Differential Brain Activity in Reading Hangul and Hanja in Korean Language

Hyo Woon Yoon and Ji-Hyang Lim

Department of art therapy, Daegu Cyber University, Daegu, Korea
hyowoonyoon@dcu.ac.kr

Abstract. Even though the Korean words (Hangul) are characterized as phonemes like other alphabetic languages, their shape resembles much more morphemes like Chinese characters (Hanja). The use of functional magnetic resonance imaging permits the collection of brain activation patterns when native Korean speakers (12 persons as subjects) read Hangul and Hanja. The Korean language uses both alphabetic Hangul and logographic Hanja in its writing system. Our experimental results show that the activation patterns obtained for reading Hanja by Korean native speakers involve neural mechanisms that are similar to Chinese native speakers; i.e. strong left-lateralized middle frontal cortex activation. For the case of Korean word reading, the activation pattern in the bilateral fusiform gyrus, left middle frontal gyrus, left superior temporal gyrus, right mid temporal gyrus, precentral gyrus, and insula was observed

Keywords: Word perception, brain activity, frontal cortex.

1 Introduction

It is generally known that perceiving or reading visually presented words encompasses many processes that collectively activate several specialized neural systems to work in concert. Functional imaging techniques such as Positron Emission Tomography (PET) or functional Magnetic Resonance Imaging (fMRI) have provided meaningful insights into the neural systems that underlie word recognition and reading process in the human brain. In the proposed model of written word perception [1,2], it is proposed that a large-scale distributed cortical network, including the left frontal, temporal, and occipital cortices, mediates the processing of visuo-orthographic, phonologic, semantic, and syntactic constituents of alphabetic words. For example, the posterior fusiform gyri are relevant to visual processing, whereas the inferior frontal lobe emphasizes their role in semantic processing [3,4]. Regarding various written languages or writing systems, the question of how the surface form of words influences the neural mechanisms of the brain during word recognition is of interest.

One of the most different writing systems from alphabetic words is the Chinese character. Alphabetic systems are based on the association of phonemes with graphemic symbols and linear structure, whereas Chinese characters are based on the association of meaningful morphemes with graphic units, the configuration of which is square and nonlinear. Previous studies using visual hemifield paradigms demonstrated

T.-h. Kim et al. (Eds.): UCMA 2011, Part II, CCIS 151, pp. 52–59, 2011.

that the right cerebral hemisphere is more effective in processing Chinese characters than the left cerebral hemisphere [5]. This leads to a Chinese character-word dissociation hypothesis for a lateralisation pattern, since word perception is regarded to be left-lateralised. This conclusion has been disrupted, because some more current results of brain activation based on fMRI experiments suggest that the reading of Chinese characters is bi-lateralized. In particular, the left inferior frontal cortex (BA 9/45/46) emphasized the importance of the semantic generation or processing of Chinese characters [6,7]. Chinese characters are used not only in the writing systems of Chinese language, but are also widely used in the Japanese and Korean languages. The Korean writing system consists of the mixture of the pure Korean words and Chinese characters. The Korean words are characterized as phonemic components similar to the alphabetic words used in English or German. However, the shape of Korean words is nonlinear. The composition of its symbols is shaped into a square-like block, in which the symbols are arranged left to right and top to bottom. Its overall shape makes Korean more similar to Chinese than other alphabetic orthographies [8]. Furthermore, unlike alphabetic words, these phonemic symbols are not arranged in a serial order, but are combined into a single form to represent a syllable. These syllabic units are spatially separated from each other. Each Korean syllable is constructed of two to four symbols that in various combinations represent each of 24 phonemes. Thus, in a sense, Korean words, Hangul, can also be regarded as syllabograms (Figure 1). Hangul is the name of the Korean alphabet. In addition, the Korean vocabulary consists of pure Korean words (24.4 %), Chinese-derivative words (69.32 %), and other foreign words (6.28 %). Chinese derivative words can be written either in the form of Chinese ideogram or its corresponding Korean words [9]. In the current Korean writing system, e.g. daily newspapers or boulevard magazines in South Korea, the use of Chinese characters is relatively sparse. According to the statistics of the year 1994 [10], the proportion of Chinese characters in the body of daily newspapers are about 10 % and since then this has continuously diminished. Surprisingly, although these are unique and interesting characteristics, the neural mechanisms involved in reading Korean words have been rarely studied, at least with modern functional imaging techniques. Using functional magnetic resonance imaging technique, we investigated the neural mechanism involved in reading these two different writing systems by Korean native speakers. In doing so, we hope to identify specific neural mechanisms that are involved in reading Korean words (phonemes) and Chinese characters (morphemes).

2 Materials and Methods

2.1 Subjects

Seven male and five female right-handed subjects (mean age: 22 years, S.D. 1.5 years) participated in the study. All were native Korean speakers who has been educated for Chinese characters for more than 6 years in school. They did not have any medical, neurological or psychiatric illness at past or present, and they did not take medication. All subjects consented to the protocol approved by the Institutional Ethics and Radiation Safety Committee.

2.2 Experimental Design

As stimuli, two-character Chinese words and Korean words with equivalent phonetic as well as semantic components were chosen (Figure 1). There were 60 words for each category. All words were nouns. Half consisted of abstract meanings and the other half concrete meanings.

Stimuli were presented using custom-made software on a PC and projected via an LCD projector onto a screen at the feet of the subjects. The subjects viewed the screen via a homemade reflection mirror attached on the head RF coil. Each stimulus was presented for 1.5 seconds long, followed by a blank screen for 500 ms. Ten different items of this stimulus pattern were presented, including a blank screen for one second prior to the first stimulus within a block. These stimuli blocks were alternated with the baseline task. During the baseline task, a fixation point was projected on the middle of the screen for 21 seconds. Two kinds of stimuli (Korean words and Chinese characters) and baseline task blocks lasted equally for 21 seconds each. A total of six blocks of Korean words and six blocks of Chinese characters were presented, and these were intermixed at random.

During the experiment, the subjects were instructed to press the right button for nouns with an abstract meaning and the left button for those with a concrete meaning. Simultaneously, they should respond covertly to the stimuli presented.

2.3 Data Acquisition and Analysis

Images were acquired by using 1.5 Tesla MRI scanner (Avanto, Siemens, Erlangen, Germany) with a quadrature head coil. Following a T1-weighted scout image, high-resolution anatomic images were acquired using an MPRAGE (Magnetization-Prepared RApid Gradient Echo) sequence with TE = 3.7 ms, TR =8.1 ms, flip angle = 8°, and image size of 256 x 256. T2*-weighted functional data were acquired by using echo planar imaging (EPI) with TE = 37 ms, flip angle = 80°, TR = 3000 ms, and image size of 64 x 64. We obtained 30-slices EPI images with slice thickness of 5 mm and no gaps between slices for the whole brain. Total 172 volumes were acquired per an experimental run. For each participant, the first four volumes in each scan series were discarded, which were collected before magnetization reached equilibrium state.

Image data were analyzed using SPM2 (Wellcome Department of Cognitive Neurology, London). The images of each subject were corrected for motion and realigned using the first scan of the block as a reference. T1 anatomical images were coregistered with the mean of the functional scans and then aligned to the SPM T1 template in the atlas space of Talairach and Tournoux [11]. Finally, the images were smoothed by applying Gaussian filter of 7 mm full-width at half-maximum (FWHM). In order to calculate contrasts, the SOA (stimulus onset asynchrony) from the protocol was defined as events and convolved with the hemodynamic response function (HRF) to specify the appropriate design matrix. The general linear model was used to analyze the smoothed signal at each voxel in brain. Significant changes in hemodynamic response for each subject and condition were assessed using t-statistics. For the group analysis, contrast images of single subject were analyzed using a random effect model. Activations were reported if they exceeded a threshold $P < 0.05$, corrected on the cluster level ($P < 0.0001$ uncorrected at the single voxel level). Significance on the cluster level was calculated in consideration of peak activation and extent of the cluster.

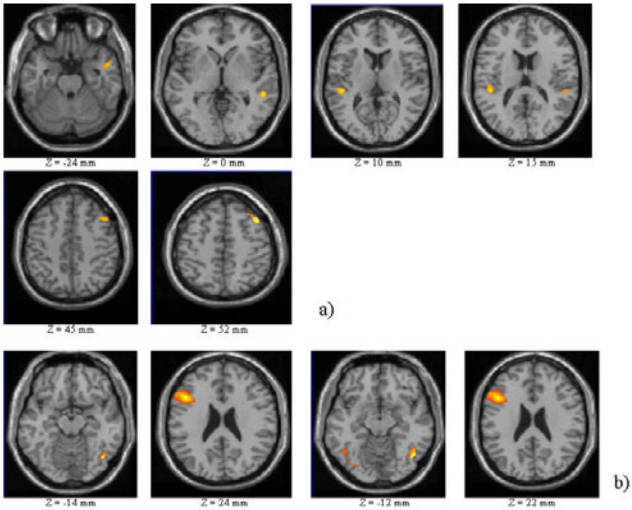

Fig. 1. a) indicates the activation map “Korean word reading” minus “Chinese character reading” in 12 subjects (threshold at $p < 0.0005$, uncorrected at a single voxel level). b) indicates the activation map of Korean words minus baseline (left two images) and Chinese character minus baseline (right two images). Threshold p-value for b) is 0.0001 (uncorrected at the single voxel level).

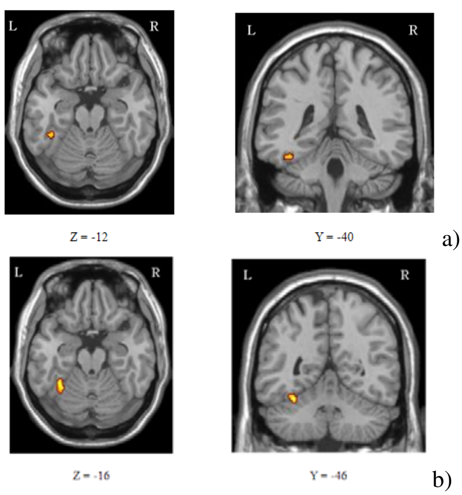

Fig. 2. Brain areas showing the repetition suppression effect. The anterior portion of the left fusiform gyrus showed reduced activation in case of the cross script condition a), whereas a more posterior portion of the fusiform gyrus is responsible for the repetition suppression in the case of the same script condition b).

3 Results

The mean reaction time for subjects during Korean word reading was 1.01 sec (S.D.: 325 ms), whereas, for Chinese character reading, it was 1.24 sec (S.D.: 367 ms). A paired t-test verified the significance between these two reaction times ($p < 0.00001$). Significant signal changes for Korean words reading vs. baseline were detected bilaterally in the fusiform gyrus (BA 19/37) and in the left middle frontal area (BA 46/6). In addition, right hemispheric activation was observed in the medial frontal gyrus (BA 8). For Chinese characters vs. baseline, the activation patterns appeared to be slightly different. In the region, responsible for the visual stimuli per se, we observed bi-hemispheric activation for the Chinese character reading vs. baseline task. In the frontal (superior, BA 8 and inferior area, BA 9) and parietal (superior, BA 7) cortices, only left hemispheric activation was significant in contrast with the baseline task. Brain areas responsible for the repetition suppression are summarized in Table 2. Repetition suppression effect in the case of prime Hanja and target Hanja was clearly seen in the area of bilateral middle fusiform gyrus. In contrast, the suppression effect of priming was found in the area of left medial fusiform gyrus (x = -36, y = -40, z = -12) in the case of prime word Hanja, target word Hangul condition. According to the further analysis this area also showed a repetition priming suppression in the case of the cross-script condition. This was done by doing computerizing a linear combination of prime Hanja-target Hangul and prime Hangul-target Hanja conditions (inclusively masked by both contrast at $p < .05$). This suggests that the left medial portion of fusiform gyrus seemed to exhibit a significant effect of repetition suppression, irrespective of the direction of script alternations. To the contrary, the repetition priming suppression effect in the case of the same script conditions (linear computerizing of prime Hanja-target Hanja and prime Hangul-target Hangul) showed also in the area of left fusiform gyrus, but more posterior to coronal section and lateral to sagittal section (x = -42, y = -46, z = -16).

4 Discussion

In the different contrast of Korean words minus Chinese character conditions, significant positive signal changes were observed in the right superior gyrus of the frontal lobe (BA 8), the left superior temporal lobe (BA 41), and the right midtemporal lobe (BA21), precentral gyrus (BA 6) and insula (BA 13) and for the condition of Chinese character minus Korean words, activation was observed in the bi-hemispheric visual area (BA 19).

In terms of behavioral data, significantly longer reaction times were observed for Chinese character reading compared to Korean word reading. Since very simple Characters were used as stimuli, it would appear that the reaction time advantage for reading Korean words is not derived from a familiarity effect. Rather, it might rely on differences in characteristics of phonological processing between these two writing systems. The phonological processing in Chinese character recognition is at the syllable-morpheme phonology level. This is the fundamental difference regarding the role of phonology between Chinese and alphabetic writing systems. The concept of pre-lexical phonology is misleading for Chinese character reading [8]. However, in processing Korean words, pre-lexical phonology is activated rapidly and automatically. Reading Korean words for meaning involves pre-lexical information processing [12].

In the functional imaging data, the activated area for the condition of Chinese character vs. baseline reading was found to be in the left hemispheric inferior and superior gyri of the frontal lobe (BA 6/9). This demonstrates the left lateralized pattern of the frontal cortex during Chinese character reading. This activation can be attributed to the unique square configuration of Chinese characters [13,14]. Chinese characters consist of a number of strokes that are packed into a square shape according to stroke assembly rules, and this requires a fine-grained analyses of the visual-spatial locations of the strokes and subcharacter components [15]. In addition, it is known that the left middle frontal cortex (BA 6/9) is the area of spatial and verbal working memory by which the subject maintains a limited amount of spatial and verbal information in an active state for a brief period of time [16,17]. More precisely, this area may play a role as a central executive system for working memory, which is responsible for coordination of cognitive resources [18]. In our experiment, even though a working memory process was not involved in the subjects' decision, they indeed needed to coordinate the semantic (or phonological) processing of the Chinese characters. These two processes of coordination of cognitive resources and semantic processing were explicitly required by the experimental task and the intensive visuospatial processing of the Chinese characters. It seems that the activation of the left middle frontal gyrus should be involved in these two cognitive processes. This left frontal activation pattern is consistent with other studies, in which functional imaging techniques of Chinese character reading by native Chinese speakers were used, especially the activation of BA 9 [7,19,20].

Left hemispheric middle frontal activations (BA 46/6) were also observed for the condition of Korean words vs. baseline and this appears to be correlated with similar mechanisms associated with the reading of other alphabetic words [21]. Since our subjects were ask to respond after seeing and the covert speaking of Korean words (forced choice option), which is connected with semantic processing, the activation of middle frontal area seems to underlie this cognitive process. We propose that this might be the reason for why the left frontal area is strongly activated during this experimental task.

Occipital lobe activation was observed for Chinese character reading in contrast with baseline as well as a direct comparison with Korean words (Table 1). The activated occipital areas, such as the fusiform gyrus, are thought to be relevant to the visual processing of Chinese characters. Interestingly, we observed right hemispheric dominant occipital activation, even though two-character Chinese words were presented as stimuli. There were some indications that the reading of two-character Chinese word is left lateralized [19,20], but our results did not support the dissociation hypothesis of single and two-character Chinese word perception. Bilateral activation of occipito-temporal area was also observed for the Korean word reading. It is generally thought that this area is relevant to the processing of the visual properties of Korean words. The activation pattern is bilateral, but the left hemispheric activity was relatively weaker (Table 1). This is not in agreement with previous studies with alphabetic words [22].

Another interesting imaging result of the present study is that the more anterior, medial area (x = -36, y = -40, z = -12) of the left fusiform gyrus is involved in the repetition suppression in case of cross script condition. This cross script related site of the present study lies further along 14 mm in the posterior temporal region. A study of Thompson-Schill et al. (1999)[23] reported that there was activation reduction of left temporal region (averaged coordinates x = -40, y = -28, z = -12, with standard deviation of y-axis 17 mm) involved in the repeated retrieval of semantic knowledge. The decreased activity in this area during semantic retrieval of primed items may be related to the phenomenon of repetition suppression observed in neurons in anterior-ventral inferotemporal cortex of nonhuman primates [23]. Furthermore, Devlin et al. (2004) [24] reported that reduced activation of the left middle temporal gyrus was found for word pairs with a high degree of semantic overlap. Moreover, according to a previous study of cross script masked priming effect in Japanese by Nakamura et al. (2005)[10], the left middle temporal cortex (x = -48, y = -43, z = -2) was found to be involved in the repetition suppression. They suggested that this activation may correspond to a progressive abstraction process, as is also proposed for object recognition, whereby the raw visual features of stimuli are progressively transformed from perceptual to conceptual. In fact, this part of the left temporal gyrus was reported to be associated with the semantic network. In addition, in the behavioral results of masked priming experiment of Kim and Davis (2002)[25], they have shown priming effect of Hangul-Hanja prime-target relations. It was also suggested that this priming effect was occured at the semantic level. They further postulated that the facilitation due to priming depends upon the semantic process, which should be happening with the lexical information simultaneously (Kim and Davis, 2002). Taken together, the result of the present study due to cross script repetition suppression in the anterior part of fusiform gyrus seems to be related to the semantic representation influenced by subliminal primes, even though the activity reduction area of the present study lies closer to the occipital region compared to aforementioned previous studies. It seems that this region is related with the anterior-posterior progression in word processing. In terms of this interpretation one point should be considered. As Nakamura et al. (2005) [10] have mentioned in their study, some cautious approaches should be made due to this interpretation. The posterior temporal activity reduction due to repeated items could include the effect of motor congruity as a potential confounding variable, which is inflated by response association learned through repeated exposure to the same items). The result of the present study indicating that the stronger priming effect in case of prime Hanja, target Hangul condition may lead to an similar interpretation of them, since the subliminal primes in Hanja and their orthography-to-lexicon route seem to be activated ultimately by the phonological route of visible target words in Hangul.

References

1. Price, C.J.: The anatomy of language: contributions from functional neuroimaging. J. Anat. 3, 335–359 (2000)
2. Demonet, J.E., Chollet, F., Ramsay, S., Cardebat, D., Nespoulus, J.N., Wise, R., Rascol, A., Frackowiak, R.: The anatomy of phonological and semantic processing in normal subjects. Brain 115, 1753–1768 (1992)

3. Bookheimer, S.: Functional MRI of language: New approaches to understanding the cortical organization of semantic processing. Ann. Rev. Neurosci. 25, 151–188 (2002)
4. de Zubicaray, G.I., Wilson, S.J., McMahon, K.L., Muthiah, S.: The semantic interference effect in the picture-word paradigm: An event-related fMRI study employing overt responses. Human Brain Mapping 14, 218–227 (2001)
5. Tzeng, O., Hung, D., Cotton, B., Wang, W.S.-Y.: Visual lateralisation effect in reading Chinese characters. Nature 282, 499–501 (1979)
6. Ding, G., Perry, C., Peng, D., Ma, L., Li, D., Xu, S., Luo, Q., Xu, D., Yang, J.: Neural mechanisms underlying semantic and orthographic processing in Chinese-English bilinguals. NeuroReport 14, 1557–1562 (2003)
7. Tan, L.H., Spinks, J.A., Gao, J.-H., Liu, H.-L., Perfetti, C.A., Xiong, J., Stofer, K.A., Pu, Y., Liu, Y., Fox, P.T.: Brain activation in the processing of Chinese characters and words: a functional MRI study. Human Brain Mapping 10, 16–27 (2000)
8. Wang, M., Koda, K., Perfetti, C.A.: Alphabetic and nonalphabetic L1 effects in English word identification: a comparison of Korean and Chinese English L2 learners. Cognition 87, 129–149 (2003)
9. Kim, H., Na, D.: Dissociation of pure Korean words and Chinese-derivative words in phonological dysgraphia. Brain and Language 74, 134–137 (2000)
10. Nakamura, K., Dehaene, S., Jobert, A., Le Bihan, D., Kouider, S.: Subliminal Convergence of Kanji and Kana Words: Further Evidence for Functional Parcellation of the Posterior Temporal Cortex in Visual Word Perception. J. Cog. Neurosci. 17(6), 954–968 (2005)
11. Gusnard, D., Raichle, M.: Searching for a baseline: functional imaging and the resting human brain. Nat. Rev., Neurosci. 2, 685–694 (2001)
12. Kuo, W., Yeh, T.C., Duann, J.-R., Wu, Y.-T., Ho, L.-W., Hung, D., Tzeng, O.J.L., Hsieh, J.-C.: A left-lateralized network for reading Chinese words: a 3 T fMRI study. NeuroReport 12, 3997–4001 (2001)
13. Tan, L.H., Liu, H.-L., Perfetti, C.A., Spinks, J.A., Fox, P.T., Gao, J.-H.: The neural system underlying Chinese logograph reading. NeuroImage 13, 836–846 (2001)
14. Chee, M., Tan, E., Thiel, T.: Mandarin and English single word processing studies with functional magnetic resonance imaging. J. Neurosci. 19, 3050–3056 (1999)
15. Chee, M.W., Weekes, B., Lee, K.M., Soon, C.S., Schreiber, A., Hoon, J.J., Chee, M.: Overlap and dissociation of semantic processing of Chinese characters, English words, and pictures: evidence from fMRI. NeuroImage 12, 392–403 (2000)
16. Zhang, W., Feng, L.: Interhemispheric interaction affected by identification of Chinese characters. Brain and Cognition 39, 93–99 (1999)
17. Mathews, P.M., Adcock, J., Chen, Y., Fu, S., Devlin, J.T., Rushworth, M.F.S., Smith, S., Beckmann, C., Iversen, S.: Towards understanding language organization in the brain using fMRI. Human Brain Mapping 18, 239–247 (2003)
18. Courtney, S.M., Petit, L., Maisog, J.M., Ungeleider, L.G., Haxby, J.V.: An area specialized for spatial working memory in human frontal cortex. Science 279, 1347–1351 (1998)
19. Owen, A.M., Doyon, J., Petrides, M., Evans, A.C.: Planning and spatial-working memory: A positron emission tomography study in humans. Eur. J. Neurosci. 8, 353–364 (1996)