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An Electrophysiological Study of Hemispheric Asymmetry in Recognizing Two Korean Scripts: The Effects of Hanja Proficiency*

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Reading the Korean Hanja (logographic) and Hangul (alphabetic) scripts invokes different underlying neural mechanisms based on the degree of grapheme-to-phoneme correspondence (GPC) in the two scripts. This study examined the distinct brain asymmetries in processing Hanja and Hangul scripts of the Korean language according to the Hanja proficiency levels of Korean native speakers. Twenty-five participants were divided into two groups according to their Hanja proficiency levels: High and low groups. Participants performed a lexical decision task (LDT) during the electroencephalogram (EEG) recording. Results revealed differential brain asymmetry patterns according to the participants' Hanja proficiency levels. The high Hanja proficiency (HP) group showed a larger N400 lexicality effect in the right hemisphere, whereas the low Hanja proficiency (LP) group showed a larger N400 lexicality effect in the left hemisphere during Hanja script recognition. However, no distinct hemispheric asymmetry was observed according to Hanja proficiency levels when participants processed words written in Hangul script. These findings indicate that the processing of Korean Hanja script involves distinct neural processes distinguished from Hangul script processing, whereby different hemispheric specializations are involved according to the Hanja proficiency level of the reader.

Key words : grapheme-to-phoneme correspondence (GPC), event-related potential (ERP), N400 lexicality effect, visual word recognition, Hanja proficiency

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For many decades, hemispheric specialization was thought to involve a left hemisphere dominance for all language processes and a right hemisphere dominance for other cognitive processes. However, recent studies have shown evidence where hemispheric dominance varies depending on the language being processed (Hellige, 1993). Many previous studies have documented the degree of hemispheric specialization in language processing according to the different psycholinguistic characteristics of stimuli. (Chiarello, Liu, & Shears, 2001; Chiarello, Shears, Liu, & Kacinik, 2005; Frost & Katz, 1989). One of the important variables discussed in the literature is the type of grapheme-to-phoneme correspondence (GPC), which is the degree of regularity during the translation of orthography to phonology (Cousin, Perrone, & Baciu, 2009; Cousin, Peyrin, & Baciu, 2006; Simon, Bernard, Lalonde, & Rebaï, 2006). For instance, a transparent GPC script adheres to GPC rules and therefore has a regular relationship between orthography and phonology. Hence, the phonological information can be easily mapped onto the orthographic information of the word during word recognition. In contrast, if the script violates the GPC rule, then it has an irregular relationship between orthography and the sounds of words. This is considered to be an opaque script and is usually processed by visual-orthographic forms (Katz & Feldman, 1981; Turvey, Feldman, & Lukatela++, 1984).

In a previous study (Beaton, Suller, & Workman, 2007) involving Welsh words have demonstrated that Welsh words have greater left hemisphere superiority with relatively high transparent GPC compared to English words, which are characterized as having relatively opaque GPC. A Chinese character study (Tzeng, Hung, Cotton, & Wang, 1979) also verified things of GPC and its relation to hemisphere asymmetry in that the right hemisphere is closely related to the processing logographic scripts which have inconsistent letter-sound relationships. Moreover, previous findings have argued that the left hemisphere is related to phonological processing, while the right hemisphere is mainly related to orthographic processing (Halderman & Chiarello, 2005). Consequently, these studies support the hypothesis that GPC can largely influence the magnitude of hemispheric asymmetry in linguistic processing. Moreover, due to the left hemisphere dominance for phonological processing, hemispheric specialization for transparent GPC scripts is assumed to be lateralized in the left hemisphere. In contrast, the opaque GPC scripts are assumed to be more right hemisphere lateralized because visual stimuli are believed to be predominantly processed in the right hemisphere.

Previous studies have investigated the brain asymmetry during the reading of Kana versus Kanji scripts in Japanese. The Kana script is characterized as an alphabetic script that has somewhat transparent GPC, whereas the Kanji script is categorized as being a logographic script with relatively opaque GPC. A neuroimaging study (Nakamura, et al., 2005) also investigated differential hemispheric dominance using functional magnetic resonance imaging (fMRI), and the results revealed a right-lateralized activation for logograms and objects, whereas a left-lateralized activation was found for phonogram stimuli during a word-naming task.

Similar to the Japanese language, the Korean language also has two different written scripts. The Hanja (logographic) script is classified as having relatively opaque GPC, whereas the Hangul (alphabetic) script is identified as having transparent GPC. In a cortical asymmetry study, Lee and Carter (1988) found left hemisphere superiority in processing the Hangul script. Moreover, an event-related potential (ERP) study investigating the hemispheric asymmetry in the two Korean writing systems revealed a different hemispheric specialization according to the degree of GPC of the two Korean scripts (Jang & Nam, 2013). The results showed that the Hanja script had a larger N400 lexicality effect in the right hemisphere over the left. The N400 component of the ERP refers to a negative voltage shift in the averaged signal amplitude starting at around 250 ms and peaking at approximately 400 ms after stimulus onset (Kutas & Hillyard, 1980). The amplitude of the N400 component shows a larger negativity when the presented stimuli are semantically unexpected than when the stimuli are readily expected. Moreover, the N400 effect is sensitive to lexicality, word frequency, word concreteness, orthographic neighborhood size, and many things (Van Petten & Luka, 2006). The result observed in Jang and Nam (2013) is in line with previous behavioral studies of hemispheric asymmetry which demonstrated that the hemispheric specialization of language is dependent upon the type of GPC (Cousin, Perrone, & Baciu, 2009; Cousin, Peyrin, & Baciu, 2006).

There is a difference in Hanja script processing according to the proficiency levels of the reader. When individuals with higher Hanja proficiency access the semantic information of Hanja script, the phonological inform ation does not seem to play a critical role in processing words written in Hana script. In contrast, individuals with lower Hanja proficiency seem to access semantics via phonological information when processing words written in Hanja scripts (Cho & Chen, 1999). These results highlight not only the different roles of phonology during Hanja and Hangul script processing, but also the different use of phonological information between the Hanja HP and LP groups.

Although the two Korean written scripts, Hangul and Hanja, may have the same pronunciation and meaning, they have distinct orthographic forms. Hence, just as many previous studies have documented the influence of the second language on the first language processing (Pavlenko, 2000), learning and the use of the Hanja script could influence Hangul script recognition of Korean native speakers. Individuals who began to learning and using Hanja script fairly early in their lives may process Hanja scripts in the same way as they process Hangul scripts. Since phonological processing has been ruled out in recognizing the Hanja script, individuals may process Hangul script without using its phonological information.

The main purpose of this study was to examine the hemispheric asymmetry involved in the processing of Korean Hanja and Hangul scripts, and whether such hemispheric asymmetry is distinguished according to the participants' Hanja proficiency levels. Although different strategic patterns of Hanja processing by different levels of Hanja proficiency has been previously reported (Cho & Chen, 1999), the neural mechanisms underlying such strategies, and the nature of any distinct hemispheric dominance, remains unclear. In this study, different hemispheric specialization is expected according to different levels of Hanja proficiency. Another important prediction of the present study is that participants who show higher proficiency in Hanja script would show differential hemispheric patterns as compared to those who have low proficiency. Such group differences are expected since earlier exposure to Hanja script might have led to similar patterns of hemispheric activation as in processing words in Hangul script. On the other hand, those who are exposed to Hanja script later in life, hence have lower Hanja proficiency, may show different hemispheric activation compared to those with higher Hanja proficiency during Hanja script processing.

Method

Participant. Twenty-five undergraduate and graduate students (17 men and 8 women) from Korea University participated in the current study. All participants were right-handed and had normal or corrected-to-normal vision with no history of neurological impairment. All participants were asked to take a pre-test prior to the experiment to assess their proficiency in using the Hanja script. Participants were divided into two Hanja proficiency groups according to the test scores obtained from the pre-test: 13 participants (10 men and 3 women) were assigned to high-proficiency group (i.e., HP group), and 11 participants (6 men and 5 women) were assigned to low-proficiency group (i.e., LP group). Those who scored above 70% on the Hanja pre-test were assigned to HP group, and those who scored below 70% were assigned to LP group. The Hanja pre-test score of HP group was significantly higher than that of the LP group ($t(22)$ = 5.188, p <.005). As indicated in Table 1, the age of Hanja script acquisition was earlier in HP group compared to LP group ($t(22)$ = -3.343, p < .05), and the number of hours spent reading Hanja scripts was greater in HP group than in LP group ($t(8)$ = 6.791, p < .001). One male participant in LP group was excluded from further data analysis due to excessive artifacts in his EEG data.

Stimuli. A total of 240 stimuli were used, which consisted of 120 Korean bisyllabic noun words and 120 pseudowords. Stimuli were extracted from the Se-jong corpus (Kang & Kim, 2009), which comprises approximately 15 million Eojeols that can be written in both Hanja and Hangul scripts. Therefore, all Hanja and Hangul scripts stimuli used in this study were semantically and phonologically equivalent. The only difference between Hanja and Hangul stimuli was the degree of GPC within the scripts. For example, 心理 (Hanja) and 심리 (Hangul) in Korean scripts not only have the same meaning ("psychology"), but are also identical in their pronunciations (/sim-li/).

Procedure. The experiment was conducted in a sound-attenuated and electrically shielded room. A chin-rest was used to stabilize the participant's head and eye movements. Stimuli were presented via IBM PC, on a 17" high-resolution monitor that was placed 60 cm away from the participant. The inner and outer edges of the presented stimuli were respectively lateralized 3.3° and 5.7° from the center of the screen. MATLAB (PTB3) was used to display stimuli and to record participants' responses.

The procedure for the experiment was as follows: a fixation cross (+) was presented at the center of the screen for 500 ms, followed by the target script, which was randomly presented in the LVF or RVF for 300 ms. The inter-trial interval (ITI) varied randomly from 2,000 to 3,000 ms. The experimental sessions were divided into Hanja and Hangul sessions, and the order of sessions was counterbalanced across participants. All participants were asked to perform a lexical decision task (LDT) in which they were instructed to press one of the two buttons on the response pad. For each script sessions, participants were told to decide whether the presented stimulus was an appropriate Korean word or not by pressing "Yes" or "No" button. The assignment for response buttons was counterbalanced among participants.

EEG recording and data analysis. The EEG was recorded from a 32-channel system (BrainAmp, Brain Products GmbH, Germany) using an EasyCap with Ag/AgCl electrodes placed according to the International 10–20 system. An electrode was attached below the participants' right eye to monitor the eye movements, and two electrodes were placed on right and left mastoids as reference channels. All electrode impedances were kept below 10 kΩ. An analog band-pass filter of 0.01—100 Hz was applied and the sampling rate was 500 Hz. Reaction times (RT) less or greater than 2 standard deviations (2SD) from the mean and incorrect trials were excluded from the analysis. In order to test the differences in the mean error rate (ER) and the mean RT for both Hangul and Hanja scripts between the left and right hemispheres, a repeated-measure analysis of variance (ANOVA) was conducted with visual field (LVF/RVF) as the within-subject factor and Hanja proficiency (HP/LP) as the between-subject factor.

The EEG data were processed using EEGLAB software (version 9.0.4.5) (Delorme & Makeig, 2004). Data were re-sampled at 250 Hz and an offline band-pass filter of 0.1 to 30 Hz was applied. Epochs were segmented into a time window ranging from 100 ms prior to the onset of the stimulus to 700 ms after stimulus onset. The epochs with voltage values exceeding ±75 uV were rejected, and data were corrected for eye movement artifacts using independent component analysis (ICA) (Vigário, 1997). Electrode sites were clustered into six regions: anterior-left (F3, FC1, FC5), anterior-right (F4, FC2, FC6), central-left (C3, CP1, CP5), central-right (C4, CP2, CP6), posterior-left (P3, P7, O1), and posterior-right (P4, P8, O2). Mean amplitude values from the time windows between 300—500 ms and 500—700 ms were chosen to investigate the N400 lexicality effect (Perre, Midgley, & Ziegler, 2009), and separate repeated-measures ANOVAs were conducted for each electrode cluster (anterior-left, anterior-right, central-left, central-right, posterior-left, posterior-right), with visual field (LVF/RVF) and lexicality (word/pseudoword) as within-subject factors and Hanja proficiency (HP/LP) as the between-subject factor.

Results

Behavioral data. The behavioral data (Table 2) did not show any statistically significant difference between the HP and LP groups for both Hanja and Hangul scripts. Although the error rates for the Hangul scripts failed to show a significant difference between the two visual fields, Hanja scripts showed more

Table 1. Language background measures of participants

	High Hanja Proficiency (HP) Group		Low Hanja Proficiency (LP) Group	
	Mean	SD	Mean	SD
Age of Hanja script acquisition	10.64	3.04	17.27	3.72
Time spent using Hanja script (hours)	20.82	8.70	5.45	2.46
Pre-test score (%)	80.00	3.89	53.45	10.59

Table 2. Behavioral data according to stimuli presented in each visual field

	High Hanja Proficiency (HP) Group				Low Hanja Proficiency (LP) Group			
	LVF		**RVF**		**LVF**		**RVF**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hanja RT (ms)	1151.12	154.44	1209.29	154.04	1297.02	179.67	1371.75	203.69
Hanja ER (%)	17.41	5.72	18.52	3.38	18.15	5.56	25.56	11.18
Hangul RT (ms)	825.65	57.80	813.25	62.30	864.80	79.42	812.91	74.38
Hangul ER (%)	3.33	2.89	2.96	2.61	2.59	1.47	3.33	1.67

accurate performance when they were presented in the LVF ($F(1, 22) = 21.280$, $p < .005$) compared to the RVF. Furthermore, the Hanja scripts elicited faster RTs when they were presented in the LVF ($F(1, 22) = 8.059$, $p < .05$), whereas the RTs for the Hangul scripts did not show such difference between the two visual fields.

ERP data. Fig. 1 and Fig. 2 illustrate the grand averaged waveforms and topographic distributions elicited by Hanja and Hangul scripts for HP and LP groups, respectively. For the analysis of the Hanja scripts, a long-lasting N400 lexicality effect was found in the 300—500 ms ($F(1, 22) = 13.376$, $p < .005$) and 500—700 ms time windows ($F(1, 22) = 9.815$, $p < .005$), showing larger N400 amplitudes for pseudowords than for words.

A 3-way interaction between Hanja proficiency, N400 lexicality effect, and visual field was found in both of these time ranges (300—500 ms: $F(1, 22) = 13.376$, $p < .005$; 500—700 ms: $F(1, 22) = 11.447$, $p < .005$). For the 300—500 ms time window, the simple effects analysis revealed a larger N400 lexicality effect for HP group when the scripts were pres ented in the LVF than in the RVF ($F(1, 12) =$

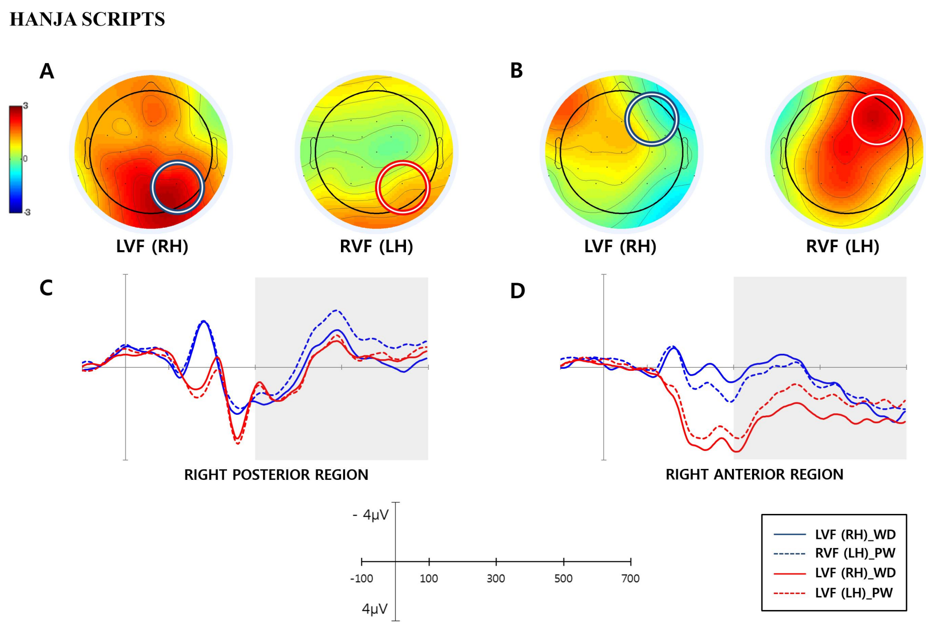

Figure 1. The grand averaged ERPs across 13 participants at 32 channels for Hanja scripts. The topographic distributions of high (A) and low (B) Hanja proficiency groups according to word (WD) and pseudoword (PW) scripts (the N400 lexicality effect) when stimuli were presented in the left visual field (LVF) and the right visual field (RVF), respectively. The grand averaged ERPs at right posterior region are shown (indicated as circles in the topographic distributions) for the high proficiency group (C) and right anterior region is shown for the low proficiency group (D).

7.728, $p < .05$). In contrast, the LP group showed a larger N400 lexicality effect when the stimuli were presented in the RVF than in the LVF ($F(1, 10) = 5.837$, $p < .005$). For the analysis of the 500—700 ms time window, similar N400 lexicality effect was found, although the interaction between the N400 lexicality effect and visual field did not reach statistical significance (HP group: $F(1, 12) = 9.450$, $p < .005$; LP group: $F(1, 10) = 3.205$, $p = .104$).

The Hangul scripts showed a long-lasting N400 lexicality effect in the time range between 300—500 ms ($F(1, 22) = 30.706$, $p <. 005$) and 500—700 ms ($F(1, 22) = 18.256$, $p < .005$), with greater N400 amplitudes for pseudowords than for words. The Hangul scripts, however, did not show any statistically significant interaction between the visual field and N400 lexicality effect, and no group effects were found according to Hanja proficiencies. In sum, no N400 lexically effect was observed

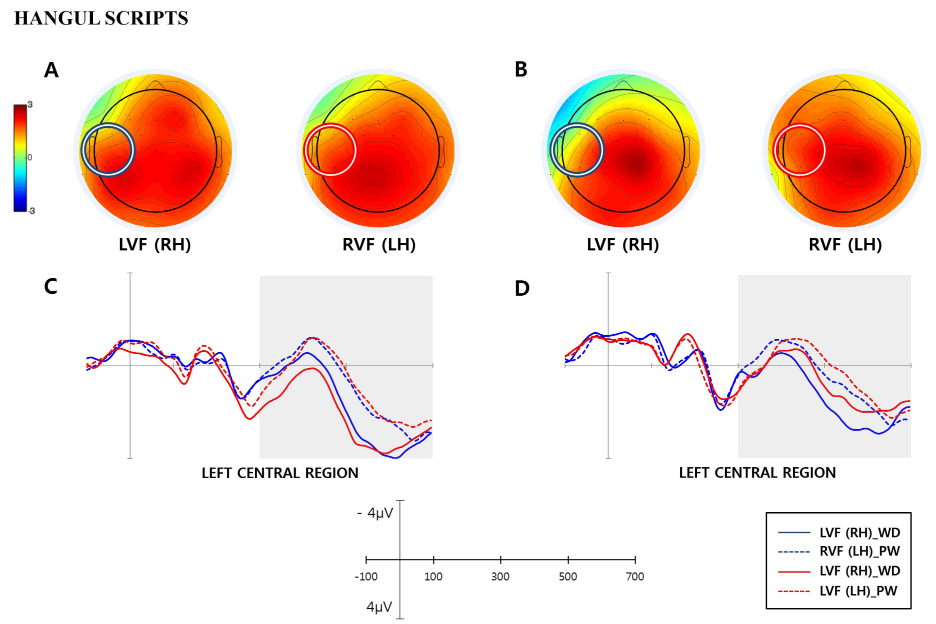

Figure 2. The grand averaged ERPs across 13 participants at 32 channels for Hangul scripts. The topographic distributions of high (A) and low (B) Hanja proficiency groups according to word (WD) and pseudoword (PW) scripts (the N400 lexicality effect) when stimuli were presented in the left visual field (LVF) and the right visual field (RVF), respectively. The grand averaged ERPs at left central region (indicated as circles in the topographic distributions) are shown for the high (C) and low (D) proficiency groups.

between the two visual fields when stimuli were presented in Hangul scripts, and the results were not affected by the Hanja proficiency level of the participants.

An interaction between visual field and electrode region for both Hanja and Hangul scripts was found in the time range of 100—300 ms for the anterior electrode clusters only. The basis of this interaction was that the waveforms elicited at electrodes contralateral to the visual field of presented stimuli showed greater negativity than did those elicited ipsilateral to the visual field of the stimuli (Hangul script: $F(5, 18) = 21.008$, $p < .005$; Hanja script: $F(5, 18) = 20.890$, $p < .005$).

Discussion

The main purpose of this study was to investigate the brain asymmetries involved in processing two writing systems in the Korean language: Hangul and Hanja. Differential N400 lexicality effects were expected between the two cortical hemispheres according the GPC rule and

Hanja proficiency level when processing Korean words written in Hanja script compared to those written in Hangul script. This study also examined if there was a differential hemispheric activity in processing Hangul script according to the participants' Hanja proficiency levels.

The behavioral results of the current study are in line with the previous study of two Korean scripts (Jang & Nam, 2013), which demonstrated different hemispheric specialization according to language type: Hanja script showed right hemisphere superiority, while no significant hemispheric difference was found for the Hangul script processing. A significant finding of the present study is that although there was no statistically significant difference in the ER and RT between HP and LP groups in the behavioral results, there was a significant group effect according to Hanja proficiency in the electrophysiological results.

In the ERP analyses, an effect of Hanja proficiency was found with different hemispheric specialization between HP and LP groups during the Hanja script recognition. In the analyses of both the 300—500 ms and 500—700 ms time windows, the interaction between the N400 lexicality effect and visual field significantly differed according to Hanja proficiency levels. For HP group, right hemisphere specialization effect was revealed during Hanja script recognition. In contrast, left hemisphere lateralized pattern was observed when LP group processed Hanja scripts. These results are consistent with results shown in previous studies, where right hemisphere specialization was evident in scripts with relatively opaque GPC, where as more left hemisphere dominance was found in the processing of phonological information (Halderman & Chiarello, 2005; Hanavan & Coney, 2005; Jang & Nam, 2013). As mentioned above, a previous study (Cho & Chen, 1999) provided evidence for different use of phonological information in processing Hanja scripts, and stated that those with lower Hanja proficiency levels would normally use the visual orthographic information rather than processing the script by converting grapheme information to phonological information during visual recognition. Because the N400 lexicality effect has been considered to reflect the degree of lexical-semantic activation and lexical search process (Holcomb., Grainger, & O 'Rourke), these distinct hemispheric activities of the lexical process during the Hanja script recognition might be caused by the fact that readers usually use different strategies when finding associated lexical-semantic information.

In Hanja script data, the difference in the N400 lexicality effect between the LVF and RVF was not equally distributed for each of the electrode regions ($F(5, 18) = 2.924$, $p < .05$). The topographical distribution (Fig. 1, 2) revealed larger locational differences in the N400 lexicality effect between HP and LP groups. The HP group had a larger N400 lexicality effect at the central and posterior electrode regions than the anterior regions, while LP group showed greater anterior lateralized effect. Since ERP experimental paradigm measures neural signals at the scalp, it is difficult to estimate the exact location of neural sources. However, such data can still provide a general understanding of the source location of the measured neural signal. In line with previous research on language processing, the IPL (especially the supramarginal gyrus) is known to be involved in linguistic processing (Cohen, Dehaene, Chochon, Lehericy, & Naccache, 2000; Lecours, Lhermitte, & Bryans, 1983). Greater lexicality effect shown at posterior regions in the current study could be an indication of that IPL is closely related to script processing. Unlike the HP group, LP group seems to rely heavily on the processing of phonological information during Hanja recognition, leading to greater activation in anterior regions (Siok, Jin, Fletcher, & Tan, 2003). Participants with lower Hanja proficiencies require greater effort in converting grapheme to phoneme when processing the Hanja script.

In contrast to prior studies, both the differential hemispheric processing of the Hangul scripts between HP and LP groups and the distinct N400 lexicality effect between the LVF and RVF were not found in the present study. Although we expected a right hemisphere superiority effect in the HP group during Hangul script recognition. Contrary to our expectation, the N400 lexicality effect was robust for both Hanja proficiency groups and in both hemispheres. The primary basis of this result might be due to the different levels of familiarity and complexity between the two Korean scripts. Participants were asked to judge, the familiarity of the presented scripts after the experiment on a 7-point Likert scale (“7” being “highly familiar” and “1” being “highly unfamiliar”). The mean familiarity score of the presented stimuli was higher for the Hangul scripts (6.2) than for the Hanja scripts (5.7). Moreover, the visual complexity of the stimuli was higher for the Hanja scripts than for the Hangul scripts due to the nature of how the Hanja script are formed to make up a word. In sum, more time seems to be needed to process Hanja versus Hangul scripts. That is, the presentation time of 300 ms in the Hangul session seems to be relatively long enough, and that participants could therefore have surplus time to process words in Hangul script in both hemispheres.

The ERP waveforms elicited at electrodes contralateral to the visual field of presented stimuli show greater negativity than did those elicited ipsilateral to the visual field of the stimuli (Jolicœur, Brisson, & Robitaille, 2008). In this study, similar patterns of waveforms were identified. The waveform in the left hemisphere showed greater negativity for Hanja script shown in the RVF than in LVF. Conversely, the waveform in the right hemisphere showed greater negativity for Hanja script presented in the LVF than when they were presented in the RVF. This results on this study imply that the target stimuli were processed by the hemisphere opposite to the visual field in which the stimuli were presented.

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한자와 한글 처리에서 보여지는 좌우반구 비대칭에 대한 전기생리학적 연구: 한자 능숙도 효과*

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한국어에는 철자열-음소 대응의 정도가 다른 두 가지의 표기체계가 존재한다. 한자는 비교적 자음-음소 대응의 정도가 낮은 편이고, 반대로 한글은 자음-음소 대응의 정도가 높은 편이다. 본 연구는 한국어 화자의 한자와 한글을 처리하는 과정에서 각 문자의 자음-음소 대응 정도에 따라 독특하게 나타나는 신경기제를 밝히기 위해 수행하였으며, 한자 능숙도가 다른 두 집단의 한자와 한글 재인 과정에서의 좌우반구 비대칭성에 대한 실험을 진행하였다. 총 25명의 한국어화자가 본 실험에 참가하였고 한자 능숙도 사전 검사를 통해 한자 능숙도에 따라 두 개의 집단으로 나누었다. 실험 참가자들은 뇌파기록을 하는 동시에 어휘판단과제를 수행하였다. 그 결과 한자 능숙도에 따라 서로 다른 양상의 좌우반구 비대칭이 발견되었다. 한자 능숙도가 높은 집단은 우반구에서 더 큰 N400 어휘성 효과가 나타난 반면에 한자 능숙도가 낮은 집단은 좌반구에서 더 큰 N400 어휘성 효과를 보였다. 그러나 한글의 좌우반구 비대칭성은 두 집단 간의 차이가 나타나지 않았다. 이러한 결과는 한국어화자가 한자를 처리함에 있어 한글과는 다른 신경기제를 가지고 있고, 한자 능숙도에 따른 한자의 독립된 전략적 처리과정이 서로 다른 양상의 좌우반구 비대칭성으로 나타났음을 시사한다.

주제어 : 철자열-음소 대응, 사건 관련 전위, N400 어휘성 효과, 시각 단어 재인, 한자 능숙도

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