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CASE REPORT

Ideographic Alexia without Involvement of the Fusiform Gyrus in a Korean Stroke Patient: A Serial Functional Magnetic Resonance Imaging Study

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Background Korean orthography is composed of Hanja (ideograms) and Hangul (phonograms). Based on previous studies, the fusiform gyrus has been associated with ideogram reading. We examine serial functional magnetic resonance imaging (fMRI) images in a patient exhibiting dissociation of Hanja and Hangul reading to identify brain areas associated with Hanja reading.

Case Report fMRI were taken of a 63-year-old man showing profound Hanja alexia with normal Hangul reading after an acute stroke involving the left frontal and parietal lobes, who later spontaneously recovered his Hanja reading ability. Scans were taken while performing Hanja and Hangul reading tasks on three occasions. As a result, in spite of having profound Hanja alexia, partial activation of the fusiform gyrus was observed on the first fMRI. Serial fMRI scans showed activation of the bilateral middle frontal gyri that increased in parallel with the patient's recovery of Hanja reading.

Conclusions The frontal lobe, not only fusiform gyrus, may play role in reading Hanja, although more evidence is needed.

Key Words alexia, fusiform gyrus, ideogram, phonogram.

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INTRODUCTION

The Korean orthographic system consists of both phonograms (Hangul) and ideograms (Hanja). Hangul is a phonetic alphabet comprised of consonants and vowels that are grouped together to form syllables that generally exhibit regular correspondences between graphemes and phonemes. On the other hand, Hanja is derived from complex Chinese characters with distinct meanings. In this respect, Hanja and Hangul are similar to Kanji (ideograms) and Kana (phonograms), respectively, of the Japanese language. Many Japanese language studies have described dissociations between the neural substrates involved in the reading of Kanji and Kana. For example, difficulty in Kana reading has been associated with lesions of the left angular gyrus, adjacent lateral occipital gyri, deep perisylvian temporoparietal area, and posterior superior temporal gyrus, whereas lesions involving the fusiform gyrus and left posterior inferior temporal cortex have been identified in individuals with difficulty in Kanji reading.[1-4]

The results of some Korean studies on the dissociation between Hangul and Hanja reading have concurred with previous Japanese findings.[5-7] However, the exact brain regions involved in the processing of Hangul and Hanja reading have not been firmly established.[8-10]

The authors conducted serial functional magnetic resonance imaging (fMRI) to identify the areas of the brain associated with Hanja reading by investigating a patient exhibiting Hangul/Hanja reading dissociation after an acute ischemic stroke.

CASE REPORT

A 63-year-old right handed man was admitted because of memory impairment. His past medical history included hypertension and angina of ten years duration, for which he had been placed on regular antihypertensive medication. The patient denied a history of diabetes mellitus, episodes of stroke, or neuropsychological symptoms. He had been educated for 12 years and had learned Hanja at school. His wife said he had no problems reading or writing Hanja before admission. During neurological examinations, he was fully conscious and had a Korean Mini-Mental State Examination score of 22/30. Deficits were observed mainly in the domains of attention, calculation, and immediate memory recall. Interestingly, we found that he was unable to read or write Hanja, but could read Hangul. Hangul writing was partially impaired. In his wife's statement, he did not have any problems reading Hanja and Hangul before this stroke event. Conventional brain MRI revealed an infarct involving the left frontal and parietal lobe including the angular gyrus. Fluorodeoxyglucose positron emission tomography scans showed decrease uptake in these infarcted regions (Fig. 1). There were no additional hypometabolic regions. fMRI and simple language tests were performed two weeks, six weeks, and six months after stroke onset to identify activated brain regions associated with Hanja and Hangul reading in each scan. An implicit reading task was performed during each fMRI scan. Three sets of test were prepared for the fMRI experiment. Each set included ten two-syllable Hanja and Hangul words and each test included 20 words: 10 Hanja and 10 Hangul words, and a total of 30 Hanja and Hangul words were tested in one visit (Supplementary Table 1 in the online-only Data Supplement). After the fMRI, an independent reading and writing task was performed to obtain response times and hit-rates. Written consent was obtained from the study

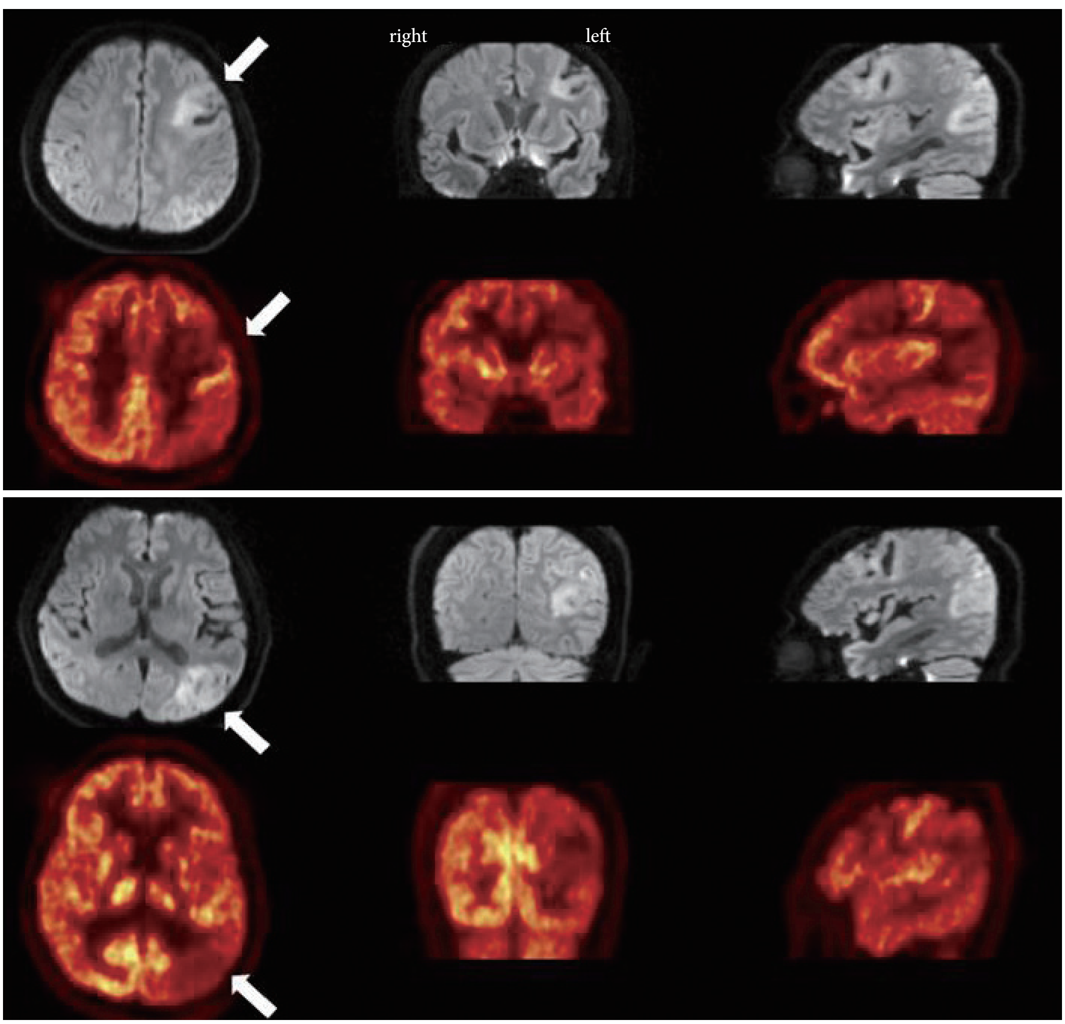

Fig. 1. Diffusion weighted images (upper row) and corresponding FDG-PET CT images (lower row) revealed destructive lesions (white arrow) in the area of left frontal and left parietal lobe. FDG-PET: fluorodeoxyglucose-positron emission tomography.

subject, and the study protocol was approved by the Institutional Review Board (GIRBD 0024-2012) of Gil Medical Center. Detailed fMRI scan protocol and analysis method are described in the Supplementary data (Supplementary data in the online-only Data Supplement).

Hit-rates for Hangul reading were perfect (30/30) at every session for language tasks. The mean response time for Hangul reading improved from 2.8 seconds per letter [standard deviation (SD) 2.1 sec] to 1.03 seconds per letter (SD 0.2 sec) over the 6-month experimental period. In contrast, Hanja reading, Hanja writing and Hangul writing was markedly impaired initially. However, the number of correct hits increased from 8 to 28, and the mean response time for Hanja reading shortened from 3.3 to 1.5 seconds after six months. Hangul agraphia also improved to almost normal; however, Hanja agraphia persisted. The overall results are provided in Fig. 2.

fMRI scans during Hanja reading showed activation of the occipital regions bilaterally including the lingual gyrus, extending to the parietal cortex bilaterally from the prefrontal area, and both insula at the initial time point and six months after the onset of symptoms (Fig. 3, Table 1 and 2). Although the fusiform gyrus was partially activated bilaterally (Fig. 3A, Supplementary Table 2 in the online-only Data Supplement), the patient could not read Hanja. At six months after symptom onset, his ability to read Hanja greatly improved; however fMRI revealed no significant changes in the fusiform gyrus region (Fig. 3B). Instead, both middle frontal gyri showed significantly greater activation after six months (Fig. 4, Table 3).

DISCUSSION

Several models have been proposed to explain the mechanisms related to reading and brain localization. The dual route of phonogram-ideogram processing is one such model, which has been predominantly studied for Japanese.[1]

Two different orthographic systems exist in the Japanese

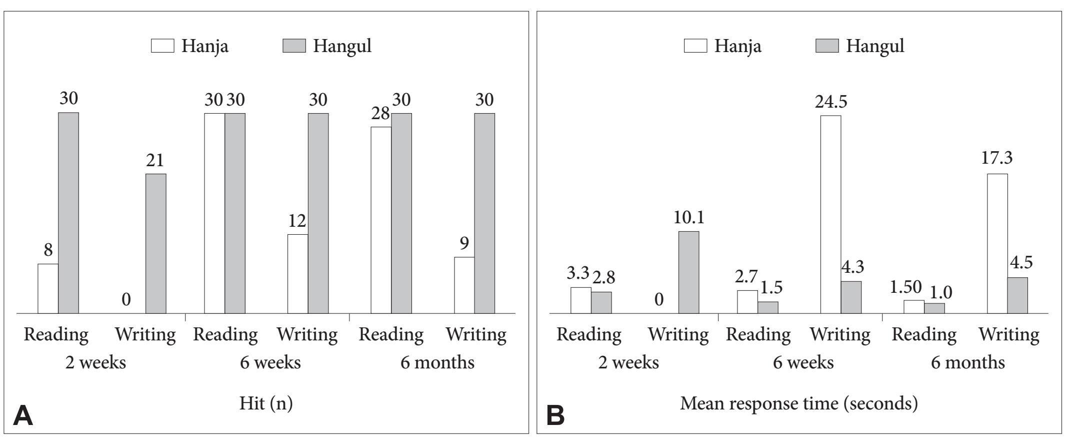

Fig. 2. Language tasks presented as a bar chart at time of 2 weeks, 6 weeks and 6 months after the symptom onset. A: Total number of hits (correct) during the reading and writing of Hanja and Hangul. B: Mean response time for the same test.

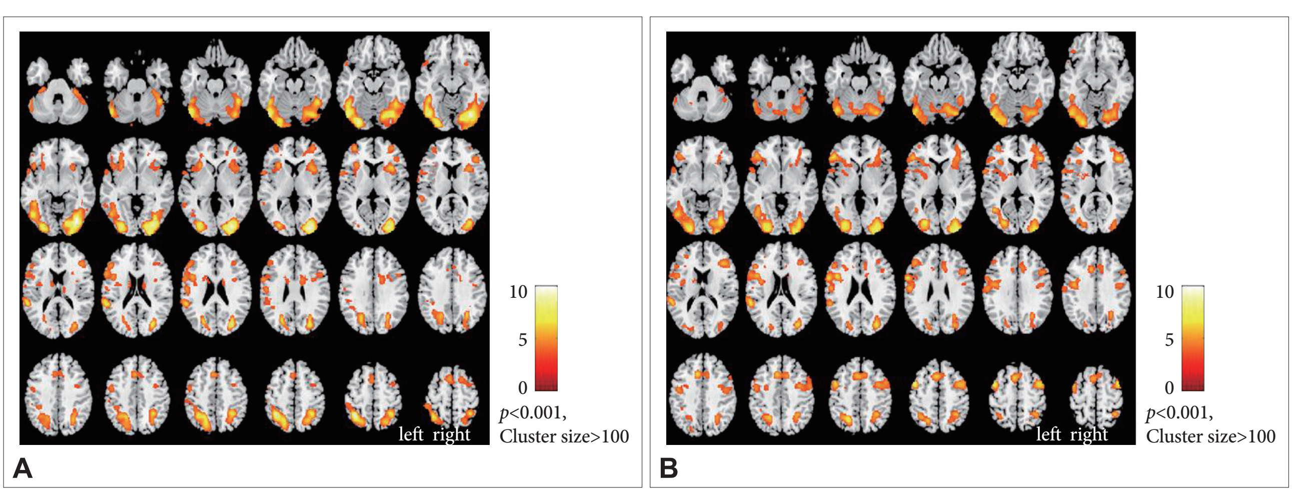

Fig. 3. The activation areas for “Hanja reading” minus “baseline” (A) at 2 weeks and (B) at 6 months after the symptom onset (Threshold at $p<0.001$, uncorrected, cluster size >100).

language [i.e., Kanji (ideogram) and Kana (phonogram)]. Although the correlation between Kanji and Kana is not straightforward, it is generally believed that the anatomical substrates mediating ideograms and phonograms differ. Thus Japanese alexia patients sometimes show dissociative disturbances when reading Kanji or Kana. Lesion studies have shown that angular gyrus involvement more frequently leads to difficulty reading Kana, whereas patients with lesions in the posterior inferior temporal lobe, including the fusiform gyrus, are likely to develop difficulty reading Kanji. These studies also suggest that the anatomical pathways mediating ideograms and phonograms differ, that is, the ventral pathway (posterior portions of the middle and inferior temporal gyri) is involved in reading ideograms[2,4,11,12] and the dorsal pathway (inferior parietal lobe) is used in reading phonograms.[1,3,13] Similar findings have been reported on the dissociative reading disturbances seen in lesion case studies regarding Korean orthography. Two patients with Hanja alexia had a lesion in the left posterior inferior temporal lobe,[6,7] while one case of Hangul alexia was associated with a lesion in the inferior parietal lobule, insula and cingulate gyrus.[7] Another fMRI study in Korean speaking volunteers showed that the right fusiform gyrus and adjacent temporo-occipital region seem to be more specifically involved in processing Hanja script.[8]

Our patient also showed a dissociative disturbance between reading Hanja and Hangul. MRI scans showed two distinct ischemic lesions in the left middle frontal gyrus and left inferior parietal lobe with preservation of the posterior inferior temporal cortex, which is supposed to be the anatomical substrate for ideogram reading. Nevertheless, he initially presented with severe Hanja alexia and normal Hangul reading. The areas with increased signal on fMRI during Hanja reading were mainly occipital and frontal regions bilaterally rather than the inferior occipito-temporal region, such as the fusiform gyrus.

Table 1. Activated areas of “Hanja reading” compared to “baseline” at 2 weeks after stroke onset

Region	Side	Extents (K_E)	x, y, z (mm)	Z-value
Hanja minus baseline				
Inferior occipital gyrus	Right	7548	36, -74, -10	>8
Inferior parietal gyrus	Left	3139	-36, -51, 56	>8
Lingual gyrus	Left	3562	-28, -86, -16	>8
Superior temporal gyrus	Left	2682	-58, -38, 18	7.15
Insula	Right	758	34, 18, 8	5.97
Middle frontal gyrus	Left	188	-36, 52, 8	5.58
Supplementary motor area	Left	1734	-4, 20, 46	5.40
Inferior frontal gyrus	Right	303	44, 32, 14	5.20
Cerebellum	Left	402	-30, -28, -34	5.02
Middle frontal gyrus	Right	285	34, 52, 6	4.92
Precentral gyrus	Left	147	-50, -2, 46	4.32
Caudate	Left	141	-12, -6, -16	3.70

It represents corresponding image series in Fig. 3A. Threshold at $p<0.001$, uncorrected, cluster size >100. MNI coordinates (x, y, z) were measured in millimeters.
MNI: Montreal Neurological Institute.

Table 2. Activated areas of “Hanja reading” compared to “baseline” at 6 months after stroke onset

Region	Side	Extents (K_E)	x, y, z (mm)	Z-value
Hanja minus baseline				
Middle frontal gyrus	Left	3916	-46, 4, 52	>8
Middle occipital gyrus	Right	5399	32, -96, 4	>8
Middle occipital gyrus	Left	4634	-26, -82, 4	7.69
Inferior frontal gyrus	Right	1349	40, 30, 12	6.59
Middle frontal gyrus	Right	1392	40, 6, 58	6.46
Superior temporal gyrus	Left	345	-58, -36, 18	6.42
Superior frontal gyrus (medial part)	Left	1404	-10, 20, 40	6.31
Middle frontal gyrus	Left	169	-36, 48, 8	4.85

It represents corresponding image series in Fig. 3B. Threshold at $p<0.001$, uncorrected, cluster size >100. MNI coordinates (x, y, z) were measured in millimeters.
MNI: Montreal Neurological Institute.

In addition, as the patient's Hanja alexia improved, activation increased in both middle frontal gyri.

These findings, 1) initial profound Hanja alexia with a destructive lesion involving the left frontal lobe and 2) improved Hanja alexia with increased fMRI activation in both middle frontal gyri, suggest the possibility that the frontal lobe, as well as the fusiform gyrus, could contribute to mediating Korean ideogram reading.

Differences exist between the usage, exposure rate, and age of acquisition of the Korean and Japanese ideographic systems. In contrast to Japanese orthography which heavily incorporates the usage of Kanji, the Korean system depends less on Chinese derived characters, and most Korean words and sentences can be communicated without the use of any ideograms (Hanja). Also the same ideograms in Japanese can be pronounced in different ways, which is not the case in Korean.[5,7] For these reasons, the two language systems may show different patterns of brain activation when ideograms and phonograms are read.

It is difficult to designate the exact location associated with Hanja alexia in this study, due to the fact that two ischemic lesions were concomitantly present. An fMRI study conducted on normal Korean subjects revealed strong activation in the left lateralized middle frontal cortex during Chinese character reading.[9,10] Chinese investigators observed a wide area of activation associated with Chinese letter reading including the left frontal and temporal cortices, the right visual system including the fusiform gyrus, the right parietal lobe and cerebellum.[14-16] Different regions where associated with reading Chinese characters by Korean (Hanja) and Chinese native speakers; however, both groups showed activation in the left frontal area.

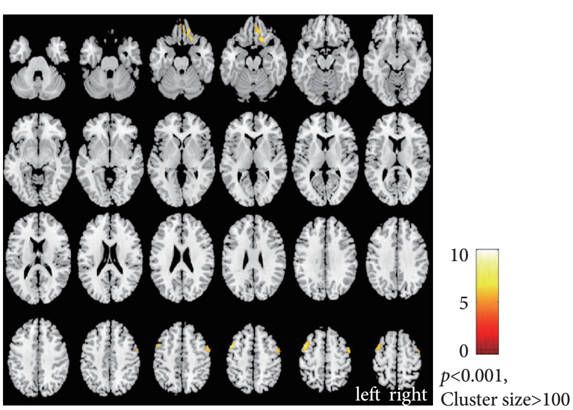

Fig. 4. The middle frontal gyrus bilaterally showed greater activation after six months in parallel with Hanja reading improvement (Threshold at p<0.001, uncorrected, cluster size >100).

Taken together, these studies indicate that different cerebral regions might be associated with reading Chinese characters by Korean (Hanja), Japanese (Kanji) and Chinese native speakers. In the case of Korean orthography, different results have been reported regarding the areas involved in processing ideograms, which are similar to Japanese[6-8] and Chinese[9,10] populations. Our case study supports that the frontal lobe might play a role in reading Korean ideograms.

Increasing activation in the bilateral middle frontal gyri in parallel with Hanja reading improvements may also represent the activation of language restorative processes from perilesional areas or compensatory processes from contralateral neural circuits post stroke.[17] However, because this study was conducted on one subject, we cannot comment on the statistical significance of our findings.

Our study has some limitations. First, the presence of two lesions in the left cerebral hemisphere makes it difficult to conclude which is causative of his dissociative alexia. The analysis of additional subjects with single lesions associated with ideographic alexia would be needed to answer these questions. Second, there were no fMRI data on a control group to determine the normal substrates dissociating the two systems. Third, detailed error analysis of mistaken words was not fully performed. However, our subject showed either fully normal reading or no responses attempted and error analysis was inadequate. Finally, functional and neurophysiological changes after ischemic stroke, for example diaschisis, need to be considered when interpreting the fMRI results.

In conclusion, we found that not only fusiform gyrus, but also the frontal lobe may be involved in reading Hanja (Korean ideograms) after analyzing serial fMRI scans of a patient presenting with dissociative Hanja alexia after an acute ischemic stroke.

Table 3. The different activated areas for Hanja reading between two times of 2 weeks and 6 months after stroke onset

	Region	Side	Extents (K_E)	x, y, z (mm)	Z-value
(Hanja > baseline) at 6 months minus (Hanja > baseline) at 2 weeks	Middle frontal gyrus	Left	167	-44, 8, 52	5.35
	Superior frontal gyrus (orbital part)	Right	170	12, 38, -24	5.09
	Middle frontal gyrus	Right	124	50, 0 ,56	3.93

It represents corresponding image series in Fig. 4. Threshold at p<0.001, uncorrected, cluster size >100. MNI coordinates (x, y, z) were measured in millimeters.
MNI: Montreal Neurological Institute.

Conflicts of Interest

The authors have no financial conflicts of interest.

Acknowledgements

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