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Neural Cognitive Correlates of Orthographic Neighborhood Size Effect for Children During Chinese Naming

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1. Introduction

A lot of researchers are concerned of orthographic neighborhood (N) effect (Andrews, 1989, 1992; Carreiras et al., 1997; Laxon et al., 1988; Peereman & Content, 1995; Sears et al., 2006), which can reflect how the potential word candidates with similar orthography affect the word naming task. In alphabetic writing systems, orthographic neighborhood refers to a word pool, which is consisted by changing one letter of a given word while keeping other letters unchanged (Coltheart et al., 1977). Behavioral researches with naming tasks have reported a facilitatory effect of N size (Andrews, 1989, 1992; Carreiras et al., 1997; Peereman & Content, 1995; Sears et al., 1995), which the presence of many orthographic neighbors facilities phonological retrieval of the target word, and such facilitation would be more prominent for low-frequency words (Andrews, 1989, 1992; Peereman & Content, 1995). This large N advantage is also found as orthographic distinctiveness effect in memory (Glanc & Greene, 2007; 2009). Modeling researches suggested that the facilitation of large N arises from the overlapping phonemes of their neighbors (Coltheart et al., 2001) and the feedback activations from orthographic units to feature units strengthen the phonological retrieval (Reynolds & Besner, 2002). Recently, Fiebach et al. (2007) examine the neural mechanisms of N size effect using fMRI. Their results demonstrated the interactions of lexicality and N size in mid-dorsolateral and medial prefrontal cortex, suggesting domain general processes during word recognition.

Another important lexical factor related to orthographic neighbors is neighborhood frequency (N frequency). Researchers have found that the presence of neighbors which have a higher word frequency would facilitate naming processing in French (Grainger, 1990) and Spanish (Carreiras et al., 1997), whereas no influences in English (Sears et al., 2006). One possible reason of these different results is language characteristics. As well known, Spanish and French are both of shallow orthography, and words in the same orthographic neighborhood tend to be phonological neighbors, speeding up phonological activation of the target word. In comparison, English is a kind of language with deeper orthography, in which there are some orthographic neighbors with different pronunciation with the target word, resulting in the null effect.

Chinese is known as a typical logographic writing system (Tan et al., 2001), complex visual-spatial information exits in the form of each character (Li & Kang, 1993). Chinese with a deeper orthography has no grapheme-to-phoneme correspondence (GPC), similar orthographic structures arbitrarily correspond to different phonological information. Based on the above definition of N size in alphabetic languages, there is no N in Chinese without individual letters, but over 81% Chinese characters are compound characters (Li & Kang, 1993), consisting of phonological and semantic radicals. Generally speaking, phonetic radical provides the pronunciation of the whole character, and semantic radical indicates its meaning. Bi et al. (2006) defined the neighborhood of Chinese characters as the characters with the same phonetic radical because they focused the phonological processing. For example, [璜(huang2, upholster), 簧(huang2, reed), 磺(huang2, sulfur), 横(heng2, across)] is a orthographic neighborhood with the same phonetic radical 黄(huang2, yellow). Bi et al. (2006) reported a surprising result that target characters with more neighbors would produce a slower naming latency than those with few neighbors. This result is inconsistent with the finding in alphabetic researches, the authors inferred that the large N disadvantages in Chinese naming resulted from the phonological interference of neighbors. Due to the low level of phonological consistency, there would be some different sounds in a given neighborhood. The different phonologies of neighbors would be activated to inhibit phonological retrieval of target. Recently, researchers explored the N effect in Chinese character naming in details, and the large N advantages in Chinese naming was found, the inhibitory effect in Bi et al. (2006) was accounted by the uncontrolled N frequency (Li et al., 2011), just like what found by Huang et al. (2005) that characters with higher-frequency neighbors induced an inhibitory effect in RT and elicited more N400 than those with no higher frequency neighbors (Huang et al. 2005). Li et al. (2011) argued that the presence of many neighbors with the same orthographic structure facilitates characters' recognition and phonological retrieval when there is no higher-frequency neighbors, higher-frequency neighbors with different phonologies would interfere the target word naming due to their higher level of static activation, there are more high-frequency neighbors in large neighborhoods, so, the inhibitory N effect appeared in Chinese naming. Following Neuroimaging study supported these opinions. Researchers (Li et al., 2010) found that target characters with smaller Ns elicited greater activation in left middle frontal gyrus, while those with larger Ns induced more prominent activation in right middle occipital gyrus in silent naming tasks in without- higher-frequency neighbor conditions. The authors argued that right middle occipital gyrus was associated with orthographic facilitation, which the activated visual form information of neighbors facilitated the target character recognition and further processing, left middle frontal gyrus reflected the difficulty of mapping visual forms to phonemes, the target character from smaller neighborhood needed more involving of this area to search information for such mapping. In addition, the authors also revealed a main effect of N frequency, which target characters with higher-frequency neighbors induced more activation in bilateral inferior frontal gyrus suggesting phonological competition and the inhibition of wrong information.

For the development of N size effect in alphabetic languages, only a few researches consistently showed that such N effect exited in English (Laxon et al., 1988) and Spanish (Dunabeitia & Vidal-Abarca, 2008) beginning readers, but for Chinese children, the cognitive characteristics and neural basis of N effect were still not explored.

The purposes of this research were two, one was to examine whether there is N size effect in Chinese children reading just like findings in alphabetic languages, and if it exists, whether N size effect in Chinese children reading is the same as what found in Chinese adults reading (Li, et al., 2011); the other was to explore the neural basis responsible for N size effect in Chinese children reading.

2. Behavioral study

2.1 Materials and methods

2.1.1 Participants

Forty students of grade 3 from Beijing normal primary schools (mean age=9.5, range: 9.2-9.9, n=20 males) participated in this study. All the children are native Chinese speakers with normal or corrected normal vision, right-handed.

2.1.2 Stimuli

There were 34 characters, 17 characters were for large neighborhood size and 17 characters for small neighborhood size. Following Bi et al. (2006), the orthographic neighbors 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 2-7 neighbors for the small size, and 10-16 neighbors for the large size. The characters selected were just learnt by the students in the recent two years.

Following Li et al. (2011), the criteria for selection of stimuli were: All stimuli were compound characters with the structures proceeded from left to right, phonetic radicals were on the right-hand side, the phonetic radicals were single characters, no two characters shared the same phonetic radical, each had its own meaning, none of the characters were polyphones, stroke number and consistency level had no significant differences between two conditions. The information of stimuli was shown in Table 1.

According to Fang et al. (1986), the consistency level (con) was calculated from the ratio of the number of neighbors with the same pronunciation (n) and N size (con=n/N). The ‘same pronunciation’ refers to the same initial consonant and compound vowels, tones were not considered here. For example, in the neighborhood including the phonetic radical 及 (ji2, and), the neighbors are 圾 (ji1, garbage), 汲 (ji2, draw), 极 (ji2, pole), 笈 (ji2,book), 岌 (ji2, danger), 级 (ji2, class), 吸 (xi1, absorb), and 靸 (sa3, shoes) (N=8). There are six neighbors with the pronunciation of ji: 圾 (ji1,garbage), 汲 (ji2, draw), 极 (ji2, bally), 笈 (ji2, danger), 岌 (ji2, danger), 级 (ji2, class, n=6), so the consistency level of the pronunciation ji in this neighborhood is produced as .75 by con=n/N=6/8.

Neighborhood size					
Large			Small		
Number of neighbors	Consistency level	Stoke number	Number of neighbors	Consistency level	Stoke number
14.9	0.33	9.5	4.6	0.30	8.2

Table 1. Information of stimuli

2.2 Procedure

All the stimuli were presented by E-Prime professional 2.0 on an IBM laptop computer. The viewing distance was of 45 cm, subtending a visual angle of approximately 3°×3°. The characters were presented in a randomized order, each for 2000 ms. A fixation cross was displayed for 500 ms in the interval between the presentation of two characters. Participants were tested individually and instructed to read the characters aloud as accurately and quickly as possible to activate the voice-key. The voice-key was connected between the computer and the SRBOX to record reaction times. The character disappeared upon response, or at the end of the 2000 ms response window. The reaction times longer than 2000 ms or that the voice-key activated by other sounds were excluded from analysis.

Practice was conducted for all children before the normal study in order to make them familiar with the study. The practice contained 20 characters different from the stimuli in real experiment.

2.3 Results

The data of 9 children with error rate more than 50% in one condition were eliminated. Thus, the data from 31 participants were included for further analysis. Incorrect responses and response latencies out of the range of three standard deviations were excluded from analysis. Mean latencies for correct responses and average error rates (see Table 2) were submitted to one-way ANOVA (N size: large/small).

The analysis of reaction times revealed a significant facilitatory neighborhood size effect ($F(1, 30)=8.25$, $p<.008$), participants responded faster to characters with large Ns than to characters with small Ns. And the analysis of error rates showed that there was less error to characters with large Ns than to characters with small Ns ($F(1, 30)=12.29$, $p<.002$).

Neighborhood size			
Large		Small	
RT(ms)/SD	ER (%)/SD	RT(ms)/SD	ER (%)/SD
712.0/123.4	3.1/1.2	739.3/117.3	4.6/1.4

Table 2. Mean reaction latencies (RT, in ms) and error rates (ER, in %) in behavioral study

2.4 Discussion

Both the results of naming time and error rate revealed a significant facilitatory N effect for participants of grade 3. The large-N advantage for participants suggested that facilitation of similar orthographic structures exited in children with early reading experience, which is consistent with the results of developmental studies in alphabetic languages (Laxon et al., 1988; Dunabeitia & Vidal-Abarca, 2008). Such results suggested that at early stage of reading, neighbors with similar orthographic structure would facilitate character recognition and phonological retrieval. That is to say, similar visual forms of characters would help naming processing for children. After re-analysis the stimulus characters, we found that there were more than 88% target characters having higher-frequency neighbors with different pronunciations in each experimental condition. In this circumstance, according to the finding from adults (Li, et al., 2011), inhibitory N size effect is expected for the reason of phonological interference from higher-frequency neighbors, but the present result is different. The interferences of higher-frequency neighbors were not found for grade-3 students. One possible reason is that the potential higher-frequency neighbors might not be learned by the participants at their age, so the pronunciation of these higher-frequency neighbors didn't affect the target character naming; Another possible reason is that these higher-frequency neighbors were not of higher frequency indeed for grade-3 children, because we judge the frequencies of characters including target words and their neighbors by the criterion of the character frequency of adults, the frequency information may not be formed due to their limited reading experience.

3. fMRI study

3.1 Materials and methods

3.1.1 Participants

Eleven students of grade 3 from a Beijing normal primary school (mean age=9.3, range: 9.1-9.4, n=7 males) were scanned, these children also participated in behavioral study. All the participants are native Chinese speakers with normal or corrected normal vision, right-handed. The study was approved by the ethics committee of the Institute of Psychology, Chinese Academy of Sciences, China. Written consent for participation was obtained from the children's parents as well as their school teachers.

3.1.2 Stimulus characteristics

The stimuli were the same as what used in behavioural study. The fMRI Procedure was the same as the paradigm in behavioral study, except that children were instructed to read the characters silently as soon as each character was presented. After fMRI scanning, participants were asked to perform a post naming test. Post-naming test was a typical naming task, the experimental set and the stimulus characters was the same as in the behavioural study. What's more, there are 20 buffer trials in this session in order to counteract practicing effect.

3.1.3 Image collection

Hemodynamic responses were acquired on a 3T Siemens Trio MR system (Siemens Trio Magnetic Resonance Imaging system, Germany). All the participants were instructed to keep still, and their heads were aligned to the center of the magnetic field.

For each participant, a high resolution, three-dimensional anatomical data set was acquired, using Siemens' magnetization-prepared rapid acquisition gradient echo (MPRAGE) sequence (Repetition time/TR=2s, 30 contiguous axial slices, 1.33 mm thick,TE= 30 ms, flip angle = 90˚, 256 mm field of view). A BOLD-sensitive gradient echo-plane imaging (EPI) sequence was acquired (30 contiguous axial slices, 1.33 mm thick TR=2000 ms, TE=30 ms, matrix=64×64, 200 mm field of view).

3.1.4 Data preprocessing and statistical analyses

Data processing and statistical analyses were conducted using the AFNI software package (Cox, 1996, Cox & Hyde, 1997, http://afni.nimh.nih.gov/afni/). For each dataset of individual child, slice timing correction, motion correction and temporal filtering of functional images were performed. 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 7-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 condition. 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.

N size effect analysis was performed by direct comparison between the statistical images of different neighborhood size using paired t-test, uncorrected.

3.2 Results

Brain activations relative to the resting baseline are shown in Table 3 and Fig 1, revealing common network regions for children reading, including left fusiform gyrus, right middle occipital gyrus, left precentral gyrus, left inferior frontal gyrus, and left middle frontal gyrus.

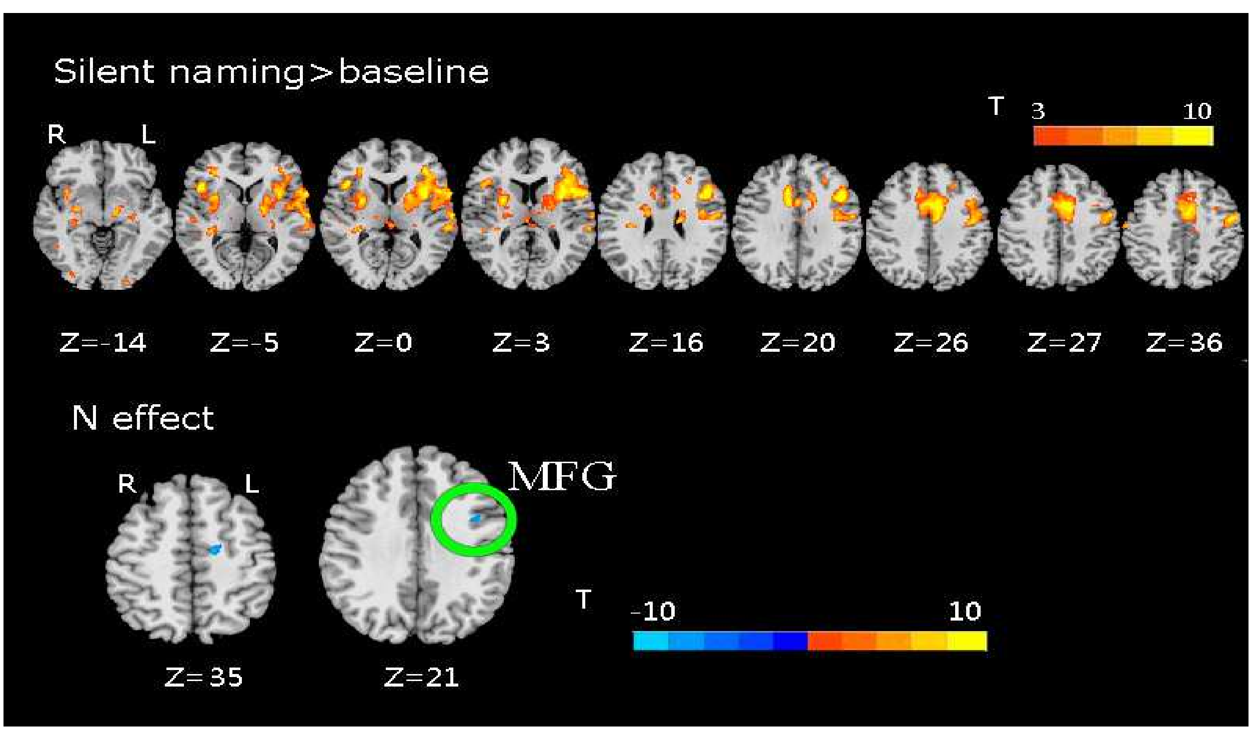

Fig. 1. Brain activations of silent naming contrast to rest baseline and ON size effect

Contrast	Brain area	X	Y	Z	Volume	t
Silent naming>baseline						
	R middle occipital gyrus/fusiform gurus	30	-78	-4	2048	6.993
	L middle occipital gyrus/fusiform gyrus	-32	-79	-8	4774	5.680
	L inferior frontal gyrus/middle frontal gyrus	-32	32	2	2829	5.542
	L precentral gyrus	-46	6	7	184	9.982
	L medial frontal gyrus	0	14	44	4800	7.417
	R precentral gyrus	31	-8	24	288	4.235
	R inferior frontal gyrus	28	21	9	757	5.153
	L inferior parietal lobule/supramaginal gyrus	27	49	39	443	4.064
	L middle temporal gyrus	-37	-53	0	278	5.531
N effect (large>small)						
	L cingulate gyrus	-14	-12	46	163	-4.954
	L middle frontal gyrus	-35	2	35	126	-4.453

Table 3. Summary information for brain activations. Note: 'Silent naming>baseline' means naming performance contrast to rest baseline, in this section the areas activated were reported, 'N effect (large>small)' refers to the contrast of targets from large neighborhoods to that from small neighborhoods. X, Y and Z are coordinates in Talairach space of the peaks. Targets from small N induced more activation on left middle frontal gyrus and left cingulate gyrus than those from large N for children. While there was no activated area accounting for large N advantage.

3.3 Discussion

The fMRI imaging results showed the neural net-works involved phonological processing in Chinese children. The activated brain areas by the contrast between silent naming and baseline include: left fusiform gyrus, right middle occipital gyrus, left precentral gyrus, left inferior frontal gyrus, and left middle frontal gyrus. These results are in line with previous imaging studies on Chinese children reading process (Bitan et al., 2007; Bookheimer et al., 1995; Booth et al., 2002; Booth et al., 2006; Cao et al., 2009; Herbster et al., 1997).

Children showed significant activation in left middle frontal gyrus for characters with small Ns than for characters with large Ns, and this result is similar with adults' in Li et al. (2010). Left middle frontal gyrus are reported highly involved in Chinese reading (Booth et al., 2006; Chee et al., 2004; Kuo et al., 2004; Perfetti et al., 2005; Tan et al., 2005; Tan et al., 2001; Tan et al., 2003). Other previous research (Li et al., 2010) revealed that left middle frontal gyrus was partially responsible for the facilitation of large ON, more activity in this area reflected more difficulty in integrating orthography to phonology. Present results suggested that children with early reading experience could already take advantages from orthographic neighbors as adults did.

In present study, we didn't found greater activation for large-neighborhood characters compared with small-neighborhood characters in left inferior frontal gyrus and right inferior frontal gyrus. These two areas were reported to be related to higher-frequency neighbors in the previous study (Li et al., 2010). That is, the greater activation in bilateral inferior frontal gyrus reflected the automatic phonological activation of higher-frequency neighbor and the inhibition of uncorrected sound. As mentioned above, more than 88% target characters had higher-frequency neighbors. However, we didn't found the effect of higher-frequency neighbors as adults, and this result was supported by the findings in the first behavioral experiment. So, it is understandable that the neural networks for the effect of higher-frequency neighbors haven't formed.

Till now, we can conclude that the grade-3 children can be facilitated by the similar orthographic forms in character reading, but not be influenced by the frequency information of orthographic neighbors.

We have strong desire to determine the precise time of activation among different regions and the relationship relative to different brain areas during N effect for children, however, due to the low temporal resolution of fMRI, the BOLD signal peaks about 5s after neuronal firing, it is difficult to interpret the effects in different locations of brain in real-time.

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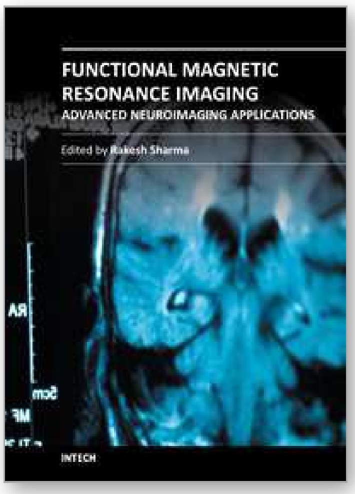

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