


FIG. 1. (A–D) Brain activations as compared with the resting baseline in the large neighborhood size with-HFN, small neighborhood size with-HFN, large neighborhood size without-HFN and small neighborhood size without-HFN conditions, respectively. (E) The left middle frontal gyrus region was activated more for small neighborhood size than for large neighborhood size. (F and G) Bilateral IFG regions were activated more for the with-HFN condition than for the without-HFN condition. (H) A right MOG region manifesting an interaction between neighborhood size and the HFN factor. Significance level was set at $P < 0.05$, corrected for multiple comparison.

fMRI results

Brain activations relative to the resting baseline are shown in Fig. 1A–D, revealing a network of regions comparable across the four conditions in which participants performed character naming. These regions included the left fusiform gyrus, right middle occipital gyrus (MOG), left precentral gyrus, left IFG, and left middle frontal gyrus. The 2×2 ANOVAs on the imaging data identified three set of regions, listed in Table 2. One point to note is that activation of the left intraparietal area, which is usually activated in fMRI language studies using visual language stimuli (e.g. Takeda *et al.*, 1999; Wilson *et al.*, 2009; Turkeltaub *et al.*, 2003), was not observed here. It remains to be seen whether this reflects some language-specific activities, as there are also some other imaging studies on Chinese that have failed to see activation in this region (e.g. Tan *et al.*, 2000; Kuo *et al.*, 2003).

One region in the left middle frontal gyrus (Fig. 1E) was activated significantly more for the small neighborhood size than for the large

neighborhood size. No brain region was found for the opposite contrast. Two regions in the bilateral IFG (Fig. 1F and G) showed greater activation for the with-HFN condition than for the without-HFN condition. No brain region was activated for the opposite contrast. Activity in a right MOG region showed a significant interaction between neighborhood size and neighborhood frequency (Fig. 1H). Mean signal intensity pooled over all voxels in this region was significantly greater for the large neighborhood size than for the small neighborhood size for the without-HFN condition, but not different between the two sizes for the with-HFN condition (Fig. 2A).

Discussion

In the present study, we asked participants to name Chinese characters that had either large or small numbers of orthographic neighbors. At each neighborhood size level, we also distinguished between charac-

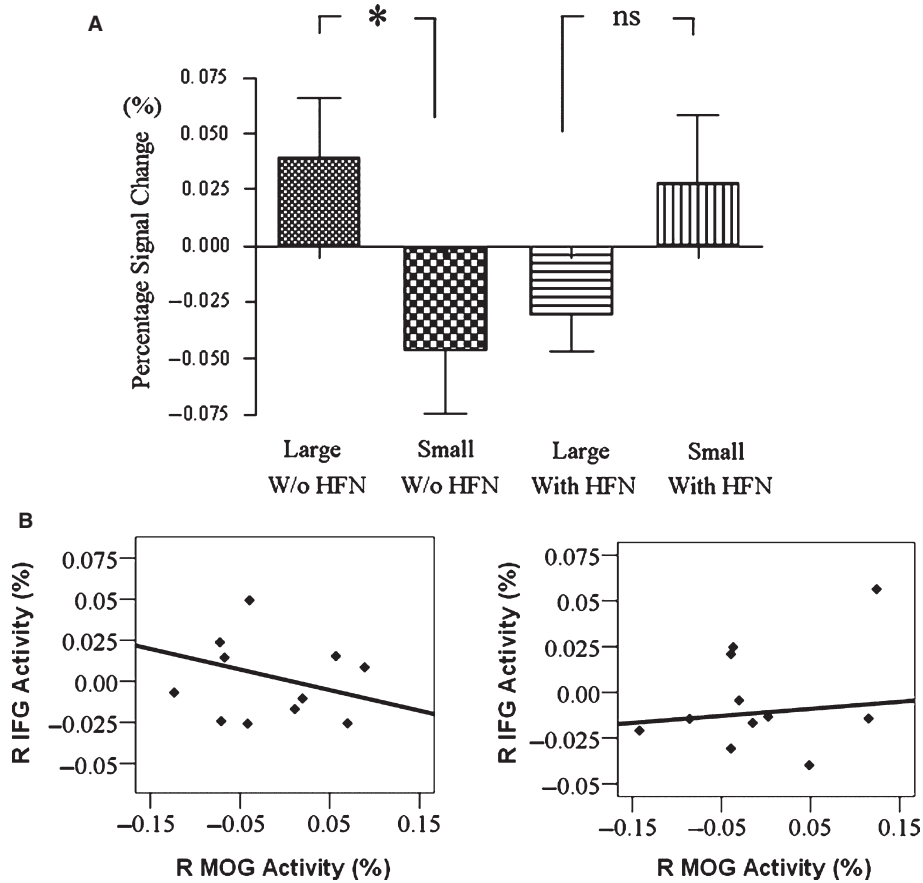


FIG. 2. (A) Percentage BOLD signal changes in the right MOG activation shown in Fig. 1H, revealing the specific pattern of interaction. BOLD responses were significantly greater for the large neighborhood size than for the small neighborhood size for the without-HFN condition, but there was no difference for the with-HFN condition. (B) Functional connectivity analysis identifying a significant negative correlation of brain activity (percentage of signal changes) between the right IFG (R IFG) and the right MOG (R MOG) when naming characters with HFNs but not when naming characters without HFNs.

ters that had HFNs and those that did not. Consistent with our previous studies (Bi *et al.*, 2006; Li *et al.*, under review), the behavioral results revealed a clear interaction between the two factors, showing an inhibitory neighborhood size effect for the with-HFN condition, but a significant facilitatory neighborhood size effect for the without-HFN condition. In all conditions, the imaging data revealed several regions of activation for the naming process, as compared with a fixation baseline, including the left fusiform gyrus, right MOG, left precentral gyrus, left IFG, and left middle frontal gyrus. These are all typical language areas, and the results were generally consistent with literature studies on naming and word processing (Cohen *et al.*, 2000; Tan *et al.*, 2000, 2001, 2005; Perfetti *et al.*, 2005; Booth *et al.*, 2006; Bitan *et al.*, 2007).

When different conditions were compared, the left middle frontal gyrus was found to be associated with the neighborhood size effect, showing greater activity for small neighborhood size words than for large neighborhood size words. This region has been consistently reported in the literature to involve the processing of Chinese characters (Tan *et al.*, 2001, 2003, 2005; Chee *et al.*, 2004; Kuo *et al.*, 2004; Siok *et al.*, 2004; Perfetti *et al.*, 2005; Booth *et al.*, 2006; Cao *et al.*, 2009), and is considered to play an important role in Chinese reading (Cao *et al.*, 2009). Some even propose it to be a 'Chinese reading area' (Perfetti *et al.*, 2005). Specific functions attributed to this area include addressed phonology (Tan *et al.*, 2005) and integration of orthographic information with phonology (Tan *et al.*, 2005; Cao *et al.*, 2009). Words with more orthographic neighbors may induce the

global activation suggested by Grainger & Jacobs (1996), facilitating access of the correct phonology. The stronger activation in the left middle frontal gyrus for words with fewer neighbors would then reflect the increased difficulty in retrieving the correct phonology, owing to greater reliance on the target words' orthography.

We did not find any region that was more activated for large neighborhood size than for small neighborhood size. Such null findings have also been reported by Binder *et al.* (2003) and Fiebach *et al.* (2007), although they used lexical decision tasks. One suggestion from Fiebach *et al.* (2007) is that facilitation from neighbors may be broadly distributed rather than being confined to a specific single brain region.

Regardless of neighborhood size, the brain responses in the bilateral IFG were found to be modulated by the HFN factor, showing stronger activation when the target words had HFNs than when they did not. As has been widely documented, a primary function of the left IFG is phonological processing (Pugh *et al.*, 1996; Herberster *et al.*, 1997; Rumsey *et al.*, 1997; Bitan *et al.*, 2005, 2006). Specifically for Chinese, Luo & Niki (2000) reported that it is involved in phonological competition. If activation of this region in the present study also reflects such competition, our results indicate that the effect of a target word's HFNs on its naming, as observed in our previous behavioral studies (Li *et al.*, under review) and replicated here, can be attributed to interference from phonological activation, as we hypothesize. Correspondingly, right IFG activation (with HFN > without HFN) may be associated with a process that inhibits this extraneous phonological activation from the

HFNs, given that this area has been implicated in inhibition in previous studies (Garavan *et al.*, 1999; Aron *et al.*, 2004).

Several studies have shown that the right MOG, where there was an interaction between neighborhood size and the HNF factor, is more involved in Chinese reading than in English reading (Tan *et al.*, 2000, 2005; Fu *et al.*, 2002; Siok *et al.*, 2004; Bolger *et al.*, 2005; Cao *et al.*, 2009). This may reflect the fact that reading Chinese characters may rely more on orthography but less on phonology as compared with alphabetical scripts, in line with the functional specialization of the right hemisphere in spatial processing (Jonides *et al.*, 1993; Kosslyn *et al.*, 1993; McCarthy *et al.*, 1994; Smith *et al.*, 1995).

The imaging result showing that the right MOG showed greater activity for the large neighborhood size than for the small neighborhood size in the absence of HFNs was consistent with the behavioral finding of a facilitatory neighborhood size effect, and can be readily interpreted to reflect the joint orthographic activation of the target words and their neighbors. That is, the more words there are with orthographically similar structures to those of the target words, the stronger they will engage the right MOG for spatial analysis.

The other simple effect of the interaction effect in the right MOG, that is, the absence of a neighborhood size effect in the presence of HFNs, was not in accordance with the behavioral finding of an inhibitory neighborhood size effect. This argues against a simple understanding that the right MOG activation reflected only orthographic processing, because if this were so, one would expect its activation to be modulated by the phonological HFN factor.

One speculative interpretation is that this area is also subject to an influence of feedback modulation from upstream processing from the frontal regions. That is, in the presence of HFNs, the right IFG may feed back on the right MOG to suppress the orthographic activations of the HFNs and reduce their associated phonological interference. Therefore, the right MOG may reflect counteracting effects from upstream and downstream processing, meaning that there is no net effect of family size. A functional connectivity analysis seems to provide some evidence supporting this explanation. As shown in Fig. 2B, the right IFG and the right MOG showed correlated brain activities in the presence of HFNs (left panel) but no correlation in the absence of HFNs (right panel). One spherical region of interest (radius, 4 mm) was defined for each of the two regions, centering at their respective peak activations.

The anatomical locations of some brain activations in the present study were not so close to some relevant previous studies. For example, whereas the peak point in our left IFG activation was at (−39, 38, 4), it was reported to be at (−39, 24, 24) in Cao *et al.* (2009), (−50, 30, 2) in Tan *et al.* (2005), and (−45, 32, 7) in Bolger *et al.* (2005); and whereas the peak point in our right MOG activation was at (45, −68, 25), it was reported to be at (27, −90, 6) in Cao *et al.* (2009), at (27, −84, 1) in Tan *et al.* (2005), and at (33, −67, −14) in Bolger *et al.* (2005). Although such discrepancies may be attributed to individual differences or to the different anatomical brain models used, there is always a possibility that different sub-regions in the same general brain areas were identified in different studies.

In conclusion, the present study supports the proposal that language characteristics play important roles in determining the neighborhood size effect in word naming. In addition to facilitatory contributions resulting from orthographic activation from a target word's neighborhood words, character naming is also affected by whether there are higher-frequency members among those neighbors. In scripts with deep orthography, where orthographic neighbors may be pronounced differently from the target word, larger neighborhood sizes may elicit competing phonological activation that interferes with naming of the target word.

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Abbreviations

BOLD, blood oxygen level-dependent; fMRI, functional magnetic resonance imaging; IFG, inferior frontal gyrus; MOG, middle occipital gyrus; O-P, orthography-to-phonology.

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