Available online at www.sciencedirect.com
SCIENCE DIRECT
Neuroscience Letters 373 (2005) 206–211
Neuroscience Letters
www.elsevier.com/locate/neulet

Neural mechanisms of Korean word reading: a functional magnetic resonance imaging study

Hyo Woon Yoon[a,*], Kyung-Duk Cho[b], Jun-Young Chung[c], HyunWook Park[a,c]

[a] *fMRI Laboratory of Brain Science Research Center, Korea Advanced Institute of Science and Technology, Daejeon, South Korea*
[b] *Department of Psychology, Paichai University, Daejeon, South Korea*
[c] *Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea*

Received 19 August 2004; received in revised form 1 October 2004; accepted 4 October 2004

Abstract

The use of functional magnetic resonance imaging permits the collection of brain activation patterns when native Korean speakers (12 persons as subjects) read Korean words and Chinese characters. The Korean language uses both alphabetic Korean words and logographic Chinese characters in its writing system. Our experimental results show that the activation patterns obtained for reading Chinese characters 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. This suggests that the activation pattern for Korean word reading appears to corroborate with that of alphabetic words at the general level. A further noteworthy finding of our study is the strong activation of the posterior part of the right dorsolateral prefrontal cortex (BA 8). The right hemispheric BA 8 belongs to the visual higher order control area and we propose that this area should be responsible for processing of visuospatial (surface form) information of Korean words.

Keywords: Chinese characters; fMRI; Korean words; Posterior part of the right dorsolateral prefrontal cortex; Visual higher order control area

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 [6,22], 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 [1,8]. 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 that the right cerebral hemisphere is more effective in processing Chinese characters than the left cerebral hemisphere [28]. This leads to a Chinese character–word dissociation hypothesis for a liberalization pattern, since word perception is regarded to be left-liberalized. This conclusion has been disrupted, because some more current results of brain activation based on

* Corresponding author. Tel.: +82 42 8698495; fax: +82 42 8698361.
E-mail address: hwyoon@fmri.re.kr (H.W. Yoon).

0304-3940/$ – see front matter © 2004 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.neulet.2004.10.021

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 [9,27].

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 [29]. 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 (Fig. 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 [14]. 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 [25], the proportion of Chinese characters in the body of daily newspapers are about 10% and since then this has continuously diminished. Furthermore, it is important to note that number of years that students are exposed to Chinese characters in Korean schools are shorter than that for Korean words. It can be therefore argued that the familiarity and expertise of Chinese characters and Korean words, Hangul, for young Korean students are not identical. In attempts to overcome this different difficulty/expertise, in this study we used the simplest words written in Chinese characters as stimuli. Words, which are taught in the first year of Chinese character education, were chosen for our experiment. In addition, these words appear relative frequently in the daily newspapers and boulevard magazines. Two syllable Chinese-derivative words were used as stimuli. These can be written, as mentioned above, either in the form of Korean words or as Chinese characters with same meaning and pronunciation (Fig. 1).

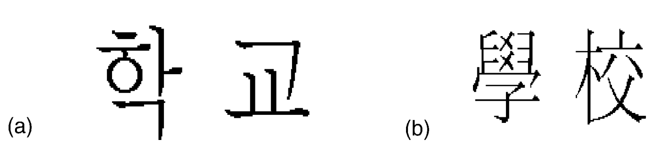

Fig. 1. Examples of experimental stimuli used in the experiments: (a) a two-syllable Korean word and (b) a two-character words with equivalent phonological and semantic components as (a). Both words (a) and (b) are pronounced /hakyō/, meaning "school". In the experimental task, subjects should covertly pronounce each word and judge if the meaning of a word was abstract or not. Although the Korean words are defined as phonemes, their shape looks similar to the morpheme like Chinese characters, as shown.

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). Due to the different role of Chinese characters in the Korean language compared to Chinese, it is also of interest to investigate the brain activation pattern associated with reading Chinese characters by Korean 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 have 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.

As stimuli, two-character Chinese words and Korean words with equivalent phonetic as well as semantic components were chosen (Fig. 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 s long, followed by a blank screen for 500 ms. Ten different items of this stimulus pattern were presented, including a blank screen for 1 s 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 s. Two kinds of stimuli (Korean words and Chinese characters) and baseline task blocks lasted equally for 21 s 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.

Images were acquired by using 3 T MRI scanner (ISOL Technology, Korea) with a quadrature head coil. 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 image size of 256 × 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 × 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 SPM99 (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. 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) for the task of Korean words and Chinese characters versus baseline. Significance on the cluster level was calculated in consideration of peak activation and extent of the cluster. The threshold for $p < 0.0005$ (uncorrected) at the single voxel level was chosen for the direct comparison of Chinese characters and Korean words. Activations are based on the extent of 10 voxels (Fig. 2).

The mean reaction time for subjects during Korean word reading was 1.01 s (S.D. 325 ms), whereas, for Chinese character reading, it was 1.24 s (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 versus 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 versus 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 versus 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 (Table 1).

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

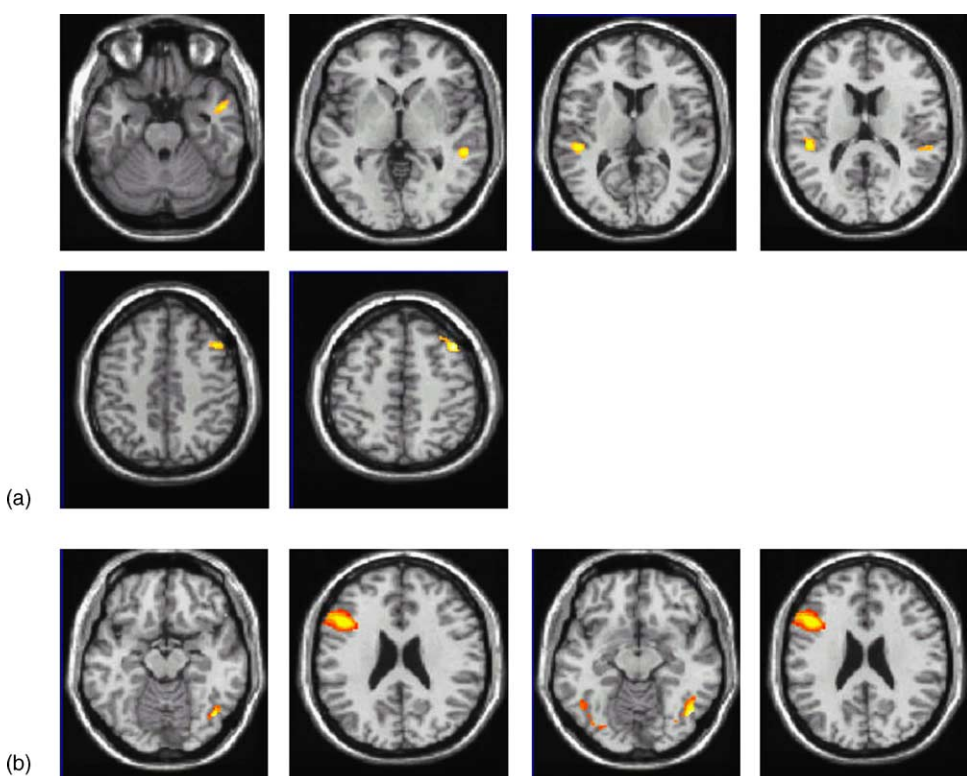

Fig. 2. (a) The activation map "Korean word reading" minus "Chinese character reading" in 12 subjects (threshold at $p < 0.0005$, uncorrected at a single voxel level). (b) The activation map of Korean words minus baseline (left two images) and Chinese character minus baseline (right two images). Threshold *p*-value for (b) is 0.0001 (uncorrected at the single voxel level).

Table 1
Areas of activation for each contrast

	Cerebral area	BA and side	*x*, *y*, *z* (mm)	*Z*-value
Korean words vs. baseline	Fusiform gyrus	19 R	42, −66, −18	6.05
	Fusiform gyrus	37 L	−44, 56, −20	4.45
	Midfrontal gyrus	46 L	−44, 18, 24	5.36
	Medial frontal gyrus	8 R	6, 26, 46	4.94
	Middle frontal gyrus	6 L	−32, 10, 52	4.6
Chinese characters vs. baseline	Fusiform gyrus	19 R	46, −66, −14	5.85
	Fusiform gyrus	19 L	−38, −76, −10	4.44
	Middle frontal gyrus	9 L	−48, 18, 22	4.85
	Superior parietal gyrus	7 L	−26, −50, 46	4.49
	Superior frontal gyrus	6 L	−4, 18, 54	4.49
Chinese characters minus Korean words	Fusiform gyrus	19 R	48, −64, −10	5.75
	Fusiform gyrus	19 L	−34, −40, −24	4.81
Korean words minus Chinese characters	Superior frontal gyrus	8 R	42, 20, 52	4.98
	Superior temporal gyrus	41 L	−46, −30, 12	4.15
	Midtemporal gyrus	21 R	52, 4, −24	3.80
	Precentral gyrus	6 R	20, −18, 62	3.70
	Insula	13 R	50, −34, 20	3.38

Talaraich coordinates (Tal *x*, Tal *y*, Tal *z*) were measured in millimeters. BA indicates for the Brodmann area.

8), the left superior temporal lobe (BA 41), and the right midtemporal lobe (BA 21), 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 [29]. However, in processing Korean words, pre-lexical phonology is activated rapidly and automatically. Reading Korean words for meaning involves pre-lexical information processing [16].

In the functional imaging data, the activated area for the condition of Chinese character versus 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 [2,26]. 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 [3]. 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 [17,30]. More precisely, this area may play a role as a central executive system for working memory, which is responsible for coordination of cognitive resources [5]. 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 [7,19,27].

Left hemispheric middle frontal activations (BA 46/6) were also observed for the condition of Korean words versus baseline and this appears to be correlated with similar mechanisms associated with the reading of other alphabetic words [23]. 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 [7,19], 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 [18].

The activation of the right hemispheric superior frontal lobe (BA 8) was reported in the conditions of Korean words reading minus Chinese character reading as well as the contrast of Korean words versus baseline (Table 2). This area belongs to part of the dorsolateral prefrontal cortex (BA 8 is the posterior portion). The activation of the right dorsolateral prefrontal cortex (or right hemispheric dominance at least) was reported in some working memory studies, in which functional imaging techniques such as PET or fMRI were used [4,11]. However, in our study, the meaning of this area relates more to the visual systems per se. This area is close to the frontal eye field, which is linked anatomically and physiologically with the visual and oculomotor systems [15,20]. In monkey, lesions in BA 8 cause severe impairment of the performance of conditional tasks in which the appropriate visual stimuli must be chosen depending on the particular visual cues presented [10] and this would suggest that BA 8 might play an important role in the selection of specific visual stimuli. Failure on visual conditional tasks following lesions in BA 8 in the monkey may reflect the loss of this visual higher order control [24]. In a comparable study, the activation of BA 8 was reported to be related to language proficiency; this seems to readily rely on the encoding and retrieval of visual nonverbal forms, similar to the processing of shape judgment, and this aspect of visual processing may have placed greater demands on BA 8 [3]. This finding herein suggest that the activation of the right hemispheric BA 8 of our subjects during Korean word reading relies on visual nonverbal higher order control or on the visuospatial analysis of Korean words. This activation seems to be associated with the analysis of the specific surface form of Korean words as well. Superior midtemporal activation was observed in the condition of Korean words minus Chinese characters. According to some previous studies with alphabetic words, the left-lateralized activation of the superior midtemporal area is known to be related to phonological processing [13], and is particularly responsible for fine-grained phonemic analysis [21]. Our results are in general agreement with these previous studies, since we believe that Korean words are phonemes like alphabetic words despite their square-like shape. The activation of insula would be better appreciated under the context of the concomitant of the precentral gyrus (BA 6). The insula and precentral gyrus work in concert in formulating articulatory plans and coordinating speech articulation of alphabetic words [22].

Overall, our results of activation patterns during Chinese character reading seem to involve similar mechanisms to that for native Chinese speakers, e.g., strong activation of the left middle frontal area. The activation pattern of Korean words in our results appears to be corroborated with that of alphabetic words at the general level, but some differences in details were noted, e.g., the right hemispheric dominance of occipital lobe. The right hemispheric activation of the posterior part of the dorsolateral prefrontal cortex would be related to specific higher order visual control or visuo-spatial analysis for Korean words.

In summary, we investigated the neural mechanisms of reading Korean words and Chinese characters by Korean native speakers using a functional magnetic resonance imaging technique. Our results indicate similar mechanisms for reading Chinese characters by our subjects compared to the previous studies with Chinese people. The neural mechanisms for reading Korean words appear similar to that of alphabetic words at a general level, in that activation of right superior frontal area occurs. We suggest that this activation is correlated with the specific visuospatial analysis of reading Korean words. This might reflect the unique character of Korean words. Indeed, further studies will be needed to clarify the neural mechanisms involved in reading Korean words.

Acknowledgement

This study was partly supported by MOST (Korean Ministry of Science and Technology) with Grant No. M10413000002-04N1300-00210.

References

[1] S. Bookheimer, Functional MRI of language: new approaches to understanding the cortical organization of semantic processing, Ann. Rev. Neurosci. 25 (2002) 151–188.

[2] M. Chee, E. Tan, T. Thiel, Mandarin and English single word processing studies with functional magnetic resonance imaging, J. Neurosci. 19 (1999) 3050–3056.

[3] M.W.L. Chee, B. Weekes, K.M. Lee, C.S. Soon, A. Schreiber, J.J. Hoon, M. Chee, Overlap and dissociation of semantic processing of Chinese characters, English words, and pictures: evidence from fMRI, NeuroImage 12 (2000) 392–403.

[4] Y. Chen, S. Fu, S.D. Iversen, S.M. Smith, P.M. Mathews, Testing or dual brain processing routes in reading: a direct contrast of Chinese characters and pinyin reading using fMRI, J. Cogn. Neurosci. 14 (2002) 1088–1098.

[5] S.M. Courtney, L. Petit, J.M. Maisog, L.G. Ungeleider, J.V. Haxby, An area specialized for spatial working memory in human frontal cortex, Science 279 (1998) 1347–1351.

[6] J.E. Demonet, F. Chollet, S. Ramsay, D. Cardebat, J.N. Nespoulus, R. Wise, A. Rascol, R. Frackowiak, The anatomy of phonological and semantic processing in normal subjects, Brain 115 (1992) 1753–1768.

[7] M. D'Esposito, J.A. Detre, D.C. Alsop, R.K. Shin, S. Atlas, M. Grossman, The neural basis of the central executive systems of working memory, Nature 378 (1995) 279–281.

[8] G.I. de Zubicaray, S.J. Wilson, K.L. McMahon, S. Muthiah, The semantic interference effect in the picture-word paradigm: An event-related fMRI study employing overt responses, Human Brain Mapp. 14 (2001) 218–227.
[9] G. Ding, C. Perry, D. Peng, L. Ma, D. Li, S. Xu, Q. Luo, D. Xu, J. Yang, Neural mechanisms underlying semantic and orthographic processing in Chinese–English bilinguals, NeuroReport 14 (2003) 1557–1562.
[10] P.T. Fox, J.M. Fox, M.E. Raichle, R.M. Burde, The role of cerebral cortex in the generation of voluntary saccades: a positron emission tomography study, J. Neurophysiol. 54 (1985) 348–369.
[11] S. Fu, Y. Cheng, S. Smith, S. Iversen, P.M. Mathews, Effects of word form on brain processing of written Chinese, NeuroImage 17 (2002) 1538–1548.
[13] U. Halsband, R. Passingham, The role of premotor and parietal cortex in the direction of action, Brain Res. 240 (1982) 368–372.
[14] H. Kim, D. Na, Dissociation of pure Korean words and Chinese-derivative words in phonological dysgraphia, Brain Lang. 74 (2000) 134–137.
[15] J.J. Kim, M.S. Kim, J.S. Lee, D.S. Lee, M.C. Lee, J.S. Kwon, Dissociation of working memory processing associated with native and second languages: PET investigation, NeuroImage 15 (2002) 879–891.
[16] W.-J. Kuo, T.-C. Yeh, J.-R. Duann, Y.-T. Wu, L.-W. Ho, D. Hung, O.J.L. Tzeng, J.-C. Hsieh, A left-lateralized network for reading Chinese words: a 3 T fMRI study, NeuroReport 12 (2001) 3997–4001.
[17] P.M. Mathews, J. Adcock, Y. Chen, S. Fu, J.T. Devlin, M.F.S. Rushworth, S. Smith, C. Beckmann, S. Iversen, Towards understanding language organization in the brain using fMRI, Human Brain Mapp. 18 (2003) 239–247.
[18] C.J. Moore, C.J. Price, Three distinct ventral occipitotemporal regions for reading and object naming, NeuroImage 10 (1998) 181–192.
[19] A.M. Owen, J. Doyon, M. Petrides, A.C. Evans, Planning and spatial-working memory: a positron emission tomography study in humans, Eur. J. Neurosci. 8 (1996) 353–364.
[20] M. Petrides, B. Alivisatos, A.C. Evans, Functional activation of the human ventrolateral frontal cortex during mnemonic retrieval of verbal information, Proc. Natl. Acad. Sci. U.S.A. 92 (1995) 5803–5807.
[21] M. Petrides, B. Alivisatos, A.C. Evans, E. Meyer, Dissociation of human mid-dorsolateral frontal cortex in memory processing, Proc. Natl. Acad. Sci. U.S.A. 90 (1993) 873–877.
[22] C.J. Price, The anatomy of language: contributions from functional neuroimaging, J. Anat. 3 (2000) 335–359.
[23] A. Sevestianov, B. Horwitz, V. Nechaev, R. Williams, S. Fromm, A.R. Braun, fMRI study comparing names versus pictures of objects, Human Brain Mapp. 16 (2002) 168–175.
[24] G.B. Shanton, S.Y. Deng, M.E. Goldberg, N.T. McMullen, Cytoarchitectural characteristic of the frontal eye fields in macaque monkeys, J. Comp. Neurol. 282 (1989) 415–427.
[25] J. Talairach, P. Tournoux, Co-planar Stereotaxic Atlas of the Human Brain, Thieme, New York, 1988.
[26] L.H. Tan, H.-L. Liu, C.A. Perfetti, J.A. Spinks, P.T. Fox, J.-H. Gao, The neural system underlying Chinese logograph reading, NeuroImage 13 (2001) 836–846.
[27] L.H. Tan, J.A. Spinks, J-H. Gao, H-L. Liu, C.A. Perfetti, J. Xiong, K.A. Stofer, Y. Pu, Y. Liu, P.T. Fox, Brain activation in the processing of Chinese characters and words: a functional MRI study, Human Brain Mapp. 10 (2000) 16–27.
[28] O.J.L. Tzeng, D.L. Hung, B. Cotton, W.S.-Y. Wang, Visual lateralisation effect in reading Chinese characters, Nature 282 (1979) 499–501.
[29] M. Wang, K. Koda, C.A. Perfetti, Alphabetic and nonalphabetic L1 effects in English word identification: a comparison of Korean and Chinese English L2 learners, Cognition 87 (2003) 129–149.
[30] W. Zhang, L. Feng, Interhemispheric interaction affected by identification of Chinese characters, Brain Cogn. 39 (1999) 93–99.