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An electrophysiological investigation of translation and morphological priming in biscriptal bilinguals

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ABSTRACT

The current study used event-related potentials (ERPs) to investigate whether the pattern of cross-language masked translation priming reflects the asymmetric link between first language (L1) and second language (L2) and whether it occurs via morphological decomposition with unbalanced Korean-English bilinguals. In Experiment 1, the targets were Korean (L1) compound words (e.g., 꿀벌, "kkwu-pel", *honeybee*), and the primes were English (L2) words: either 1) translated compound words (e.g., *honeybee)*, 2) translated constituents (e.g., *bee*), or 3) unrelated constituents (e.g., *ear*). Experiment 2 was the same as Experiment 1, except that the targets were in English (L2), and the primes were in Korean (L1). In the ERP results, the unrelated constituent primes relative to the translated compound or constituent primes produced N400 effects for both language directions (L1 to L2 and L2 to L1). In addition, the translated constituent primes relative to the translated compound primes elicited both P250 and N400 effects only in the direction of L1 to L2, suggesting translation priming via morphological decomposition. Taken together, the results indicate that both cross-language translation priming and morphological priming occur between different scripts (between non-cognate words), and that the effects are stronger when L1 primes L2 than the other way around.

1. Introduction

Many studies on the morphological processing of bilingual readers have enhanced our understanding of how two (or more) languages are represented in their mental lexicon. However, the majority of this research has relied heavily on behavioral experiments or has concentrated on inflectional or derivational morphology (Bosch, Krause, & Lemine, 2017; Coughlin & Tremblay, 2015; De Diego Balaguer, Sebastian-Galles, Diaz, & Rodriguez-Fornells, 2005; Deng, Shi, Dunlap, Bi, & Chen, 2016; Dijkstra, del Prado Martin, Schulpen, Shreuder, & Baayen, 2005; Hahne, Mueller, & Clahsen, 2006; Jiang, 2004; Kim, Wang, & Ko, 2011; see Bosch & Leminen, 2018 for a review). In addition, the languages in most of the studies on bilingual processing use Roman alphabetic scripts and contain cognates (e.g., German and English). Thus, the present study attempts to fill the gaps in the literature by investigating electrophysiological responses to compound words in biscriptal bilingual readers, Korean learners of English.

Compounding, as the most universal form of word formation across languages (Dressler, 2006), can serve as an ideal case, as compared to derivation and inflection, for investigating morphological/lexical representation and processing because a compound word consists of two (or more) independent lexemes. Previous studies in L1 have demonstrated that a compound word (e.g., *doorbell*)

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is decomposed into its constituents (*door* + *bell*) using various methodologies such as masked priming (e.g., Dunabeitia, Laka, Perea, & Carreiras, 2009; Fiorentino & Fund-Reznicek, 2009; Shoolman & Andrews, 2003), overt priming (e.g., Libben, Gibson, Yoon, & Sandra, 2003), production (e.g., Bien, Levelt, & Baayen, 2005; Gagne & Spalding, 2016), eye-tracking (e.g., Frisson, Niswander-Klement, & Pollatsek, 2008; Pollatsek & Hyona, 2005), and lexical decision (e.g., Andrews, 1986; Dunabeitia, Perea, & Carreiras, 2007; Ji, Gagné, & Spalding, 2011; Juhasz, Starr, Inhoff, & Placke, 2003; Libben et al., 2003; Taft & Forster, 1976). For example, Fiorentino and Fund-Reznicek (2009) found that, for English native speakers, compound words (e.g., *jailbird*) as primes elicited faster reaction times for their constituent targets (e.g., *bird*) than length- and frequency-matched unrelated control compound words (e.g., *floormat*) in a lexical decision task. This evidence supports the morpheme-based representation of compound words (i.e., morphological decomposition).

Based on the argument from native speakers' morpheme-based processing of compound words, one could ask whether bilingual readers are also sensitive to morphological structure when they read L2 compound words and decompose them into their constituents. Past studies (Alonso, Castellanos, & Müller, 2016; De Cat, Klepousniotou, & Baayen, 2015; Ko & Wang, 2015; Ko, Wang, & Kim, 2011) reveal morphological decomposition in L2 compound processing. For example, Alonso et al. (2016) found comparable constituent priming effects for both native English speakers and Spanish-English bilinguals with relatively advanced levels of proficiency. Thus, the Spanish-English bilinguals showed faster reaction times in lexical decisions for English L2 compound words (e.g., *fundraiser*) when preceded by their constituents (e.g., fund) than by unrelated words (e.g., *cool*). Because there was no priming effect from the orthographic conditions (e.g., *funk* for the first constituent, *raisin* for the second constituent), the authors argued that the morphological representation in L2 is qualitatively comparable to that in L1.

Using cross-language prime-target pairs (i.e., L1 primes and L2 targets) in a masked priming lexical decision experiment with Korean-English bilinguals, Ko and Wang (2015) found a significant morphological priming effect where English L2 compound word targets (*bedroom*) elicited faster reaction times when they were preceded by their Korean translated constituent primes (e.g., 방, “pang,” *room*) than by length- and frequency-matched unrelated word primes (e.g., 곧, “kot,” *soon*). Ko and Wang concluded that L1 morphemic information can be activated rapidly in reading L2 compound words. Note, however, that they tested the direction from L1 to L2 only in their priming experiment, but not vice versa. Therefore, the question of whether L2 morphemic information can also be activated during reading of L1 compound words has remained unanswered. The current study using ERPs further investigates this issue with Korean-English bilinguals presented with compound word targets in Korean L1 preceded by their constituent primes in English L2, and vice versa, in a masked priming lexical decision task. The absence of orthographic overlap between Korean and English can provide a sound experimental design to examine whether the processing of compound targets (e.g., honeybee) in one language can be affected by their translated compound primes (꿀벌, “kkwul-pel”, honeybee in Korean), translated constituent primes (벌, “pel”, bee in Korean), or unrelated constituent primes (e.g., 귀, “kwi”, ear in Korean).

Among several accounts that explain how bilinguals' lexical representation changes over time in L2 acquisition, the Revised Hierarchical Model (RHM, Kroll & Stewart, 1994) assumes the asymmetric lexical link between L1 and L2 in unbalanced bilinguals. More specifically, the RHM is grounded on the evidence of a stronger link from L2 to L1 than from L1 to L2 when late bilinguals begin to learn their L2. In reading L2 words, late bilinguals tend to rely more on L1 lexical information corresponding to L2 words, but they do not necessarily do so in the opposite direction. Note that the link from L1 to L2 becomes stronger as L2 proficiency increases (i.e., co-activation in L1 and L2). Thus, both directions can be equally strong in balanced bilinguals. The model has been supported by a number of studies that demonstrated the asymmetric link between the two languages in unbalanced bilinguals (e.g., Gollan, Forster, & Frost, 1997; Jiang, 1999; Jiang & Forster, 2001) and the symmetric links between the two languages in highly proficient bilinguals (Dunabeitia, Perea, & Carreiras, 2010). For instance, Jiang (1999) found a stronger masked priming effect when Chinese-English bilinguals were presented with Chinese L1 primes and English L2 targets than with English L2 primes and Chinese L1 targets. However, the asymmetric pattern of priming effects in bilinguals is expected to diminish for more balanced bilinguals (e.g., Dunabeitia et al., 2010). Note that the direction between L1 and L2 in the RHM is opposite to the prime-target direction in the masked priming paradigm (see Jiang, 1999). Thus, we expect to observe larger masked priming effects with L1 primes and L2 targets than vice versa.

The asymmetric link between L1 and L2 has also been supported by several recent ERP studies showing differential translation priming effects in the N250 and N400 components modulated by the direction of two languages (Alvarez, Grainger, & Holcomb, 2003; Hoshino, Midgely, Holcomb, & Grainger, 2010; Pu, Holcomb, & Midgley, 2016; Schoonbaert, Holcomb, Grainger, & Hartsuiker, 2011). As the most relevant ERP component to the current study, the N400 has been repeatedly found when a target word is semantically unrelated to the prior information established by a sentence context or a preceding word (Kutas & Federmeier, 2014). For example, Alvarez et al. (2003) have found that the larger N400 component started earlier for late English-Spanish bilinguals when Spanish L2 overt primes were followed by English L1 targets as compared to the other way around (see also Phillips, Klein, Mercier, & de Boysson, 2006). However, for highly proficient bilinguals, N400 effects were significant for both directions of masked translation priming (i.e., L1-L2 and L2-L1), and the magnitude of N400 modulation was similar in both directions (Duñabeitia, Dimitropoulou, Uribe-Etxebarria, Laka, & Carreiras, 2010).

Midgley, Holcomb, and Grainger (2009) reported evidence for an asymmetric pattern of masked translation priming effects in unbalanced French-English bilinguals. When bilingual participants were presented with L1 primes and L2 targets, they showed significant effects in the N250 and N400. However, when they were presented with L2 primes and L1 targets,a significant N400 effect was observed while N250 effect was absent. Based on the RHM, the N400 effect in L2 to L1 masked translation priming (i.e., L2 primes and L1 targets) in unbalanced bilinguals, where the link from L1 to L2 should be weak, is not expected. Note that the stronger link from L2 to L1 in the RHM can be supported by a masked priming effect with L1 primes and L2 targets because only targets are visible in a masked priming paradigm. Thus, task performance is facilitated only when targets are expected to be influenced by primes

(L1 primes to L2 targets). We therefore expect the priming effect from L1 primes to L2 targets to be greater than that from L2 primes to L1 targets (see also Jiang, 1999).

Another ERP study by Hoshino, Midgley, Holcomb, and Grainger (2010) examined within-language repetition priming in L1 and L2 as well as cross-script translation priming using the masked priming paradigm. In this experiment, Japanese-English bilinguals performed semantic categorization tasks. They found both N250 and N400 effects for L1 primes and L2 targets, but not for L2 primes and L1 targets. Thus, N250/N400 effects modulated by the L1-L2 direction were consistent with the asymmetric link between L1 and L2 postulated by the RHM.

In addition, the studies using ERP (Morris, Frank, Grainger, & Holcomb, 2007) or MEG (Cavalli et al., 2016; Pylkkänen, Feintuch, Hopkins, & Marantz, 2004; Solomyak & Marantz, 2010) showed that the N400 or M350 component is sensitive to morphological processing. For instance, Morris et al. (2007), using a masked morphological priming paradigm, demonstrated that both N250 and N400 effects were significant for semantically transparent derived words (e.g., *hunter-hunt*), but not for opaque pseudo-derived words (e.g., *corner-corn*). Thus, our cross-language morphological priming experiments with compound words will shed additional light on this issue.

In sum, ERP studies with bilinguals generally support the asymmetric link between L1 and L2 lexical representation by showing different patterns of the N250 and N400 components. In addition, the N400 (M350 for MEG) could also be regarded as a reliable component for morphological processing. Thus, we will focus on both N250 and N400 components in the present study to verify whether those components are sensitive to cross-language activation via morphological decomposition in biscriptal bilingual readers.

1.1. The present study

To determine how two languages in bilingual readers are connected, the present study investigates the following two issues: cross-language activation and morphological decomposition in compounds. Two ERP experiments with a masked priming lexical decision paradigm in unbalanced Korean-English bilinguals were conducted to examine whether the pattern of cross-language translation priming is consistent with the asymmetric link between L1 and L2 and whether the pattern occurs via morphological decomposition. The targets were Korean L1 compound words (e.g., 목선, "mok-seon," *neckline*) for Experiment 1, and English L2 compound words (e.g., *neckline*) for Experiment 2. There were three prime conditions; translated compounds (e.g., *neckline*, 목선, "mok-seon"), translated second constituents (*line*, 선, "seon"), or unrelated constituents (*work*, 일, "il").

Based on the previous studies demonstrating cross-language activation (e.g., from L1 primes to L2 targets) via morphological decomposition, we hypothesize that N400 effects will be significant or larger when Korean-English bilinguals are presented with Korean L1 primes and English L2 targets, based on the asymmetric pattern of N400 effect in translation priming for unbalanced bilinguals (Hoshino et al., 2010). In addition, this cross-language activation will be maintained via morphological priming when targets are compound words and primes are their constituents. Because translated compound primes are inherently semantically related to the compound targets, ERP components related to translated constituent primes will be critical in capturing morphological priming effects. Thus, we will additionally compare ERP responses to translated constituent primes and translated compound primes.

2. Methods

2.1. Participants

Twenty (12 female) right-handed Korean L2 late learners of English (mean age = 23 years, *SD* = 2) without immersion in an L2 English environment before puberty (corresponding to 12 years old) participated in the present experiment. They started learning English at about 10 years of age in a Korean elementary school. All the participants were undergraduate students and had normal or corrected-to-normal vision. In order to ensure the participants' moderate-to-high proficiency in L2 English, their proficiency was verified in two ways. First, they had reported high scores on a standardized English test (TOEIC: Test of English for International Communication, Maximum score: 990) as *M* = 887; *SD* = 54; range: 795–980.[1] Second, since the TOEIC score was self-reported, the participants were also tested with three English proficiency tests: a synonym test (N = 29) and an antonym test (N = 29) from Woodcock Johnson-III (Woodcock, McGrew, & Mather, 2001) and an English cloze test (adapted from O'Neill, Cornelius, & Washburn, 1981). The English cloze test included 40 sentences; the participants were asked to choose the word that would make a given sentence grammatically correct. The average accuracies of performance were 54.5% (*SD* = 11.4) for the synonym test, 60.6% (*SD* = 4.4) for the antonym test, and 80.3% (*SD* = 9.4) for the cloze test. Based on the previous studies that used the same tests (Cao, Tao, Liu, Perfetti & Booth, 2013; Kim et al., 2016 for the synonym and antonym tests; Ionin, Montrul, & Crivos, 2013 for the cloze test), we considered those scores as representing a moderate or high level of proficiency in English. The participants provided written informed consent and were paid for their participation.

[1] We take this range of TOEIC scores to represent an upper-intermediate or higher level of proficiency, on the basis of conversion from the TOEIC scores to the CEFR scores (the conversion matrix available at https://www.etsglobal.org/content/download/768/12037/version/8/file/TOEIC+L%26R+Descriptors-MAR089-LR.pdf). All of our participants' proficiency was at least B2 or above.

Table 1
Example stimuli.

Prime conditions	English targets		Korean targets	
	Prime	Target	Prime	Target
Translated compound	목선	neckline	neckline	목선
Translated constituent	선	neckline	line	목선
Unrelated constituent	일	neckline	work	목선

2.2. Stimuli

The experimental materials for the ERP study consisted of 96 real bilexemic Korean compound words and their English translated compound words. To determine the translated compound words, 10 Korean native speakers were asked to rate each translated compound word using a 4-point grading scale (“1” as the lowest preference and “4” as the highest preference). We excluded those words rated below 2 points. The mean of the translation preference for L2 to L1 was 2.6 ($SD = 0.3$), and that for L1 to L2 was 2.8 ($SD = 0.3$) (see Table 1 for stimulus samples). The frequencies of the English stimuli were determined using the CELEX English corpus (Baayen, Piepenbrock, & Gulikers, 1995), and those of the Korean stimuli were determined by the National Academy of the Korean Language (http://www.korean.go.kr).

Forty-eight compound words in each language were used as targets (e.g., 목선 “moksen,” *neckline*) and were preceded by masked primes in the other language that were 1) translated compounds (e.g., neckline), 2) translated constituents (e.g., line),[2] or 3) unrelated constituents (e.g., work). Following a Latin square design, three stimulus lists were created, each of which consists of 16 prime-target pairs per prime condition.

There was no difference in mean frequency between the three lists of the English target stimuli (first constituent: list 1 = 3.5, list 2 = 3.7, list 3 = 3.5; second constituent: list 1 = 3.7, list 2 = 3.7, list 3 = 3.7; $ps > .1$) and no difference in mean frequency between the three lists of the Korean target stimuli (first constituent: list 1 = 2.8, list 2 = 3.3, list 3 = 2.7; second constituent: list 1 = 2.9, list 2 = 3.1, list 3 = 3.0; $ps \geq .1$). To adjust the balance of each word–nonword decision, additional 48 word fillers and 96 nonword fillers (i.e., illegal combinations of two lexemes) were added as targets. In total, each participant was given 192 targets, composed of 96 words and 96 nonwords.

2.3. Semantic relatedness rating task

In addition, we measured the semantic relatedness between primes and targets to ensure that the three stimuli lists were properly matched in each experiment. Thirty-three (19 females) Korean late learners of English from the same subject pool who did not participate in the ERP experiments assessed to what extent the two words (used as a prime and a target) in one of the three stimulus lists were related in meaning using the 7-point Likert scale (1: not related, 7: highly related).

In the case of the English targets (translated compound: 목선 (neckline)-neckline; translated constituent: 선 (line)-neckline; unrelated constituent: 일 (work)-neckline), there was a significant difference between the three conditions, $F(2, 64) = 687.57$, $p < .001$, $\eta^2 = 0.96$. In pairs, there were significant differences between translated compound and unrelated constituent, $F(1, 32) = 1650.93$, $p < .001$; translated constituent and unrelated constituent, $F(1, 32) = 464.02$, $p < .001$; and translated compound and translated constituent, $F(1, 32) = 147.36$, $p < .001$ (the mean scores for the three prime conditions of translated compound, translated constituent, and unrelated constituent, were 6.5, 5.0, and 1.5, respectively). Note that the semantic relatedness for each stimuli list was matched ($p > .1$).

Similarly, in the Korean targets (translated compound: neckline-목선; translated constituent: line-목선; and unrelated constituent: work-목선), there was a significant difference between the three conditions, $F(2, 64) = 520.71$, $p < .001$, $\eta^2 = 0.94$. In pairs, there were significant differences between translated compound and translated constituent $F(1, 32) = 124.94$, $p < .001$; translated compound and unrelated constituent $F(1, 32) = 1196.37$, $p < .001$; and translated constituent and unrelated constituent $F(1, 32) = 363.62$, $p < .001$ (the mean scores for the three conditions, translated compound, translated constituent, and unrelated constituent, were 6.5, 4.7, and 1.4, respectively). Again, the semantic relatedness for each stimuli list was matched ($p > .1$).

2.4. Procedure

The participants were comfortably seated in a dimly lit, sound-attenuating room with an LCD monitor in front and a viewing distance of around 100 cm. Each experiment began with a short practice block. The participants were asked to progress at their own speed by pressing a button to begin each trial and respond as quickly and accurately as possible to indicate whether the stimulus presented was a word or not by pressing one of two response buttons. The trials were presented in black letters on a white screen in a 23-point Times New Roman font and operated with E-prime (Schneider, Eschman, & Zuccolotto, 2002). As shown in Fig. 1, each trial

[2] For the translated constituent prime condition, we used the second constituent based on the previous findings reporting the constituent masked priming effect regardless of the position of constituent in English (e.g., Alonso et al., 2016) or in Korean (Ko & Wang, 2015).

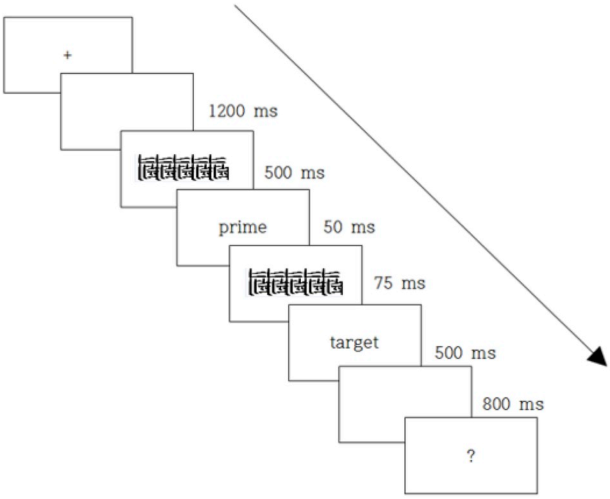


Fig. 1. Experimental procedure.

began with the presentation of a fixation point ("+") at the center of the screen, followed by a blank screen interval of 500 ms. The presentation consisted of a pre-mask for 500 ms, followed by a display of the prime for 50 ms and a post-mask for 75 ms. This was immediately followed by a presentation of the target on the screen for 500 ms. Following the target was a blank interval of 800 ms, and then the two possible answers (word and nonword) remained until the participant responded with a button press. After making a lexical decision, each participant was presented with a blank of 1000 ms to allow blinking. Half of the participants completed the English targets first, and the other half completed the Korean targets first.

2.5. EEG recording

Electroencephalograms (EEGs) were recorded from 30 Ag/AgCl electrodes, mounted in an electrode cap (Neuroscan Quikcap, USA): midline (Fz, FCz, Cz, CPz, Pz, Oz), lateral (FP1/2, F3/4, F7/8, FC3/4, FT7/8, C3/4, T7/8, CP3/4, TP7/8, P4/5, P7/8, O1/2), and referenced to linked mastoids. Additional electrodes were placed above and below the left eye and on the left and right outer canthus to monitor eye movements. The electrode impedances were kept below 5 kΩ. The EEG recordings were amplified by the SynAmps2 EEG amplifier using a band-pass from 0.3 to 100 Hz with a sampling rate of 1 kHz.

2.6. Data analysis

Before averaging, the trials with excessive eye-blink or movement artifacts were removed. ERPs were then calculated by averaging the EEG for the subsequent analysis. Average ERPs were based on 900 ms intervals, consisting of a 100 ms pre-stimulus baseline and 800 ms post-stimulus interval, and filtered at a low pass of 30 Hz.

For the statistical analyses, six regions of interest (ROIs) were used in ANOVAs, consisting of six pairs of two electrodes at each ROI: left anterior (LA: F3, FC3), left posterior (LP: CP3, P3), midline anterior (MA: FZ, FCZ), midline posterior (MP: CPZ, PZ), right anterior (RA: F4, FC4), and right posterior (RP: CP4, P4), as shown in Fig. 2.

These regions were organized into two topographic factors: laterality (left, midline, and right) and anteriority (anterior and posterior). Therefore, we performed repeated-measures ANOVAs with three within-subject factors: prime, laterality, and anteriority. For the significant effects, we applied the Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) and reported the uncorrected degrees of freedom and corrected *p*-values. Mean amplitudes were measured in three-time windows to examine the three primary ERP components in word recognition with masked priming, N/P150 (100–200 ms), N/P250 (200–300 ms), and N400 (350–500 ms).

3. Results

Figs. 3 and 4 show the grand average ERP responses to the target words in Korean L1 and English L2, respectively. Visual inspection revealed considerable differences between the two target languages at all intervals. The results from the omnibus ANOVA that included target language, prime, laterality, and anteriority factors showed a significant main effect of target language at all intervals: $F(1, 19) = 12.98$, $p < .01$ at the 100–200 ms interval, $F(1, 19) = 18.22$, $p < .001$ at the 200–300 ms interval, and $F(1, 19) = 12.98$, $p < .05$ at the 350–500 ms interval. Furthermore, there was a significant main effect of prime at the 350–500 ms interval, $F(2, 38) = 16.43$, $p < .001$, and a marginally significant effect of prime at the 100–200 ms interval, $F(2, 38) = 2.64$, $p = .09$. More interestingly, there was a significant language × prime interaction effect in both the 200–300 ms interval, F(2,

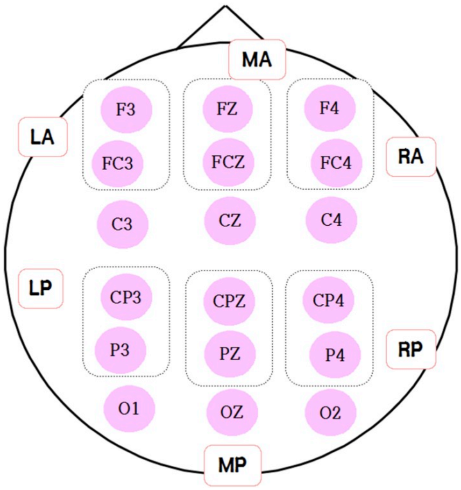


Fig. 2. Six regions of interest (ROIs): The grouped electrodes are those included for the analyses in the nine regions of interest.

38) = 4.08, $p < .05$, and 350–500 ms interval, $F(2, 38) = 10.98$, $p < .001$. To identify the source of these results, three sets of comparisons between the prime conditions were performed within each language. In the sections below, we analyzed the three ERP components, N/P150, N/P250, and N400, separately for Korean L1 targets and English L2 targets.

3.1. Experiment 1: English L2 primes – Korean L1 targets

3.1.1. Lexical decision accuracy

The mean accuracy of lexical decision on the Korean target compounds was 86.4% ($SD = 7.8$). There was a marginally significant difference between the three prime conditions, $F(2, 38) = 2.63$, $p = .09$, $\eta^2 = 0.12$.

3.1.2. ERP analyses

Both grand-average waveforms and topographic maps at the targets in the three prime conditions are shown in Fig. 3. At the 350–500 ms interval, visual inspection revealed a negativity (N400) in the unrelated constituent condition relative to the translated constituent condition or translated compound condition. In contrast, no difference was observed in the comparison of the translated constituent condition and the translated compound condition.

The overall ANOVA was first performed, and the pairwise comparisons were then carried out: unrelated constituent condition vs. translated compound condition, unrelated constituent condition vs. translated constituent condition, and translated constituent condition vs. translated compound condition. Additional comparisons within individual ROIs were also performed to better understand topographic differences (Table 2).

3.1.3. 100–200 ms interval (N/P150)

The results of the overall ANOVA at the 100–200 ms interval showed no effect of prime, but showed a significant main effect of laterality, $F(2, 38) = 9.08$, $p < .01$, and a marginal prime × anteriority interaction effect, $F(2, 38) = 2.77$, $p = .08$. The pairwise analyses and the additional comparisons within individual ROIs did not reveal any significant effects.

3.1.4. 200–300 ms interval (N250 or P250)

The overall ANOVA at the 200–300 ms interval showed no effect of prime, but significant main effects of laterality, $F(2, 38) = 13.98$, $p < .001$, of anteriority, $F(1, 19) = 11.55$, $p < .01$, and a significant prime × laterality interaction effect, $F(4, 76) = 3.05$, $p < .05$. The pairwise analyses and the individual ROI analyses did not reveal any significant effects.

3.1.5. 350–500 ms interval (N400)

The overall ANOVA at the 350–500 ms interval showed significant main effects of prime, $F(2, 38) = 8.34$, $p < .01$, and of anteriority, $F(1, 19) = 5.89$, $p < .05$. In pairwise analyses, the unrelated constituent condition relative to the translated compound condition elicited significant effects of prime, $F(1, 19) = 7.92$, $p < .01$ (with a posterior distribution of N400), and of anteriority, $F(1, 19) = 7.30$, $p < .05$. In addition, the unrelated constituent condition relative to the translated constituent condition showed significant effects of prime, $F(1, 19) = 15.59$, $p < .01$ (with a widely-distributed N400), and of anteriority, $F(1, 19) = 5.88$, $p < .05$. The translated constituent condition relative to the translated compound condition showed no significant effect.

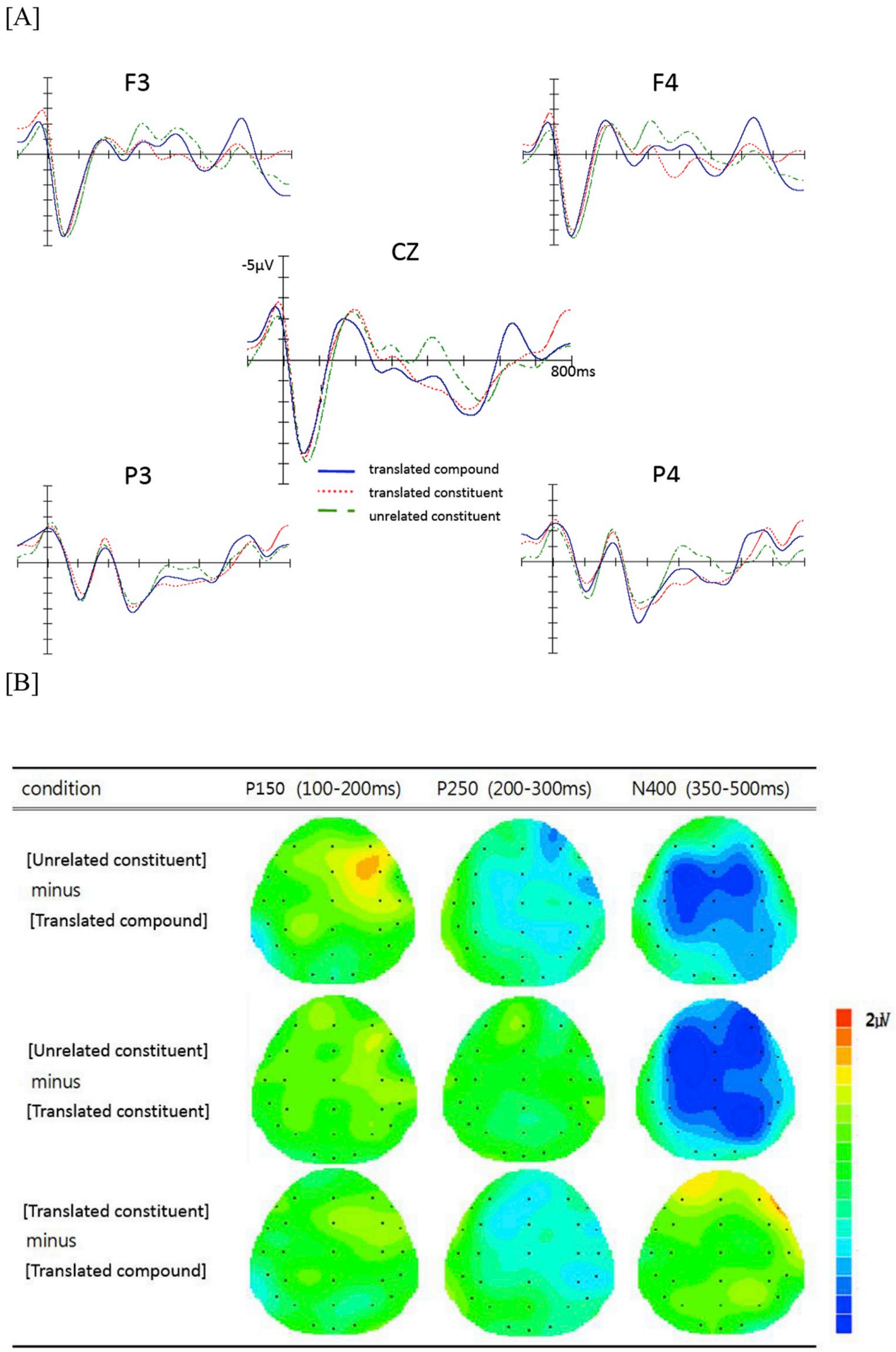
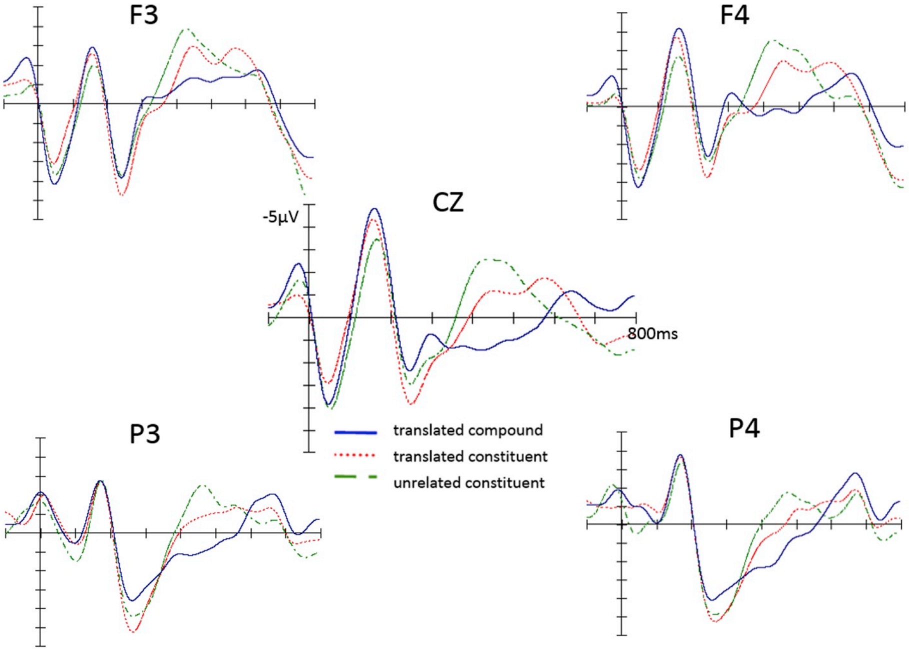


Fig. 3. [A] Grand average ERPs for each contrast from Experiment 1 (English L2 primes and Korean L1 targets). The contrasts are 1) the Korean compound targets with the translated English compound primes (blue solid line), 2) with the translated English constituent primes (red dot line), and 3) with the unrelated English constituent primes (green dash-dot line). [B] Topographical distribution of the prime effect in terms of amplitude differences between two conditions: (1) unrelated constituent minus translated compound, (2) unrelated constituent minus translated constituent, and (3) translated constituent minus translated compound. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

[A]



[B]

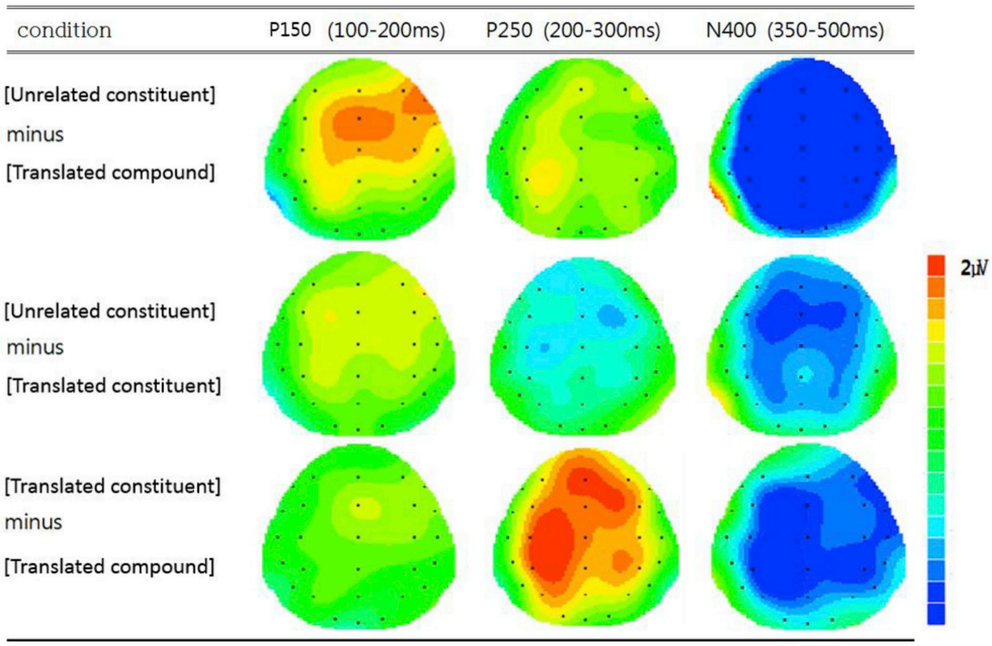


Fig. 4. [A] Grand average ERPs for each contrast from Experiment 2 (Korean L1 primes and English L2 targets). The contrasts are 1) the English compound targets with the translated Korean compound primes (blue solid line), 2) with the translated Korean constituent primes (red dot line), and 3) with the unrelated Korean constituent primes (green dash-dot line). [B] Topographical distribution of the prime effect in terms of amplitude differences between two conditions: (1) unrelated constituent minus translated compound, (2) unrelated constituent minus translated constituent, and (3) translated constituent minus translated compound. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Summary of ANOVA results for Experiment 1 (English L2 primes and Korean L1 targets).

Factor	100–200 ms			200–300 ms			350–500 ms		
Overall ANOVA									
Prime	–			–			8.34**		
Laterality	9.08**			13.98***			–		
Anteriority	–			11.55**			5.89*		
Prime × Laterality	–			3.05*			–		
Prime × Anteriority	2.77†			–			–		
Prime × Laterality × Anteriority	–			–			–		
	T vs. U	C vs. U	C vs. T	T vs. U	C vs. U	C vs. T	T vs. U	C vs. U	C vs. T
Pairwise									
Prime	–	–	–	–	–	–	7.92*	15.59**	–
Laterality	8.88**	7.59**	9.36**	12.87***	11.44***	15.51***	–	–	–
Anteriority	–	–	–	9.43**	17.01**	8.0*	7.30*	5.88*	3.98†
Prime× Laterality	–	–	–	5.33*	–	2.75†	–	–	–
Prime× Anteriority	4.83*	–	–	–	–	–	–	–	–
Prime× Laterality × Anteriority	–	–	–	–	–	2.88†	–	–	–
Individual ROIs									
Left anterior	–	–	–	–	–	–	3.92†	9.56**	–
Left posterior	–	–	–	–	–	–	10.81**	13.25**	–
Midline anterior	–	–	–	–	–	3.51†	4.29*	9.79**	–
Midline posterior	–	–	–	–	–	–	10.60**	18.31***	–
Right anterior	3.05†	–	–	–	–	–	3.66†	12.30**	–
Right posterior	–	–	–	–	–	3.40†	12.91**	22.46***	–

Note. T: Translated compound; C: Translated constituent; U: Unrelated constituent.
**$p < .001$, **$p < .01$, *$p < .05$, †$.05 < p < .1$.

3.2. Experiment 2: Korean L1 primes - English L2 targets

3.2.1. Lexical decision accuracy

The mean accuracy of lexical decision on the English target compound words was 67.3% ($SD = 9.8$). There was a significant difference between the three prime conditions, $F(2, 38) = 8.09$, $p < .01$, $\eta^2 = 0.30$.

3.2.2. ERP analyses

Both grand-average waveforms and topographic maps at the targets in the three prime conditions are shown in Fig. 4. Visual inspection revealed more positivity in the translated constituent condition than the other conditions at the 200–300 ms interval (P250). At the 350–500 ms interval, the unrelated constituent condition and the translated constituent condition relative to the translated compound condition showed a negativity (N400). At the 100–200 ms interval, the unrelated constituent condition relative to the translated compound or translated constituent conditions showed a positivity at the anterior region (P150). The overall ANOVA and additional comparisons within individual ROIs are summarized in Table 3.

3.2.3. 100–200 ms interval (N/P150)

The overall ANOVA at the 100–200 ms interval showed significant main effects of prime, $F(2, 38) = 3.53$, $p < .05$, and of laterality, $F(2, 38) = 13.27$, $p < .001$. Furthermore, there was a significant prime × anteriority interaction effect, $F(2, 38) = 4.15$, $p < .05$, and a significant three way interaction effect of prime × laterality × anteriority, $F(4, 76) = 5.22$, $p < .001$. In pairwise analyses, the unrelated constituent condition relative to the translated compound condition elicited significant effects of prime, $F(1, 19) = 7.25$, $p < .05$ (with an anterior focus of the positivity), and of laterality, $F(2, 38) = 12.89$, $p < .001$, and also a significant prime × anteriority interaction effect, $F(1, 19) = 6.80$, $p < .05$, and a significant prime × laterality × anteriority three way interaction effect, $F(2, 38) = 10.20$, $p < .001$. In addition, the unrelated constituent condition relative to the translated constituent condition elicited significant effects of prime, $F(1, 19) = 4.05$, $p = .05$, and of laterality, $F(2, 38) = 10.68$, $p < .001$, but no interaction effect. There was no effect of prime in comparison of the translated constituent condition with the translated compound condition, but significant effects of laterality and prime × laterality × anteriority interaction were found.

3.2.4. 200–300 ms interval (N250 or P250)

The overall ANOVA at the 200–300 ms interval showed significant main effects of prime, $F(1,19) = 3.23$, $p = .05$, of laterality, $F(2, 38) = 6.87$, $p < .01$, and of anteriority, $F(1, 19) = 6.71$, $p < .05$. In pairwise analyses, the unrelated constituent condition relative to the translated compound condition showed no effect of prime, but revealed significant effects of laterality, $F(2, 38) = 7.33$, $p < .01$, and of anteriority, $F(1, 19) = 6.55$, $p < .05$. Similarly, the unrelated constituent condition relative to the translate constituent condition showed no effect of prime, but revealed significant effects of laterality, $F(2, 38) = 6.40$, $p < .01$, and of anteriority,

Table 3
Summary of ANOVA results for Experiment 2 (Korean L1 primes and English L2 targets).

Factor	100–200 ms			200–300 ms			350–500 ms		
overall ANOVA									
Prime	3.53*			3.23*			19.13***		
Laterality	13.27***			6.87**			22.78***		
Anteriority	–			6.71*			34.23***		
Prime × Laterality	–			–			–		
Prime × Anteriority	4.15*			–			–		
Prime × Laterality × Anteriority	5.22**			–			6.42**		
	T vs. U	**C vs. U**	**C vs. T**	**T vs. U**	**C vs. U**	**C vs. T**	**T vs. U**	**C vs. U**	**C vs. T**
pairwise									
Prime	7.25*	4.05*	–	–	–	6.27*	25.64***	11.45**	13.59**
Laterality	12.89***	10.68***	14.88***	7.33**	6.40**	6.10**	15.54***	15.30***	23.96***
Anteriority	–	–	–	6.55*	7.98*	4.83*	34.07***	29.27***	27.81***
Prime × Laterality	2.62†	–	–	–	–	3.02†	34.28*	3.57*	–
Prime × Anteriority	6.80*	–	–	–	–	–	–	–	–
Prime × Laterality × Anteriority	10.20***	–	4.24*	–	–	3.15*	8.86**	–	9.78***
at individual ROIs									
Left anterior	5.58*	3.00†	–	–	–	4.95*	14.35**	7.09*	4.95*
Left posterior	3.02†	–	–	–	–	9.99**	24.99***	3.30†	20.02***
Midline anterior	11.24**	4.38*	–	–	–	5.91*	23.13***	24.48***	6.81*
Midline posterior	3.18†	–	–	–	–	8.00*	26.06***	7.83*	14.57***
Right anterior	17.99***	8.44**		–	–	3.80†	27.78***	6.47*	12.72**
Right posterior	–	–		–	–	4.00†	27.76***	6.81*	13.18**

Note. T: Translated compound; C: Translated constituent; U: Unrelated constituent.
***$p < .001$, **$p < .01$, *$p < .05$, †$.05 < p < .1$.

$F(1, 19) = 7.98$, $p < .05$. The translated constituent condition relative to the translated compound condition elicited significant effects of the prime, $F(1, 19) = 6.27$, $p < .05$ (with a left-lateralized positivity), of laterality, $F(2, 38) = 6.10$, $p < .01$, of anteriority, $F(1, 19) = 4.83$, $p < .05$, and a significant prime × laterality × anteriority interaction effect, $F(2, 38) = 3.15$, $p = .05$.

3.2.5. 350–500 ms interval (N400)

The results of the overall ANOVA at the 350–500 ms interval showed significant main effects of prime, $F(2, 38) = 19.13$, $p < .001$, of laterality, $F(2, 38) = 22.78$, $p < .001$, of anteriority, $F(1, 19) = 34.23$, $p < .001$, and a significant interaction effect of prime × laterality × anteriority, $F(4, 76) = 6.42$, $p < .001$.

In pairwise analyses, the comparison of the unrelated constituent condition with the translated compound condition elicited significant effects of prime, $F(1, 19) = 25.64$, $p < .001$ (with a widely-distributed N400), of laterality, $F(2, 38) = 15.54$, $p < .001$, of anteriority, $F(1, 19) = 34.07$, $p < .001$, and a significant interaction effect of prime × laterality × anteriority, $F(2, 38) = 8.86$, $p < .001$. Furthermore, the unrelated constituent condition relative to the translated constituent condition yielded significant effects of prime, $F(1, 19) = 11.45$, $p < .05$ (with an anterior focus of negativity), of laterality, $F(2, 38) = 15.30$, $p < .001$, of anteriority, $F(1, 19) = 29.67$, $p < .001$, and a significant interaction effect of prime × laterality, $F(2, 38) = 3.57$, $p < .05$. Similarly, the translated constituent condition relative to the translated compound condition elicited significant effects of prime, $F(1, 19) = 13.59$, $p < .01$ (with a widely-distributed N400), of laterality, $F(2, 38) = 23.96$, $p < .001$, of anteriority, $F(2, 38) = 27.81$, $p < .001$, and a significant interaction effect of prime × laterality × anteriority, $F(2, 38) = 9.78$, $p < .001$.

Table 4 summarizes a time-course analysis of the cross-language morphological priming effects tested in the present study at 100–200 ms, 200–300 ms, and 350–500 ms after the onset of each target. The unrelated constituent primes, as compared to the translated compound or constituent primes, elicited N400 effects for both L1 and L2 targets, and P150 effects only for L2 targets. Both P250 and N400 effects were found in the constrast of the translated constituent primes and the translated compound primes only for L2 targets.

Table 4
Summary of the significant ERP results.

Contrasts	Prime – Target English L2 – Korean L1	Prime – Target Korean L1 – English L2
Unrelated constituent vs. Translated compound	N400	P150 & N400
Unrelated constituent vs. Translated constituent	N400	P150 & N400
Translated constituent vs. Translated compound	No effect	P250 & N400

3.3. ERP evidence for the asymmetric link between L1 and L2

To test whether the asymmetric link between L1 and L2 (e.g., the RHM model) can be bolstered by our ERP results, we compared the differences in ERP responses between the two prime conditions in both directions (Korean L1 primes to English L2 targets, and vice versa).

The ERP amplitude in comparison of the unrelated constituent condition with the translated compound condition was significantly larger when L1 primes L2 than when L2 primes L1 at all time intervals: $F(1, 228) = 3.79$, $p = .05$ at 100–200 ms interval (N/P150); $F(1, 228) = 13.53$, $p < .001$ at 200–300 ms interval (N/P250); $F(1, 228) = 28.17$, $p < .001$ at 350–500 ms interval (N400). The ERP amplitude in comparison of the translated constituent condition with the translated compound condition was also significantly larger for the L1 to L2 than the L2 to L1 at the two time intervals: $F(1, 228) = 41.17$, $p < .001$ at 200–300 ms interval (N/P250); $F(1, 228) = 61.09$, $p < .001$ at 350–500 ms interval (N400). Finally, the ERP amplitude in comparison of the unrelated constituent condition with the translated constituent condition was marginally or significantly larger for the L1 to L2 than the L2 to L1 at the two time intervals: $F(1, 228) = 3.05$, $p = .082$ at 200–300 ms interval (N/P250); $F(1, 228) = 3.94$, $p < .05$ at 350–500 ms interval (N400). Taken together, the significant differences in ERP patterns between the prime conditions in the L1 to L2 than in the L2 to L1 were consistent with some of the previous accounts for the asymmetric link between the languages (e.g., Kroll & Stewart, 1994).

4. Discussion

In the following discussion, we rely on the general framework proposed by Holcomb and Grainger (2006, 2007; see Grainger & Holcomb, 2009, for a review) to account for the ERP effects observed with the masked priming paradigm. In these studies, the earliest effect of within-language repetition priming was obtained in the N/P150 component, which is taken to represent the mapping of visual features onto pre-lexical orthographic representations. Following the N/P150, the two major components modulated by masked repetition priming, the N/P250 and N400, are understood to primarily represent form-level processing and semantic-level processing, respectively. Specifically, the N/P250 component is taken to represent the processing associated with mapping pre-lexical forms onto whole-word forms. The N400 component, as found in single-word paradigms, is known to represent a range of processing associated with mapping whole-word forms onto semantics. As suggested by Grainger and Holcomb (2009), we expect the effects represented in either of the two components to be most robust when feedforward (from morphology to semantics) and feedback (vice versa) processes occur as the mapping process converges into a stable state.

The translation and morphological priming effects in compound processing observed in the present study replicate the findings by Holcomb and his colleagues and generalize them to cross-language compound processing. It should be noted that the pattern of the L1-L2 translation and morphological priming effects in compound processing differ from that of the effects in within-language repetition priming, observed in the same time-windows. The results point to the fact that different mechanisms engendered the priming effects because there was no visual overlap between the primes and targets in the L1-L2 translation and morphological priming conditions.

Given the general framework epitomized above, there are two ways that the translated constituent primes relative to the translated compound primes could induce effects in the P250 component.[3] Since the N400 effects observed in the comparisons of the unrelated constituents with the translated constituents/compounds for both language directions could be due to either morphological relatedness or semantic relatedness, or both, the significant ERP effects from the translated constituents relative to the translated compounds would be influenced by the early morphological segmentation (see Solomyak & Marantz, 2010). It is possible that the L1 primes activated the L2 compound word forms via direct associations already established between them, as the assumption of the stronger link of L2 to L1 than of L1 to L2 in the RHM (Kroll & Stewart, 1994). Thus, one might predict a stronger masked priming effect with L1 primes and L2 targets, which is evident in the present study. In line with Midgley et al. (2009), we also argue that the L1-L2 morphological priming effect on the P250 component, particularly in the translated constituent condition relative to the translated compound condition, likely follows from the semantic representations activated by the prime stimuli affecting the activation of form-level representations during target word processing. This argument is also in keeping with the findings of the recent ERP studies. A larger P250 was found for semantically related compound words than for semantically unrelated compound words, demonstrating that semantic relatedness can facilitate the morphological decomposition of compound words in an early stage (Chung, Tong, Liu, McBride-Chang, & Meng, 2010). In relatively proficient bilinguals, L1 translated words corresponding to the L2 words are activated after accessing meaning of the L2 words (Guo, Misra, Tam, & Kroll, 2012).

Alternatively, one could say that L1 or L2 words automatically evoke the corresponding phonological (Spalek, Hoshino, Wu, Damian, & Thierry, 2014) or lexical information (Thierry & Wu, 2007) through unconscious access to a non-target language. Note that those two studies found non-selective access in bilinguals when the target was their L2. Indeed, one key finding of the present study is the relatively early onset of the L1-L2 cross-language morphological priming effect on ERPs. Masked cross-language translation priming is possibly the ideal test for early semantic contributions to visual word recognition. The switch in script across primes and targets provides an optimal testing ground for prime word processing by 1) excluding pre-lexical orthographic

[3] In the following discussion, we put aside the ERP component P150 detected in the unrelated constituent prime condition vs. the translated constituent/compound prime condition. This component is known to reflect a process triggered by presentation of a printed word and primarily involves feature representations. See Holcomb and Grainger (2006, 2007) and Spironelli, Angrilli, and Stegagno (2008) for the relevant discussion.

interference from target words and 2) offering bottom-up information of the language to which prime words belong. With L2 targets, the present study revealed quite a large ERP effect for translated constituent primes compared to translated compound primes in L1 in compound processing. The L1-L2 cross-language morphological priming effects started to accumulate at around 200 ms post-target onset, mostly in posterior regions, and were robust at 250 ms of the main analysis. The timing of the L1-L2 translation priming effects observed in the present study therefore suggests that a switch in script across primes and targets does indeed facilitate prime word processing in the highly stringent condition of masked priming. It is this pertinent processing of prime stimuli in cross-language priming that is taken to elicit ERP effects in morphological priming.

As noted above, Grainger and Holcomb (2009) and Holcomb and Grainger (2006, 2007) suggested that the mapping of pre-lexical forms onto whole-word forms is represented in the EEG signal in the time window roughly spanning 200–300 ms. The early translation priming effect would therefore appear to refute our interpretation of the influence of masked primes on ERP waveforms. However, in a cascaded processing system, semantic representations may have already been made available within this time window by the fastest feedforward processes, with semantic processing about to begin. Indeed, our results indicate that, given the 125 ms SOA used in the present study, semantic representations were beginning to significantly affect target compound word processing at about 200 ms post-target onset. Moreover, it might be that the speed of access to semantics was further prompted in the L1-L2 translated constituent prime condition of the present study. However, neither the L1-L2 unrelated prime condition nor the L2-L1 conditions of the present study would show such an early effect because semantic relatedness between primes and targets is a prerequisite for morphological processing/decomposition, and because L2 primes have no influence on L1 targets. In contrast, if the source of the effect were a switch in script across primes and targets, we would observe the early translation morphological priming effect regardless of the language of the target words; this was not observed in our study.

Although some studies have reported L2-L1 translation priming (e.g., Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2010; Duyck & Warlop, 2009; Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009), L2-L1 and L1-L2 translation priming effects are typically manifested asymmetrically. Previous behavioral studies using masked priming with biscriptal bilinguals observed a reliable L2-L1 translation priming effect when the task was semantic categorization (Finkbeiner, Forster, Nicol, & Nakamura, 2004), but not when the task was lexical decision (Gollan et al., 1997; Jiang, 1999). By contrast, Schoonbaert et al. (2011) showed that a prime duration (100 ms) induced L2-L1 translation priming effects both in lexical decision RTs and in terms of modulation of the N250 and N400 ERP components with English-French bilinguals. Recall that, using a lexical decision task with 125 ms SOA (prime duration = 50 ms), our experiment observed bi-directional (L2-L1 & L1-L2) translation priming effects (N400), in the comparison of the (semantically) unrelated constituent prime condition either with the translated compound prime condition or with the translated constituent prime condition..

As discussed above, morphological priming involves both form and semantic mapping across translated constituent primes and compound targets. In other words, if primes are processed up to the point of activating both form-level representations and semantic representations, then morphological and semantic priming effects will be observed in the presence of translation priming. In fact, in our study, these effects (P250 and N400) arose in L1-L2 morphological priming. However, the N400, but not the P250, component arose in the (semantically) unrelated constituent prime condition because this condition has no chance of evoking form-level representations to facilitate the subsequent mapping of form representations onto semantics during target processing.

One limitation of the current study concerns the non-matched semantic relatedness between the translated compounds and the translated constituents. We found that the semantic relatedness scores for the translated compound primes were significantly higher than those for the translated constituent primes [$F(1, 32) = 147.36$, $p < .001$ for the English targets, $F(1, 32) = 124.94$, $p < .001$ for the Korean targets]. This result indicates that semantic relatedness may come into play as a confounding factor. A more strategic selection of stimuli should be considered in future research to control the semantic relatedness in question. Another limitation also concerns controlling the semantic ambiguity between monosyllabic (e.g., 선, “seon”, *line*) and multisyllabic constituent primes (e.g., 꼬리, “kkoli”, *tail*) in the translated Korean constituent prime condition. A syllable in Korean generally tends to have many homographs/homophones. Due to the same issue as in semantic relatedness (i.e., the limited number of available items), we could not manage to control the level of semantic ambiguity for the inventory of translated constituents. Based on the number of meanings, we found that the monosyllabic constituents were indeed more ambiguous ($M = 5.47$, $SD = 4.95$) than the multisyllabic constituents ($M = 1.63$, $SD = 0.82$).

Another issue in the present study is whether the asymmetric ERP amplitude patterns depending on the language direction may be modulated by L2 proficiency.[4] Our additional correlation analyses between the ERP responses and the participants' proficiency (i.e., their TOEIC scores) did not reveal any difference at any region or interval in any condition ($ps > .1$). This is probably because the number of participants is relatively small, and/or their proficiency scores ranged within a similar English L2 level.

In conclusion, the present study provides evidence of fast access to morphological and semantic representations in masked priming with Korean-English bilinguals. Our findings showed that the ERPs (N400) induced by target compounds were modulated by their translated compounds or translated constituents, suggesting a symmetric pattern of translation priming between L1 and L2. The N400 effect for the translated constituent primes also implies that translation priming may occur via morphological decomposition. This morphological priming effect was confirmed by significant P250 and N400 for the contrast of translated constituents vs. translated compounds.

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