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Early Effect of Phonological Information in Korean Visual Word Recognition: An ERP Investigation with Transposed Letters

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Abstract The purpose of this study was to examine the role of phonological information on visual word recognition by using letter transposition effects. The Korean writing system gives a unique opportunity to investigate such phenomenon since the transposition of the beginning consonant (onset) and the end consonant (coda) of a certain syllable allows one to keep the coda phonology constant while changing the written alphabetic characters. In this study, 23 participants' ERPs to such transposition cases were compared with the ERPs to cases that do not maintain coda phonology while the participants were performing a go/no-go lexical decision task for visually presented letter strings. The results of the current study showed that transposed materials with original phonological information produce less N250 than both the baseline condition and the transposed materials with different phonological information condition. The results suggest that phonological information is used early in the lexical process in Korean and early orthographic processing is influenced by the characteristics of the grapheme to phoneme conversion process.

Keywords Phonological information · Transposed letter · Korean · ERP · N250

The question of whether phonological information is involved in the early stages of word recognition has drawn a lot of attention. Previous experimental evidence suggests that a printed word activates phonological code and that accessing the phonological representation of a printed word is an automatic process (Frost 1998; Ferrand and Grainger 2003; Lukatela and Turvey 1994; Ziegler et al. 2000). Such results have been shown in languages with inconsistent spelling-to-sound mappings, such as English. For instance, compared with words having consistent spelling-to-sound mappings, like -uck in duck and luck, words having

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inconsistent mappings, like -ough in cough and dough, showed increased lexical decision latencies (Ziegler et al. 1997). Illustrating the influence of the non-lexical role of phonological information, pseudohomophone primes (e.g., KLIP) facilitated lexical decision latencies of target words (e.g., clip) relative to visually similar control primes (e.g., PLIP) (Lukatela et al. 1998). Moreover, recent electrophysiological studies have also supported the important role of phonology in the pre-lexical processes of visual word recognition. For example, Grainger et al. (2006) reported that a difference in the N250 ERP component was present when they compared pseudohomophone primes (e.g., brane-BRAIN) with control primes (e.g., brant-BRAIN).

Furthermore, the influence of phonological code in visual word recognition has also been found in languages with consistent spelling-to-sound orthography as well. In a Spanish behavioral study, Álvarez et al. (2004) tested the presence of phonological syllable priming (e.g., bi.rel-VI.RUS; in Spanish, there is no distinction between [b] sound and [v] sound in onset position) and found that phonological syllable primes facilitated lexical decision latencies compared to orthographically related primes (e.g. vir.ga-VI.RUS) and unrelated primes (e.g. fi.rel-VI.RUS). Similarly, in ERP studies with Spanish, Barber et al. (2004) and Carreiras et al. 2005 found that the phonologically defined syllable frequency effect began around 200 ms after stimulus onset.

As such, the possible role of phonology in the pre-lexical processes of visual word recognition was traditionally tested in the context of processing the normal word target. However, the letter transposition effect has also been used to test whether phonological information could affect the early stages of language processing (Acha and Perea 2008; Frankish and Turner 2007; Perea and Carreiras 2006, 2008; Perea and Perez 2009). A non-word made by exchanging the letters in a word (e.g., “caniso” from “casino”) is more often mistaken to be a word compared to a non-word made using substitution (e.g., “camino”). Such phenomenon known as the letter transposition effect has been widely reported using various types of psycholinguistic tasks such as the lexical decision task, eye tracking, and the priming task (e.g., Grainger and Whitney 2004; Perea and Lupker 2004; Schoonbaert and Grainger 2004).

To our knowledge, only one study found that the phonological information did in fact modulate the letter transposition effect, whereas others did not. Specifically, Frankish and Turner (2007) reported that the unpronounceable non-words (e.g., clcik) were less likely to be judged to be a word in the lexical decision task as compared to the pronounceable non-words (e.g., strom) when they made non-words by transposing adjacent two letters from based words. This result suggests that the phonological information plays a critical role in the lexical decision for the transposed letter words.

Studies other than Frankish and Turner (2007) did not find letter transposition effects when the phonological information of the letter strings was manipulated. For example, Acha and Perea (2008) reported that the normal transposed prime (e.g. caniso) did not facilitate the target (e.g., casino) more than the transposed pseudo-homophone prime (e.g., kaniso) did. Similarily, Perea and Carreiras (2008) reported no difference between the condition that elicits the phonological change for the transposed letter prime (e.g., racidal -RADICAL) and the one did not (e.g., cholocate-CHOCOLATE) in the masked priming task. The previous studies indicate that the phonological information did not contribute any extra facilitation to the target, limiting the role of phonology in the letter transposition effect and emphasizing the role of the orthographic information.

Recently, many researchers have been using ERPs to examine the transposed letter effect and investigate the role of phonological information during visual recognition processes. For example, Grainger et al. (2006) examined the effect of the transposed letter primes (e.g., barin) as well as the effect of the pseudohomophone primes (e.g., brane) on processing of the target word. They found that both transposed letter primes and the pseudohomophone primes elicited smaller N250 of target words (e.g., BRAIN) than control primes (e.g., bosin). They also found that the transposed letter priming effect arose earlier than the pseudohomophone priming effect in a distinct topographical position. Carreiras et al. (2009) used the ERP technique to test the time course of the orthographic and phonological information during visual word recognition processes as well. This study showed the influence of orthographic priming at the 150–250 ms time window while the influence of phonological priming occurred at the 350–550 ms window. Overall, such results suggest that both the phonological information and orthographic information affect the early stages of visual word recognition processes, but orthographic information has a faster route than phonological information.

While most studies with European languages consistently reported an influence of the phonological information in visual word recognition, it is still a matter of debate as to whether phonological information is used early in visual word recognition in the Korean language (Zagar 2015). Most studies concerning Korean visual word recognition reported that orthographic information is the main source of lexical access whereas the phonological information plays a minor role (Lee 1990; Park 1996, 2003; Tae et al. 2015; Yi 1993). Also, despite the results from most other alphabetic languages, studies with Korean suggested no transposed letter effect, at least when investigated using behavioral methods (Lee and Taft 2009, 2011). For example, Lee and Taft (2009, 2011) found that Korean readers did not suffer confusion from the transposed letter when they transposed consonants in various positions of a disyllabic Korean word. They explained this lack of the letter transposition effect in Korean as a result of the Korean writing system explicitly presenting the onset, vowel, and coda position within a syllable, which prevents confusion.

The fact that studies with Korean showed little effect of the phonological information in visual word recognition indicates that Korean readers may rely heavily on the orthographic coding, possibly because of the properties of the writing system. However, since most previous studies investigating languages with consistent spelling-to-sound mappings (like Korean) showed an effect of phonological information in visual word recognition and transposed letter effects, the current study tried to find such effects by using more sensitive ERP techniques and taking advantage of the properties of the Korean language.

In Korean, the transposition of the onset and the coda from certain syllables maintain the phonological information of the coda against the source syllable (e.g., 젓갈 → 섯갈 [transposed coda keeps the phonological property]) while other syllables do not maintain the phonological information. This property comes from the fact that several consonants such as "ㅅ," "ㅈ," "ㄷ," "ㅌ," "ㅊ," all have the same phonological information (/t/) when they are used as the coda. Taking advantage of this property of the Korean language, this type of transposition (TL-phonology) is compared with the other type of transposition (TL-control) that does not maintain the phonological information in the source syllable (e.g., 심지→ 밋지 [the transposed coda has a different phonological property than the original syllable]). Stimuli that have an unrelated onset and coda (substituted-letter) are also used for a baseline of the transposed letter effect. Therefore, all experimental items were pseudo-words. A more specific illustration for the stimuli is presented in the Method section.

The main focus of this study was on whether phonological manipulations of the transposition would elicit differences in the N250 ERP component, which is known to be related to the early input processing of a word. More specifically, the current study aimed to examine whether the transposed letter effect could be shown in Korean where, in some cases, the transposed coda keeps the phonological property of the original coda constant while changing the written alphabetic characters. Another purpose of the current study is to reveal the time course of the TL effect and the possible role of phonology. To do so, three representative time windows will be analyzed. According to several neurophysiological studies investigating ERP components that reflect visual word processing stages (Carreiras et al. 2009; Grainger and Holcomb 2009; Grainger et al. 2006), there are three coherent ERP components which reflect perceptual processing, sublexical processing, and lexical processing. P150 (or N/P150) is known to reflect the early form-specific processing in the perceptual processing stage (Carreiras et al. 2009; Holcomb and Grainger 2006). For example, Carreiras et al. (2009) showed that, in both words and pseudo-words, P150 amplitude varied depending on whether or not there were missing letters, regardless of whether the missing letter was a consonant or a vowel. Such results indicate that P150 is sensitive to the visual forms rather than the abstract representation of the form.

N250 is known to be related to the processing of the orthographic and phonological pathways at the sub-lexical level (Grainger et al. 2006). Although the N250 effect has been reported mostly in studies with a masked priming paradigm, if it is an ERP component that reliably reflects orthographic processing, it should also be expected to be seen in other paradigms, such as lexical decision tasks. In fact, although the N400 effect was initially shown in sentence contexts, a lot of studies using other tasks, including lexical decision tasks, showed that the N400 effect is sensitive to semantic processing (see Kutas and Federmeier 2011, for a review). For instance, Holcomb and Grainger (2006) showed that N400 amplitude is correlated with orthographic neighborhood size in a semantic categorization task, Barber et al. (2013) found that the size of the N400 effect was related to the word concreteness in a lexical decision task, and Perre and Ziegler (2008) showed that inconsistent words elicited a larger N400 effect than consistent words in an auditory lexical decision task. It is known that the N400 effect is larger in pseudo-words than in words because pronounceable pseudo-words activate more lexical candidates when deciding whether a given item is a word or a non-word (Bentin et al. 1999; Coch and Mitra 2010). In this context, even if the current study adapted the lexical decision task to the single word presentation paradigm, it is highly possible that the N250 effect could be seen if it reflects the early input processing at the sub-lexical level.

N400 is well known to be the index of semantic activation associated with lexical candidates (Holcomb et al. 2002; Kwon et al. 2012). The size of N400 also depends on the phonological nature (Barber et al. 2004) as well as the orthographic nature of lexical candidates (Holcomb et al. 2002). Thus, the modulation of the N400 effect is known to be the index of lexical level processing.

Based on the above studies, in P150, we would expect there to be no difference among the three experimental conditions, since the orthographic characteristics of the materials were tightly controlled across the experimental conditions. However, if phonological information affects the transposed letter effect, the difference between TL-phonology and TL-control would emerge from N250. The substituted-letter condition would elicit larger N250 than both TL-phonology and TL-control. More importantly, the TL-phonology condition would generate smaller N250 than the TL-control condition since the stimuli in the TL-phonology condition are phonologically more similar to the base-words compared to the stimuli in the TL-control condition. If phonological information does cause more confusion, it would be reflected in N400 as well. Since the TL-phonology stimuli are letter transposed pseudo-words maintaining most of the phonological features of the first syllable of the target word, participants might regard TL-phonology stimuli as a certain word or at least feel more familiar with it than with stimuli of other conditions. If that is the case, we would expect smaller N400 for the TL-phonology condition.

If phonological information does cause more confusion and we do find a letter transposition effect in this study, it would suggest that phonological information is used early in the lexical processes and that the previous results showing no effect of the phonological information and the letter transposition might be due to the relative insensitivity of the experimental method or to certain characteristics of the experimental materials. However, if we do not find any electrophysiological evidence of phonological influence and/or letter transposition effects in this study, it would be strong evidence that phonological processing is not activated automatically in visual word recognition and the physical cues based on the writing system prevent any confusion from a transposed letter in Korean.

To summarize the hypotheses, we expect no differences in P150 among the three experimental conditions. For N250, we expect larger N250 for the substituted-letter condition compared to other conditions if the transposed letter effect does exist in Korean. Also, we expect smaller N250 and N400 for the TL-phonology condition, which reflects the processing of phonological information in visual word recognition.

Method

Participants

Twenty-seven healthy, right-handed, native Korean speaking students (age 20–25; female: 10, male: 17) who had normal or corrected-to-normal vision participated in this EEG experiment. All participants signed a written consent form before participating the experiment. They were paid 10,000 won (about $9) for their participation.

Materials

To test the transposed letter effect, 90 bi-syllabic words having CVC–CVC or CVC-CV construction were collected from the Sejong corpus.[1] All 60 transposed letter stimuli were made by exchanging the onset and the coda from the selected bi-syllabic base words. Half of the transposed letters (30 stimuli) maintained their phonological information (TL-phonology) and the other half of the transposed letters (30 stimuli) did not maintain their phonological information (TL-control). In Korean, the spelling-to-sound consistency is very strong for the onset position but not so strong for the coda position. Although we don't have any published corpus data that shows exactly how consistent the spelling-to-sound mapping is in Korean, we calculated a coda neutralization ratio of about 3.5% for bi-syllabic nouns with a CVC first syllable structure in the Sejong corpus. Thirty substituted-letter stimuli were used for a baseline of the transposed letter effect. All experimental items were pseudo-words.

For the stimuli in the TL-phonology condition, when the onset was transposed to the position of the coda, its pronunciation remained identical to the pronunciation of the original coda. For example, in the case of 젓갈, , which is one of the base words of the TL-phonology stimuli, the initial syllable 젓 consists of three letters ㅈ(C)-ㅓ(V)-ㅅ(C), , and each letter is pronounced as /j/-/eo/-/d/. The second syllable 갈 is composed of ㄱ/g/-ㅏ/a/-ㄹ/l/. Interestingly, when the onset ㅈ, in the initial syllable is exchanged to the coda, the pronunciation is changed as /d/, which is identical to the original pronunciation of the coda ㅅ. Since the coda keeps its' original pronunciation, there is only one phonological difference between the stimulus 섲갈 /seod-gal/ and its base word 젓갈 /jeod-gal/ in the TL-phonology condition. On the other hand, the stimuli in the TL-control and the substituted-letter conditions did not

[1] The Sejong corpus was created by the Ministry of Culture, Sports, and Tourism in the Republic of Korea in 1998. This corpus comprises of approximately 1.5 billion u-juls, which is the basic unit of phrase in Korean (http://www.sejong.or.kr).

Table 1 Examples of TL-phonology, TL-control and substituted-letter base word and transposed stimuli

TL type	Base word	Transposed stimulus
TL-phonology stimulus	젓갈 /j-*eo-d* g-a-l/	섯갈 /s-*eo-d* g-a-l/
TL-control stimulus	전갈 /j-*eo-n* g-a-l/	넞갈 /n-*eo-d* g-a-l/
Substituted-letter stimulus	젓갈 /j-*eo-d* g-a-l/	걸갈 /g-*eo-l* g-a-l/

Table 2 The means and standard deviations of the characteristics of base words for TL-phonology, TL-control and substituted-letter conditions

	TL-phonology	TL-control	Substituted-letter
Word frequency of base words (log)	1.57 (0.65)	1.51 (0.59)	1.57 (0.65)
Orthographic neighborhood density of base words	0.87 (1.01)	0.52 (0.45)	0.87 (1.01)
Bigram frequency (log) after letter transition	2.79 (0.56)	2.67 (0.66)	2.87 (0.66)
Second syllable frequency (log)	2.31 (0.55)	2.31 (0.55)	2.31 (0.55)
Number of letters	5.7 (0.46)	5.7 (0.46)	5.7 (0.46)

Orthographic neighborhood density refers to the number of word neighborhoods sharing all but one letter with a target word. Log of bigram frequency refers to the log value of the frequency of occurrence of two letters of the first syllable. Values of the substituted-letter condition are the same as the TL-phonology condition because they share base words. Second syllable frequency and number of letters are the same in all conditions because we used the same second syllable and controlled the number of letters

share these same characteristics. Table 1 illustrates the characteristics of the TL-phonology, TL-control, and substituted-letter conditions.

Also, 120 filler words, which were matched in terms of frequency and number of letters with the base word used to create letter transposed non-words, were selected from the corpus to conduct a go/no-go lexical decision task. We used a go/no-go task because we wanted to collect a clean EEG signal without artifacts, including motors, as mentioned. Also, some researchers have pointed out possible problems of the LDT and that the error rates were lower in go/no-go tasks especially for less familiar materials like the materials in this study (see Perea et al. 2002). In EEG studies, Holcomb and Grainger (2006) also indicated that a yes/no response could attenuate the N400 effect.

Table 2 shows the word characteristic values of the base words in the TL-phonology, TL-control, and substituted-letter conditions for the go/no-go task. The word frequency and orthographic neighborhood density of the base words, bigram frequency after letter transposition, second syllable frequency, and the number of letters were tightly matched across all conditions. There was no significant difference among them ($ps > .1$).

Procedure

Participants sat on a comfortable chair in front of a 17" CRT monitor with a distance between them and the monitor of about 70–90 cm. The presentation of stimuli and recording of behavioral responses was controlled by E-prime 2.0 software for PC (Schneider et al. 2002). The go/no-go lexical decision task started with a fixation ("> <") appearing on the center of the screen for 500 ms. As soon as the fixation disappeared, the stimulus was presented in the same place as the fixation for 1500 ms. Participants were asked to press a "yes" button (the "1" key in the number pad), as quickly and accurately as possible, within 1500 ms if the given stimulus was a word. However if it was a non-word, they were asked not to press any key. The inter-trial interval was 2500 ms. We are aware that many recent studies used a jittering method which could be beneficial; however, there are also many studies that did not use such methods (Carreiras et al. 2005, Pattamadilok et al. 2011). Therefore, we believe that our decision to not employ a jittering method did not cause a serious problem for the results of our study. After 15 warm-up trials, the main test was conducted and participants took a short break after every 50 trials in order to get a stable EEG.

EEG Recording

All EEGs were recorded by an actiCAP having 28 active channels out of 32 and a Brain Product Brain Amp with a bandpass of 0.01 and 100 Hz. All signals were sampled at 500 Hz while the impedance level was kept below 10 kΩ. The on-line reference channel between Cz and Fz was used and the averaged value of two mastoid channels were used as off-line re-references. Additional electrodes were attached below the right eye (V-EOG) to monitor for vertical eye movements and to the left of the left eye (H-EOG) to monitor for horizontal eye movements. All recordings were conducted in an acoustically and electrically shielded room.

EEG Analysis

After continuously recorded data were re-referenced by two mastoids and an analogue band-pass filter of 0.01–100 Hz was used, a digital band-pass filter (0.01–30 Hz) was applied before segmenting the continuously recorded EEG (Carreiras et al. 2009). Epochs 200ms before onset to 800 ms after onset were then extracted. To get clean epochs, artifact rejection procedures were applied after removing epochs with incorrect responses. The parameters of the artifact rejection procedure were as follows: the lowest allowed activity was 0.5 μV, allowed maximal voltage step was 50 μV, and the range of allowed amplitude was -100 μV to $+100$ μV. Less than 11% of epochs were rejected from the analyses (TL-phonology: 10.1%, TL-control: 10.8%, substituted-letter: 10.7%). The difference in the number of artifacts across conditions was not significant [$F(2, 44) = .13$, $p = .87$]. Four participants (female: 1, male: 3) generated excessive artifacts ($>$ 50%) and were therefore removed from the ERP analysis. We defined three different time windows of analysis (125–175, 175–300, and 300–500 ms) based on visual inspection and the previous work by Holcomb and Grainger (2006). All pre- and post-processes for ERPs were conducted by EEGLAB toolbox in matlab software (Delorme and Makeig 2004).

Repeated measures analysis of variance (ANOVA) of stimulus type (TL-phonology vs. TL-control vs. substituted-letter) was used to analyze the ERP data. Six pooled electrode regions (anterior left: F3, FC1, FC5; anterior right: F4, FC2, FC5; central left: C3, CP1, CP5; central right: C4, CP2, CP6; posterior left: P3, P5, O1; posterior right: P4, P6, O2) were used in the analysis. Figure 1 shows a schematic flat representation of the 32 electrode positions and six regions used in the ERP analysis. These regions were identified in the ANOVA as the factors of laterality (left vs. right) and anterior-to-posterior extent (anterior vs. central vs. posterior). The electrode pooling was in accordance with previous studies (Barber et al. 2004; Hutzler and Wimmer 2004; Kwon et al. 2011, 2012). The Geisser-Greenhouse correction (Greenhouse and Geisser 1959) was applied to all repeated measures containing more than one degree of freedom in the numerator. In the analyses, we reported the main effect of stimulus type and the significant interactions between stimulus type and electrode regions.

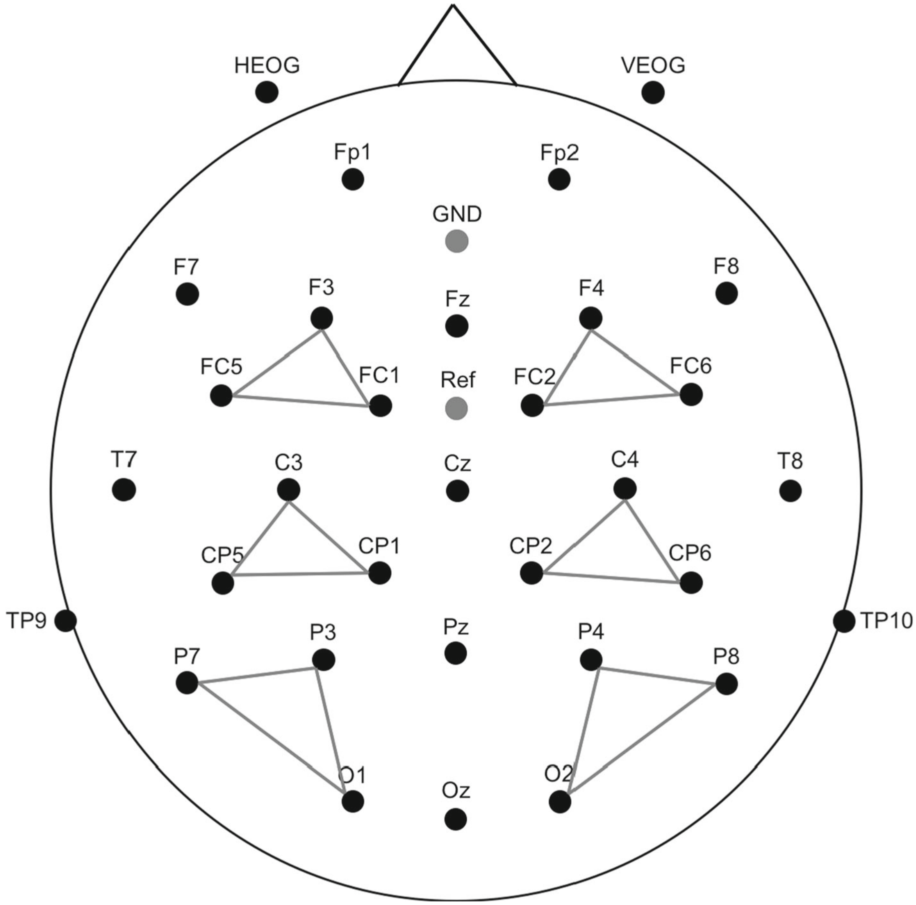

Fig. 1 The montage of 32 channels (black dots) and 6 regions used in ERP analysis

Post-hoc testing using a Bonferroni correction was applied to further analyses in cases where there were significant interactions. Since the localization was not the main interest of the study, we didn't examine the effect induced by the factors of laterality (left vs. right) and anterior-to-posterior extent (anterior vs. central vs. posterior) unless there was an interaction with the stimulus type.

Results

Behavioral Results

Since all critical target stimuli were no-go responses, there was no response time to report for TL-phonology, TL-control and the substituted-letter condition. However, false-alarm rates analysis of variance showed significant differences among conditions [$F(2, 44) = 19.64$, $p < .001$]. In post-hoc testing using the Bonferroni correction, the TL-phonology condition (9.8%, SD = 5.9) showed higher false-alarm rates than the TL-control (4.7%, SD = 5.3) ($p < .001$)

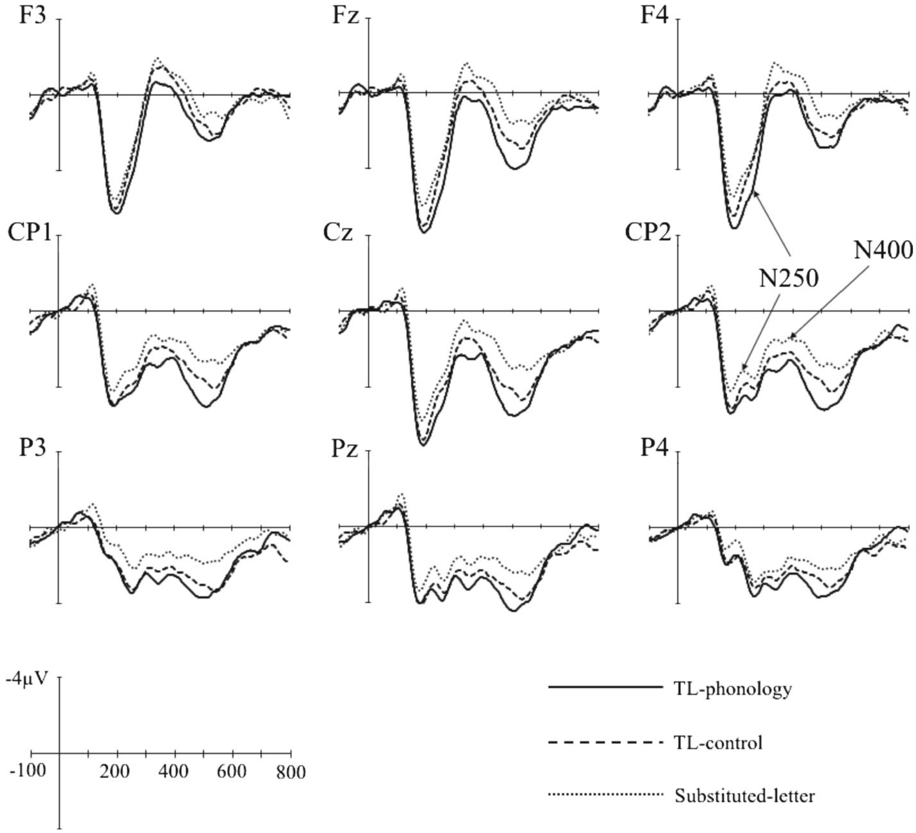

Fig. 2 The grand averaged ERPs of TL-phonology (solid-line), TL-control (dash-line), and substituted-letter (dot-line) condition in representative 9 electrode sites

and the substituted-letter (4.0%, SD = 5.4) ($p < .001$) conditions. The difference between the false-alarm rates of TL-control and substituted-letter was not significant ($p = 1.00$).

ERP Results

Approximately 83% of all epochs were categorized as artifact free and therefore were included in the ERP analyses (TL-phonology: 24 epochs (80.0%), TL-control: around 25 epochs (82.1%), substituted-letter: around 25 epochs (84.6%)). Figure 2 describes the grand averaged ERPs for the TL-phonology, TL-control, and substituted-letter conditions at the 9 electrodes.

125–175 ms

In the first time window, the main effect of stimulus type was not significant [F(2, 44) = 2.58, $p = .08$]. The 2-way interactions of stimulus type × hemisphere and stimulus type × anterior-to-posterior region was also not significant [F(2, 44) = 1.85, $p = .16$; F(2, 44) = .42, $p = .79$]. However, the 3-way interaction of stimulus type × hemisphere × anterior-to-posterior region was significant [F(4, 80) = 3.96, $p < .01$]. In a post-hoc test for 3-way interaction, the P150 effect of TL-phonology was larger than that of substituted-letter in the

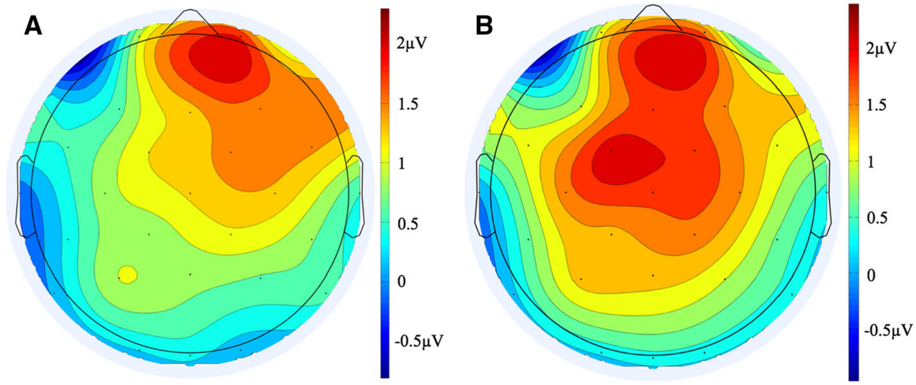

Fig. 3 **a** The voltage map of N250 (the mean voltage obtained for TL-phonology minus the mean voltages obtained for substituted-letter). **b** The voltage map of N400 (the mean voltage obtained for TL-phonology minus the mean voltages obtained for substituted-letter)

right anterior ($p < .05$) and the right central ($p < .05$) regions. None of the other differences were significant.

175–300 ms

In the second time window, the main effect of stimulus type was significant [F(2, 44) = 4.12, $p < .05$]. In a post-hoc test on the main effects, the mean amplitude of TL-phonology was smaller than that of the substituted-letter condition, which was statistically significant ($p < .05$), while other comparisons were not significant (*ps* $> .2$). The 2-way interaction of stimulus type and anterior-to-posterior region was also significant [F(4, 88) = 3.46, $p < .05$]. In a following post-hoc test, TL-phonology generated smaller negative amplitude than substituted-letter in the anterior ($p < .01$) and central regions ($p < .05$). Other comparisons were not significant (*ps* $> .1$). The other 2-way interaction (stimulus type × hemisphere) and 3-way interaction (stimulus type × hemisphere × anterior-to-posterior region) were not significant [F(4, 88) = 1.59, $p = .21$; F(4, 88) = 2.27, $p = .06$]. The left panel of Fig. 3 illustrates the voltage map of the N250 effect.

300–500 ms

The main effect of stimulus type was significant [F(2, 44) = 4.84, $p < .05$]. In post-hoc testing, the difference between TL-phonology and substituted-letter was significant ($p < .01$). The negativity of TL-phonology was smaller than the substituted-letter condition. The difference between TL-control and substituted-letter, and the difference between TL-phonology and TL-control was not significant in post-hoc testing (*ps* $> .1$). In interaction analyses of stimulus type and electrode regions, the 2-way interaction (stimulus type × anterior-to-posterior region) was significant [F(4, 88) = 3.04, $p < .05$], while post-hoc analysis for this interaction showed the amplitude of substituted-letter was larger than that of TL-phonology in the anterior ($p < .01$) and central regions ($p < .01$). Other differences, including interactions, were not significant (*ps* $> .1$). The right panel of Fig. 3 illustrates the voltage map of the difference between the TL-phonology and substituted-letter conditions.

Discussion

In this experiment, the ERP differences for non-words that have different phonological characteristics, when the onset and the coda of their initial syllable are transposed, were investigated using the Korean language. More specifically, we compared, in three time windows, ERP wave forms from the condition in which the phonological information of the coda was maintained with respect to the source word (TL-phonology) with ERP wave forms from other conditions in which the coda's phonological property changes (TL-control) and where the onset and coda were replaced by unrelated letters (substituted-letter). The results of the present study showed that the difference among TL-phonology, TL-control, and substituted-letter conditions started in the second time window (175–300 ms) which suggests that the phonological information influences orthographic processing early on during visual word recognition.

In the first time window (125–175 ms), while neither the main effect of stimulus type nor the 2-way interaction between the stimulus type and localization factors (hemisphere, anterior-to-posterior region) was statistically significant, there was a significant 3-way interaction. The TL-phonology condition produced a larger amplitude than the substituted-letter condition in the right anterior and right central regions. Since the P150 component is known to reflect early perceptual processes (Holcomb and Grainger 2006), the absence of a main effect of stimulus type suggests that the participants did not notice any perceptual difference among the conditions. Also, while there is no compelling explanation about why the 3-way interaction occurred (since the orthographic features of the three experimental conditions were tightly controlled), it is speculated that the phonological characteristics of the TL-phonology condition enlarged the perceptual familiarity compared with the substituted–letter condition. Further studies are needed to identify the effect of the phonological features on the P150 component.

The effect of the phonological information emerged from the second time window (175–300 ms), such that the mean amplitude of the TL-phonology condition was smaller than that of the substituted-letter condition. Neither the difference between TL-phonology and TL-control nor the difference between TL-control and the substituted-letter condition was significant. The TL-phonology effect was concentrated in the anterior and central regions. This finding corresponds well with the results from previous studies suggesting that phonological overlap between primes and targets influences the modulation of N250 amplitude. The results are comparable with Grainger et al. (2006), who showed a pseudo-homophone effect when they compared pseudohomophone primes (e.g., brane-BRAIN) with control primes (e.g., brant-BRAIN). They found that the topographic distribution of the pseudohomophone priming effect was concentrated in the anterior sites. According to Grainger et al. (2006), the N250 effect could be divided into two parts: the first part starts around 200 ms after target onset in the posterior region and the second part starts around 225 ms in the anterior region. The early and late N250 effect was thought to reflect sub-lexical processing such that early N250 is reflecting relative-position coded letter representation and late N250 is reflecting translation of the orthographic codes into the phonological codes (see Grainger and Holcomb 2009 for a review). In our study, following suggestions by Grainger et al., additional analyses of anterior and posterior regions showed that the peak latency of N250 in the posterior region (227.08 ms) was about 25 ms earlier than in the anterior region (252.26 ms). We suspect the early N250 in the present results reflects relative-positional letter code processing and the late N250 reflects orthography-phonology translation processing.

For N250, we tested two different predictions: (a) if the transposed letter effect could be seen in Korean, the substituted-letter condition would elicit larger N250 than both TL-phonology and TL-control; and (b) if the phonological information affects the visual word recognition process, the TL-phonology condition would generate smaller N250 than the TL-control and the substituted-letter conditions. We included the TL- control condition to test whether the transposed letter effect could be shown in Korean with more sensitive ERP techniques and, if so, to test how phonological information affects it. While there was a significant difference between TL-phonology and the substituted-letter conditions, neither the difference between TL-phonology and TL-control nor the difference between TL-control and Substituted-Letter condition was significant.

Although neither of the predictions was supported, we believe that the current results show the collective effect of the letter position and the phonological information to some degree. On the one hand, no difference between the TL-phonology and TL-control conditions indicates a lack of phonological influence and supports previous findings showing little effect of the phonological information in Korean visual word recognition (Lee 1990; Park 1996, 2003; Tae et al. 2015; Yi 1993). Also, even though the TL-control condition does not maintain the phonological information in the source syllable, it is still a transposed letter condition. Therefore, no difference between the TL-control and the substituted-letter conditions supports previous studies which suggested a lack of a letter transposition effect in Korean (Lee and Taft 2009, 2011). On the other hand, the current results showing a significant difference between the TL-phonology and the substituted-letter conditions showed that, collectively, the letter position and the phonological information have an effect on Korean visual word recognition. Since the stimuli in the TL-phonology condition are phonologically most similar to the base-words (e.g. /j-*eo*-*d*/ - /s-*eo*-*d*/) and the stimuli in the Substituted-Letter condition are least similar to the base-words (e.g. /j-*eo*-*d*/ - /g-*eo*-*l*/), it is not surprising that the only significant difference for N250 emerged between the most similar TL-phonology and the least similar Substituted-Letter conditions. Such results suggest that phonological information plays a role in the transposed letter effect and in Korean visual word recognition. This explanation fits well with the results of most other languages with consistent spelling-to-sound mappings that showed transposed letter effects and an effect of phonological information (Frankish and Turner 2007). We suspect that the difference between Korean and other consistent spelling-to-sound mapping languages is not a matter of quality but a matter of quantity. Although the transposed letter effect is relatively small, possibly because of the Korean writing system that explicitly presents the onset and coda position within a syllable, transposed letters can still bring about confusion, at least where the transposed coda keeps the phonological property of the original coda constant. A similar argument can be made for the effect of the phonological information as well.

The results from the last time window indicate that TL-phonology generated a smaller N400 effect than other conditions. This result is compatible with previous studies (Carreiras et al. 2009; Grainger et al. 2006) in which TL stimuli elicited smaller N400 compared to baseline stimuli. However, the N400 effect of previous studies and our study might stem from different sources. First of all, targets of previous N400 were word stimuli, while our targets were pseudo-words. Secondly, in the results of the present study, the N400 effect was produced by a single word presentation, and not by priming. In priming tasks, TL prime (e.g., barin) activates orthographic representations of the target word (e.g., brain) before participants see the target, which leads to a decrease in the size of the N400 waveform (Grainger et al. 2006). In the present study, the TL-phonology condition has a more similar sound to the original word compared with the other conditions, so TL-phonology could more easily activate a specific candidate at the lexical level. However, TL-control and substituted-letter stimuli might activate more candidates during lexical access, due to them not having a specific lexical candidate. Another possible reason for the smaller N400 in this study's TL-phonology condition is that it reflects familiarity of the stimuli, since frontal N400 is mostly associated with familiarity of the stimuli in psycholinguistic research (Kutas and Federmeier 2011; Rugg and Curran 2007). We tightly matched all three conditions in terms the word frequency and orthographic neighborhood density of the base words, bigram frequency after letter transposition, second syllable frequency, and the number of letters. Therefore, we believe that if the participants did not activate the base item, then the different ERP patterns between the TL-phonology condition and the substitute condition would not be seen, especially for N400. However, it is also true that there is no proof that the pseudo-words activated the particular base word. Further study measuring the ERPs while conducting the phonological priming task would provide further supporting evidence for the role of phonology in visual word processing.

The results of the current study show the early effect of phonological information in visual word processing and some trace of the letter transposition effect in Korean. Such results contradict previous studies that report null effects of the transposed letter. The difference between the results of the current study and the results of previous studies could be due to the materials and the technique used in this study. We found letter transposition effects only in cases where there was only one phonological difference between the TL-phonology condition and the real word. However, in cases where the transposed coda had a different phonological property than the real word (i.e., stimulus had more than one phonological difference from the real word), as was the case in the materials from previous studies (Lee and Taft 2009, 2011), we found no sign of letter transposition effects, consistent with previous studies. Additionally, with respect to the experimental technique, the ERP method that we used in this experiment makes it possible to look into the underlying processes during visual word recognition while behavioral lexical tasks only give the results of the whole process (Carreiras et al. 2014; Grainger et al. 2006; Holcomb and Grainger 2006).

In sum, the current study suggests that phonological information is involved in early letter processing and that early orthographic processing is influenced by the characteristics of the grapheme to phoneme conversion process. However, it also suggests that it is neither the sole influence of letter position nor phonological information that affects Korean visual word recognition, but rather their collective influence. Further study measuring the ERPs while conducting a phonological priming task would provide further supporting evidence for the role of phonology in visual word processing.

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Compliance with Ethical Standards

Conflict of interest The authors declare that we have no conflict of interest.

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