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An fMRI study of Chinese character reading and picture naming by native Korean speakers

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Abstract

Chinese characters appear in the currently used Korean language, and the system used for writing system the Korean language consists of a mixture of the Korean alphabet and Chinese characters. In the present study, neural mechanisms involved in reading a single Chinese character words and naming pictures by Korean native speakers were investigated using a functional magnetic resonance imaging technique. The findings show a right hemispheric dominance within the occipito-temporal and the left middle/medial frontal area for both reading Chinese characters and naming pictures. This should reflect the specific visual processing of reading Chinese characters. Additional activations in inferior frontal and cingulage gyrus were also observed. The activations of inferior parietal region and thalamus are of interest, since we assume that these activations are strongly related to the phonological status of single Chinese character words rather than two character words that are typically used by Korean native speakers.

Keywords: Chinese characters in Korean; Functional magnetic resonance imaging; Lateralisation; Middle frontal cortex; Inferior parietal area; Thalamus

The issue of whether neural mechanisms underlie different pathways in extracting meanings from words and pictures has been widely investigated and debated. At the perceptual level, a visual hemifield superiority exists, for example, the right side for words, and the left for pictures [2]. Studies with split-brain patients indicate that both hemispheres share different functions. It is generally thought that the processing of pictures and words involves different visual lateralisation effects [3].

Many of the cultures of the Asian Pacific region use a similar writing system, namely Chinese characters. Chinese characters are based on the association of meaningful morphemes with graphic units (square, nonlinear configuration), whereas alphabetic systems are based on the association of phonemes with graphemic symbols (having a linear structure) [15]. It has been assumed and proposed that the cognitive processes underlying the reading of Chinese characters may differ from that of alphabetic words and this may also be applied to the cognitive processes of picture perception or identification. Previous studies using a visual hemifield paradigm have demonstrated that the right cerebral hemisphere is more effective in processing single Chinese characters than the left cerebral hemisphere [17]. This leads to a Chinese character–word dissociation hypothesis in lateralisation patterns [7], which has attracted considerable attention because it is generally thought that the left hemisphere is dominant in processing alphabetic words [1].

It is also known that the right hemisphere is specialized for holistic and spatial processing, whereas the left hemisphere is thought to be specialized for analytic, semantic, and phonetic processing. In investigations of this special laterality effect, a number of studies using a functional imaging technique such as PET or fMRI have been carried out with native Chinese speakers [15,7]. Interestingly, the majority of studies indicate that the neural mechanism of Chinese character reading is rather similar to alphabetic-word reading than to picture perception. The studies indicated a left lateralised pattern for the processing of Chinese characters, especially in the inferior frontal region, even

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though more right hemispheric regions, except for the inferior frontal cortex, are involved in the reading of Chinese characters compared with English words [11,8,4].

The currently used Korean writing system consists of a mixture of pure Korean words and Chinese characters. Even though the shape of the Korean alphabet is nonlinear, similar to Chinese characters, Korean letters can be mapped onto phonemes just as English or German letters. Approximately, 70% of the Korean vocabulary can be written either in Korean words or in Chinese characters with the same phonological components. The other 30% of the vocabulary can also be written in Korean words and Chinese characters, but with different phonological components [10]. It is also noteworthy that Korean words are taught, starting in primary school, but Chinese characters are usually taught, starting in the middle school [18]. Furthermore, the use of Chinese characters in South Korea is relatively sparse, i.e. the proportions of Chinese characters in the body of the text in a daily newspaper are about 10% according to statistics for the year 1994 [16], and these proportions have tended to decrease.

Based on the aforementioned characteristics of Chinese characters in the Korean language, an investigation of the neural mechanisms of Chinese character reading by native Korean speakers would be of interest. In a related study [19], we investigated the neural mechanisms of two syllable Korean words and their corresponding Chinese characters, which represent the same pronunciation. The goal of the present study was to investigate the reading mechanisms of single Chinese character words, of which the pronunciation is not identical to those of Korean words having the same meaning. For a direct comparison, we used Chinese characters and pictures that have the same meaning, i.e. the Chinese character for dog and a picture of dog. The aims of the current study were two-fold. First, the study intends to investigate the commonality and difference associated with reading single Chinese character words by native Korean speakers compared to other studies of two Chinese character words. Second, the study attempts to explain the overlap and dissociation mechanisms of reading Chinese characters (linguistic material with specific status) and naming pictures by Korean subjects.

Fourteen healthy right-handed subjects (seven male and seven female having a mean age of 22 years and a standard deviation of 0.8 year) volunteered for the study and did not have a history of medical, neurological or psychiatric illness. After a complete description of the study, written consent was obtained from each volunteer. They were all native Korean speakers with at least three years of Chinese character education in school. They were paid for participating in the experiments. As stimuli, a total of 32 single-word Chinese characters and pictures with a precise meaning (nouns) were chosen. The characters and pictures have the same meanings. There were four stimuli blocks, where a baseline task was placed between the stimuli blocks. Each block consisted of eight single-word Chinese characters and pictures (seven living objects and one non-living object, or seven non-living and one living objects, which were randomly intermixed). Each single-word Chinese character or picture was presented for 2 s followed by a blank screen for 1 s. During the baseline task block, the subjects were presented with eight items of a fixation point. Each fixation point was presented for 2 s followed by a blank screen for 1 s. Each block presentation lasted 24 s. The subjects were instructed to press the left button upon recognition of a living object and the right button for a non-living object on a button box. Each item was presented to the subjects only one time. The presentation of stimuli as well as the measurement of the response time and accuracy were performed by using in-house developed software.

Images were acquired using a 3 T MRI scanner (ISOL Technology, Korea). Following a T1-weighted scout image, high-resolution anatomic images were acquired using an magnetization-prepared rapid gradient echo (MPRAGE) sequence with TE = 3.7 ms, TR = 8.1 ms, flip angle = 8°, and an image size of 256×256. T2*-weighted functional data were acquired using echo planar imaging (EPI) with a TE of 37 ms, a flip angle of 80°, a TR of 3000 ms, and an image size of 64×64. The FOV was 220 mm × 220 mm. We obtained 30-slices of EPI images with a slice thickness of 5 mm and with no gaps between the slices for the entire brain. The image data were analyzed using SPM99 (Wellcome Department of Cognitive Neurology, London). The images for each subject were corrected for motion and realigned using the first scan of the block as a reference. T1 weighted images were coregistered with the mean of the functional scans, then aligned to the SPM T1 template in the Montreal Neurological Institute (MNI) space and these were realigned to the Talairach space [13]. A calculated non-linear transformation was applied to all images for spatial normalization. Finally, the images were smoothed using a 7 mm full-width at half-maximum (FWHM) Gaussian filter. 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. Condition and subject effects were estimated using the general linear model at each voxel in the brain. Significant changes in the hemodynamic response for each subject and condition were assessed using *t*-statistics. For the group analysis, single subject contrast images were analyzed using a random effect model. Contrasts between the single Chinese character and picture perception task were generated and analyzed using a simple *t*-test. Activations were reported if they exceeded a threshold $p < 0.0001$ (uncorrected on the single voxel level) and on an extent level of 10 voxels.

To evaluate laterality effects, peak activation was independently chosen in regions of interest (fusiform area of defined T 1 template) for both hemispheres. In these peak activations, parameter estimates were independently extracted for each subject and then statistically analyzed using the Wilcoxon test.

The average of the response accuracy was 92.5 and the standard deviation was 6.6% for single Chinese characters and those for the pictures were 96.7 and 3%, respectively. A more accurate response was observed for pictures using the paired *t*-test ($p < 0.008$). In addition, longer reaction times for the reading of a single Chinese character (mean: 991 ms, S.D.: 237 ms) than a picture (mean: 851 ms, S.D.: 230 ms) were observed using a paired *t*-test ($p < 0.0001$). In the contrast to the baseline, activa-

Table 1
Results of significant activations ($p < 0.0001$, uncorrected at the single voxel level, $p < 0.05$, corrected at the cluster level)

Contrasts	Cerebral area	Brodmann area and side	x, y, z (mm)	Z-value
Pictures vs. baseline	Fusiform gyrus	37 L	−40, −52, −16	6.39
		37 R	40, −66, −18	5.13
	Middle frontal gyrus	9 L	−46, 18, 34	5.23
Characters vs. baseline	Fusiform gyrus	37 L	−48, −58, −10	6.1
		37 R	48, −60, −16	5.32
	Thalamus		−22, −28, −2	5.43
	Middle frontal gyrus	9 L	−46, 16, 30	4.83
	Inferior frontal gyrus	47 R	36, 28, −4	4.78
	Inferior parietal gyrus	40 R	40, −52, 48	4.55
	Medial frontal gyrus	8 L	−4, 24, 48	4.37
Character minus pictures	Thalamus		20, −8, 16	4.99
	Cingulate gyrus	23/24 L	−8, −20, 36	4.67
	Precentral gyrus	4 L	−42, −18, 36	4.33
	Medial frontal gyrus	6 L	−6, 12, 58	4.16
Pictures minus character	Fusiform gyrus	37 L	38, −62, −14	5.24
		37 R	−28, −64, −14	4.74

Activated areas are presented in Talairach coordinates.

tions of the bilateral fusiform temporal area (BA 37, 19) for both tasks as well as the middle, inferior frontal area (BA 9, 47) were observed. Specific activations for the contrast of the character versus baseline were the thalamus, right inferior parietal, and left medial frontal areas (Table 1, Fig. 1). In addition, Fig. 3 shows the results of laterality for the two experimental conditions. The selected ROI for this evaluation was the temporal fusiform area. Significant right lateralisation effects of activation were found during the experiments with both single Chinese characters and pictures.

In the contrast of picture minus Chinese character, activation of the bilateral fusiform area was observed (BA 37 right; 38, −62, −14; $Z = 5.24$ and BA 19 left; −28, −64, −14; $Z = 4.74$). Chinese character minus picture showed the activation of the thalamus, left hemispheric cingulate gyrus (BA 23/24), left precentral gyrus (BA 4), left medial frontal gyrus (BA 6), and right superior frontal gyrus (BA 6) (Table 1, Fig. 2).

The right lateralised activation pattern of the occipito-temporal areas during the reading of Chinese characters has been reported in previous studies [8]. These areas, such as the fusiform gyrus (BA 37), are thought to be relevant to the processing of the visual properties of Chinese characters (Fig. 3) [15]. Our results are in agreement with the results of previous studies that indicated the right hemisphere dominance of the occipital or temporal visual systems during Chinese character reading. In addition, the pattern of activation of the occipito-temporal area during picture naming appears to underlie a similar visual processing. For both contrasts of the picture minus baseline and the picture minus Chinese character, we observed a right hemisphere dominance of the visual area. The fact that the semantic processing of a picture produced more intense blood oxygenation level dependency (BOLD) signals in the right occipito-temporal areas than the left occipital region was reported in previous fMRI studies [12]. Furthermore, the lateralised fusiform activation is of interest, because the role of this area is somewhat controversial. We would speculate that the right dominant activation of this area is related with the processing of central visual field, which might be connected with the semantic information.

The other meaningful result is the activation of the left hemispheric middle frontal lobe (BA 9) during the naming of pictures, as well as the reading of Chinese characters in our experiment, as shown in Figs. 1 and 2. Based on previous PET or fMRI studies, the activation of this area is known to be involved in the reading of Chinese characters, regardless of whether a single or two character word is used [14,15]. This indicates that the left middle frontal area is recruited as a common region in accessing semantic information in reading Chinese. It appears that the activation of the left hemispheric middle frontal area is related to the perception of the unique square configuration of logographs and their semantic processing [14]. It is further postulated that the middle frontal area (BA 9) is involved in these two cognitive processes such as the perception of a logographic structure and their semantic processing in the case of Chinese character reading [15]. A study by Chee et al. [5] with English–Chinese bilingual subjects indicated that the left frontal area (incl. BA 9) was commonly activated during picture naming and Chinese character reading. The left frontal area should be correlated with the semantic and visual processing of the picture and the Chinese character. Picture naming, according to one model, takes place after accessing structural descriptions and semantic representations of an object [9]. Our results are consistent with this explanation. In our results, the mechanisms associated with the left hemispheric activation of the medial frontal region during character reading appears to be similar mechanisms to that for the middle frontal area [15]. The inferior frontal activation is also of interest. The issue of role of the inferior frontal lobe for reading Chinese characters between

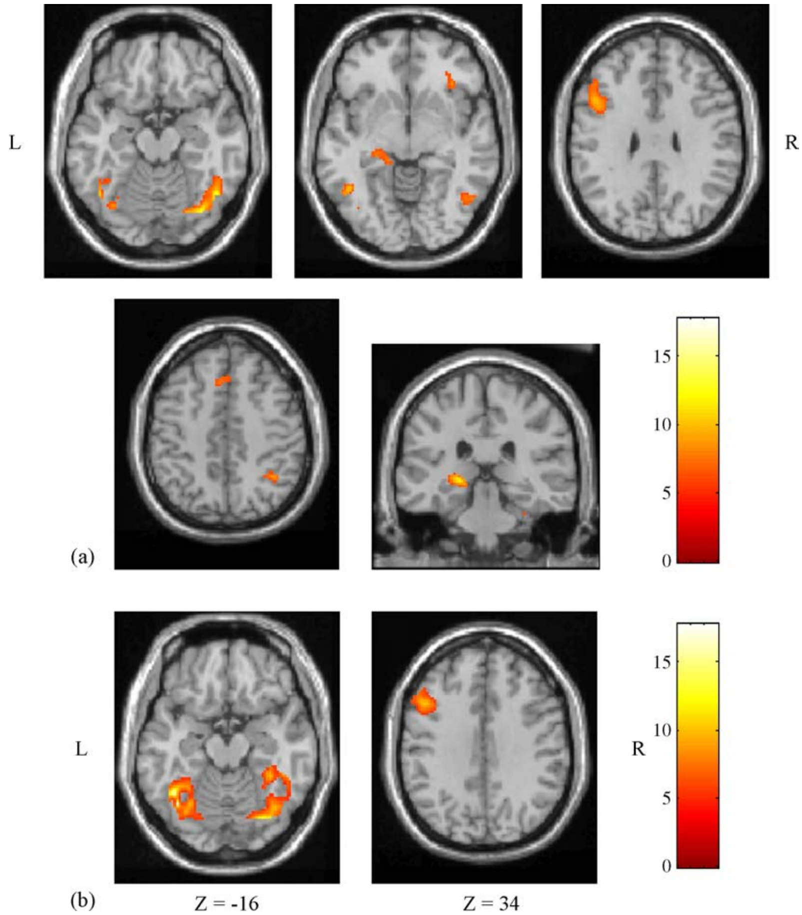

Fig. 1. Activation map for Chinese character vs. baseline (a) and pictures vs. baseline (b) ($p < 0.0001$, uncorrected at the single voxel level). L and R indicate the left and right hemispheric sides.

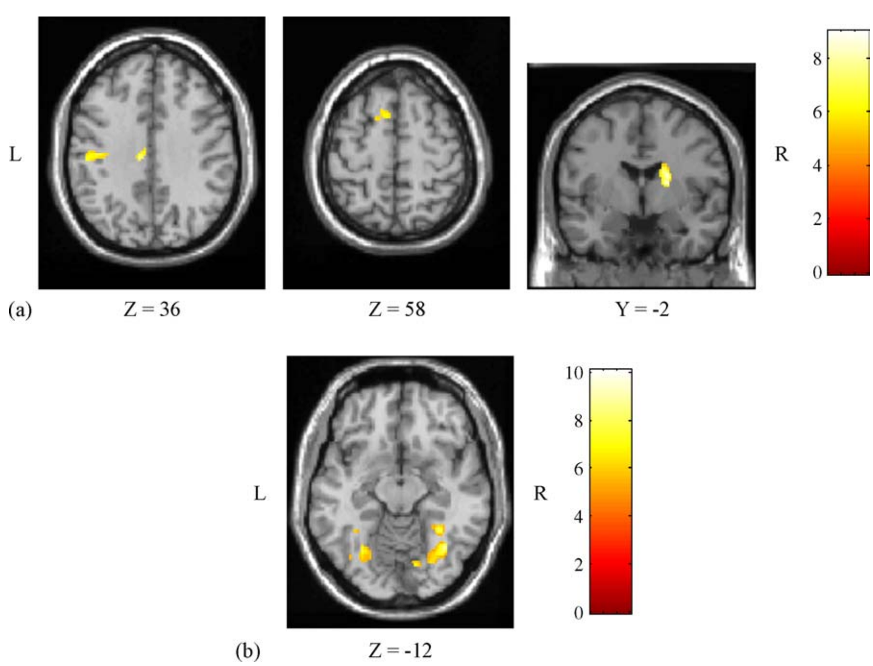

Fig. 2. Activation map for Chinese character minus pictures (a) and pictures minus Chinese characters (b) ($p < 0.0001$, uncorrected at the single voxel level).

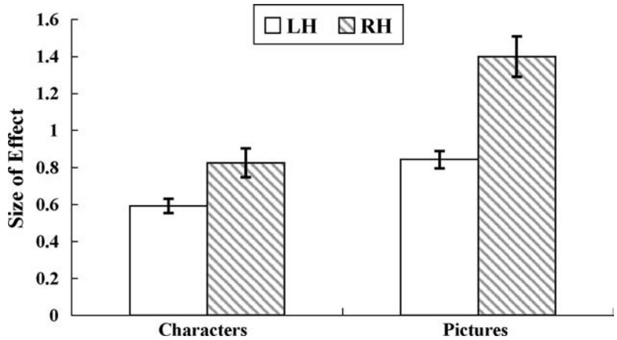

Fig. 3. Comparisons of the size of the effect (parameter estimates) in the left and right fusiform area. For the naming of pictures ($p = 0.004$) and reading of Chinese characters ($p = 0.03$), the activations are right lateralised.

their meanings of phonological and semantic tasks is a subject of debate. It is assumed that, for Chinese characters, there is a learned (and therefore directly addressed) association with meaning in which semantic processing remains important but phonological processing is less so [8]. Activation of the cingulate cortex might be related to the hypothesis that this area plays a prominent role in the executive control of cognition and in the online monitoring and evaluating of performance by detecting cognitive states such as response competition [15]. Our results also show activation of the cingulate cortex, since our subjects were asked to respond after seeing a character (forced choice option).

Activations of inferior parietal region, and thalamus were also observed only for Chinese character reading, in contrasts to both baseline and pictures. The role of the inferior parietal region for word reading is still not clear [8], but it is assumed that this is activated if a performance is novel or (specifically in the context of language) less fluent. The activation of the thalamus might be related to the form perception of Chinese characters. Ding et al. [6] reported in their study with Chinese–English bilinguals that the thalamus was activated only during orthographic processing, and not during a semantic judgment task. The thalamus appears to be connected with the processing of visual information relative to Chinese characters. In our behavioral results, significant longer reaction times and accuracy in reading Chinese characters were observed in comparison with picture naming. One possible explanation for this difference is that the reading or recognition of Chinese characters by our subjects may have been quite unfamiliar compared to a semantic decision as they simply did in the picture naming task. However, this difference might not rely on a so called familiarity effect alone, but may be more related with the phonological processing of single Chinese character of our subjects. Since the reading Chinese characters is based on the syllable-morpheme phonology level, the concept of pre-lexical phonology is misleading [18]. Furthermore, the meaning of single Chinese character words in the Korean language system is not always identical to their phonology (pronunciation), whereas both the meaning and phonology of two-Chinese-character words remain identical. This suggests that our subjects required one more level for a semantic decision by reading single Chinese characters compared to two-character words. We suggest that these specific characteristics of a single Chinese character word in the Korean language might be related to the activation of the inferior parietal lobe and thalamus.

In conclusion, the reading single Chinese character words by Korean subjects seem to be similar to that of two-character words at a general level, i.e. activation of right hemispheric dominant temporo-occipital and left middle/medial frontal lobe. However, some detailed differences also exist in the activation of the inferior parietal area and thalamus. We suggest that this different activation is related to the different phonology level. Indeed, further studies will be needed to clarify this postulation.

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