Processing semantic and phonological factors in derivational morphology by Korean L2 learners of English: An ERP cross-modal priming study

Myung-Kwan Park** · Wonil Chung***
(Dongguk University)

Park, Myung-Kwan and Chung, Wonil. 2012. Processing semantic and phonological factors in derivational morphology by Korean L2 learners of English: An ERP cross-modal priming study. Linguistic Research 29(3), 639-664. This paper examines L2 processing of derivational morphology in English. Derivational morphology in English is known to differ from inflectional morphology, in that unlike the latter whose well-known example is regular and irregular verbal morphology, the former varies in light of regularity. That is, derivational morphology does not display a categorical, regular and irregular distinction, but involves semantic and phonological/phonetic factors in shaping its various word structures. We focus on these aspects of derivational morphology to examine how Korean L2 learners of English comprehend semantic and phonological factors in processing derivational morphology. We use the event-related potentials (ERPs) paradigm to capture the finer-grained time course of processing it. It is shown in this paper that L2 learners of English start with processing both simple and derivationally complex words on the phonological level, as can be seen from the finding that only phonological/phonetic priming effects arise in the early N400 time window (324-400ms). But at the immediately following stage of processing they engage in processing derivationally complex words on the semantic level, as can be seen from the finding that only semantic priming effects arise in the late time interval (400-476ms). Since for L1 native speakers this semantic processing in fact starts in the early N400 time window, L2 learners of English are taken to be a little slower than L1 native speakers in processing derivationally complex words. Furthermore, unlike L1 native speakers, the L2 learners are found to have difficulty in understanding cumulative features of semantic and phonological/phonetic properties in processing morphologically related words.

(Dongguk University)

Keywords derivational morphology, inflectional morphology, categorical distinction, graded effects, event-related potentials, (reduced) N400, priming effects,

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** First Author *** Corresponding Author

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1. Introduction

Recent studies on the processing of words have investigated whether grammatical morphology constitutes an independent mechanism of language apart from lexical structure and processing (Marslen-Wilson et al. 2008). One particularly interesting issue on word processing is whether morphologically complex words like *acceptable* are comprehended differently from morphologically simple words like *accept*. In fact, morphologically complex words provide a window into the relation between their phonological and semantic forms because stems or affixes making up them are repeated in words with similar meaning (e.g., *bearable, walkable, beatable*). In other words, many stems or affixes are productive, such that they can occur widely to both familiar and novel forms. Thus, morphologically complex forms in contrast to morphologically simple ones are important in studying the structure of language representations.

Recent understanding of the nature of morphological complexity has been enhanced with studies of inflectional morphology, perhaps the most celebrated example being past tense in English. Interesting in this regard is the finding that they fall into two distinct types, regular and irregular forms. This distinction has been made by drawing on the differences with regards to how they are learned by children and processed by adults (McClelland and Patterson 2002; Pinker and Ullman 2002). In contrast, derivational morphology debatably does not have such a categorical distinction between regular and irregular forms. Rather, there are more sophisticated differences between derived forms and stems in regard to the degree of semantic and phonological relatedness. For example, some derived words have meanings that are transparently related to the meaning of their stems (e.g., *successful-success*); nor do these forms change the pronunciation and the stress pattern of the stem upon affixation. But not all forms are equally transparent. The meaning of the stem *depart* is not completely preserved in the word *department*. Similarly, *crime* is related in meaning to *criminal*; however, the stem is phonologically changed. These differences in morphological transparency have drawn attention because they might be used to test the validity of the theory that proposes
a clear-cut distinction in the neurocognitive systems dedicated to processing regular vs. irregular morphemes.

What’s more, English derivational morphology has a number of other properties that make it more suitable to psycholinguistic inquiry than inflectional morphology. Regular and irregular derived forms are apparently similar in several respects: they both involve affixes, even if they are not all allegedly broken or decomposed into parts (e.g., department and dresser are presumably not derived from depart and dress). Moreover, regular and irregular derived forms do not tend to differ with respect to frequency, which allows us to compare them directly in studying the neural structure of human language system.

1.1 How words are morphologically represented

1.1.1 A dual mechanism

A variety of theories have been brought forward arguing that language users break apart and store morphologically complex words as constituents (Taft and Forster 1975), and that such processes use a distinct type of linguistic knowledge that extends beyond meaning and sound (Stolz and Besner 1998). The idea of breaking apart words has led to the development of dual mechanism models that distinguish transparent words from opaque ones (Marslen-Wilson et al. 1994). On this theory, a word is either decomposed or processed as a whole, and these two different modes of processing depend on the semantic relationship between a word and its corresponding stem. Semantically transparent words are decomposed into stems and affixes and represented and processed compositionally (e.g., predict +able). On the other hand, semantically opaque words are stored as unanalyzed wholes (e.g., *ten +able). Some recent studies, however, reported facilitation effects for opaque words in the context of masked priming (cf. Rastle et al. 2004). They suggest the presence of a letter- or orthography-based morphological decomposition process involved at early stages of word recognition.
1.1.2 A convergence of linguistic codes approach

Decompositional approaches account for examples in which word forms can be categorically transparent or opaque. However, it is not easy for them to explain intermediate examples that are neither completely transparent nor opaque. English derivational morphology seems to be abundant with these graded effects, as it displays partial regularities.

According to the alternative view of convergence of codes, morphology does not rely on a set of lexical and/or rule representations, but is instead a cumulative mapping between orthography, phonology and semantics (Rumelhart and McClelland 1986). This view assumes a nonlinear interaction between semantic and formal (phonological/phonetic and/or orthographic) similarity; the combined contribution of formal and semantic relation tends to be greater than the simple effect of one or the other. As a result of this assumption, this view treats morphology as not an independent level of knowledge but a special case of lexical knowledge in which statistical regularities account for systematic relations between form and meaning information.

Likewise, this view takes a different approach to lexical processing from the decomposition theory, which assumes that any opaque derived word should be lexicalized and processed as a whole. A key feature of the former view is its ability to account for different degrees of morphological relatedness, i.e. semantic and formal (phonological and/or orthographic) similarity. For example, some words consist of morphemes that seem to contribute to their meaning but in a different way depending on different degrees of morphological relatedness. Thus, whereas discover might be decomposed into two morphemes dis- and cover, the morpheme cover presumably contributes less to the meaning of discover than that to that of uncover. This view also distinguishes different degrees of phonological relatedness depending on the amount of formal overlap between words. For example, words like pirate-piracy are more phonologically transparent than words like sign-signal that are phonologically opaque as unlike the former, the latter involve a change in the vowel of the stem.
1.2 Priming approaches to morphological processing

Crucial data about morphological processing come from studies of morphological priming (Rastle et al. 2000). The common finding among these approaches using priming paradigms shows that prior exposure to morphologically complex words like *engagement* can make it easier to process the target word like *engage* from which it is derived. Morphologically related words are associated with both form and meaning. Thus, previous studies have sought to find pure morphological effects by comparing and contrasting effects of shared morphology with the effects of not morphological, but only orthographical and phonological similarity, as in the pairs like *cars-car* vs. *card-car* (cf. Murrell and Morton 1974), or effects resulting only from semantic similarity, as in the pairs like *vowed-vow* vs. *pledge-vow* (cf. Kempley and Morton 1982). It has been generally acknowledged that lexical decisions are made easier by morphologically related primes than by unrelated primes designed on exclusively formal (Napps and Fowler 1987) or semantic similarity to targets (Napps 1989).

The decomposition theory predicts that there is an absolute distinction in priming between regular and irregular morphological forms, but the theory of convergence of codes implies that morphological relatedness is a graded rather than absolute factor. In other words, according to the latter theory, priming effects will tend to reply on the degree of semantic and formal relatedness. Thus, these effects should be interactive, such that combined effects of formal and semantic factors are greater than what is observed for each individual factor (Feldman 2000). In a nutshell, priming effects for morphologically related words are taken to come from the joint contribution of formal and semantic similarity.

There is some evidence supporting this view. For example, Stanners et al. (1979) found that orthographically dissimilar word pairs like *hung-hang* produce less priming effects than orthographically similar word pairs like *walked-walk*. In fact, across a series of morphological priming studies (Fowler et al. 1985), there has been a tendency to less priming when formal similarity is reduced. Similarly, in a cross-modal study, Gonnerman et al. (2007) observed that the magnitude of priming matches the degree of semantic and phonological relatedness.
1.3 The present study

To examine the time course and scalp distribution of morphological priming effects measured for Korean L2 learners of English, the present work replicates Kielar et al. (2011) by using the ERP paradigm. Especially, this study may allow us to look into how Korean L2 learners of English distinguish processes related to phonology, semantics and morphology by investigating the relative time course and scalp distribution of priming effects resulting from each of these factors.

In our study, ERPs were measured to lexical decisions using a cross-modal priming technique. Cross-modal priming has been shown in prior studies to be effective in examining the morphological relatedness between words (Marslen-Wilson et al. 1994). Furthermore, this technique of presenting prime and target words in different modalities is known to minimize effects due to the orthographic similarity of the two items. The design of the present study focuses on some important characteristics of derivational morphology in English, where different processes vary with respect to their productivity and semantic relatedness. In particular, we took an approach in which the degree of shared form or shared meaning was also manipulated while holding morphological relatedness constant. More specifically, stem forms as target stimuli were visually presented after (i) either their derived forms like successful-success or (ii) unrelated words like delightful-success. The priming effects were calculated by comparing the amplitude of the ERPs to related and unrelated stems. One ERP component we were interested in was N400, which is known to vary depending on primed or unprimed targets (Bentin et al. 1985). In particular, the amplitude of N400 is known to reflect the lexical-semantic aspects of language processing and/or integration processes (Kutas and Federmeier 2000), such that its amplitude mirrors the ease of accessing or activating a word in memory (Holcomb 1988).

To identify the exact locus of ERPs for priming effects, we manipulated semantic and phonological relationships between prime and target pairs along with morphological relatedness. First, phonological relatedness was examined by varying the phonological similarity of semantically similar prime-target pairs, that is, both phonologically transparent pairs like successful-success, where the stem form is constant, and partially transparent pairs like decision-decide, where the stress pattern and vowel of the stem change. Second, semantic relatedness was examined by
processing semantic and phonological factors in derivational morphology ...

contrasting semantically transparent pairs like *successful-success* with semantically intermediate pairs like *dresser-dress* and semantically opaque pairs like *department-depart*. Third, the independent contributions of phonology and semantics were measured by the words that were morphologically unrelated but related either only in phonology like *planet-plan* or meaning like *fortune-wealth*.

In our study, if there is an asymmetrical distinction between semantically transparent words and semantically opaque words based on their morphological structure, we should observe a clear distinction in the magnitude, timing or distribution of ERP priming effects for the two types of words. Furthermore, the decomposition theory predicts that the semantically quasi-regular, intermediate cases should produce priming effects that are similar to those of the opaque cases. Similarly, this theory predicts that phonologically intermediate prime target pairs like *decision-decide* should not produce N400 priming effects because they cannot be easily decomposed.

If, on the other hand, morphological effects are attributed to the correlation between formal and semantic factors as predicted by the theory of convergence of codes, then N400 priming effects are expected for all morphologically related words, but the size of these effects will vary with the degree of formal and semantic relatedness among them. Transparently derived forms like *successful-success*, which are highly similar in form and meaning, are expected to reduce the amplitude of the N400 component more strongly than opaquely derived forms like *department-depart*, which are related in form but not in meaning. On the other hand, quasi-regular cases like *dresser-dress* should yield intermediate effects compared to transparently and opaquely derived forms. Furthermore, it is expected that the size of the N400 priming effects will be affected by the degree of form similarity. The priming-related N400 effects are expected to be more reduced for pairs like *farmer-farm* that are phonologically transparent, in comparison to pairs like *decision-decide* that are less phonologically similar.
2. Experiment

2.1 Participants

Twenty-two (14 male; 8 female) Korean L2 learners of English (mean age: 23 years, SD: 2.4) participated in the present experiment. All the participants were undergraduate students, had normal or corrected to normal vision, and were right-handed except one student. Their English proficiency was relatively high; they had high scores on TOEIC (mean: 904.3, SD: 40.7, range: 850-985). They gave consent for their participation and were paid ₩20,000 for their participations.

2.2 Materials

The experimental six sets of prime-target pairs for the ERP study of derivational morphology are illustrated in Table 1. There were six experimental conditions constructed by manipulating the relationship along the three dimensions of interest such as morphology (M), phonology (P), and semantics (S). The first four sets were morphologically related. In other words, the pairs of condition 1, 2, 3 and 4 consisted of a word ending in a derivational suffix that was to prime its corresponding base word. Condition 5 and 6 were morphologically unrelated.

**Table 1.** Design of stimulus materials. Critical words are highlighted.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
<th>Primed</th>
<th>Unprimed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M + P + S</td>
<td>fully transparent</td>
<td>49</td>
<td>successful-success</td>
</tr>
<tr>
<td>2 M - P + S</td>
<td>partially transparent</td>
<td>45</td>
<td>decision-decide</td>
</tr>
<tr>
<td>3 M + P - S</td>
<td>opaque</td>
<td>47</td>
<td>department-depart</td>
</tr>
<tr>
<td>4 M + P ~ S</td>
<td>quasi-regular</td>
<td>47</td>
<td>dresser-dress</td>
</tr>
<tr>
<td>5 ~ M + P - S</td>
<td>phonological</td>
<td>42</td>
<td>planet-plan</td>
</tr>
<tr>
<td>6 ~ M - P + S</td>
<td>semantic</td>
<td>50</td>
<td>fortune-wealth</td>
</tr>
</tbody>
</table>

(M: Morphology; P: Phonology; S: Semantics)

The materials consisted of 280 target words and 300 filler nonwords. The unrelated prime-target pairs were manipulated by pairing each target in the set with an unrelated prime word from the same set. In order to avoid repeating items, two
lists were constructed, such that one half of items were related and the other were unrelated, with targets counterbalanced across lists. The nonword fillers were created by changing one or two letters of a real English word. In the nonword filler condition, the pairs consisted of an unrelated real-word English prime and a nonword target like *comfortable-grop*. They divided each of the experimental conditions into two lists by counterbalancing related and unrelated primes. Each participant was tested on a single list.

2.3 Procedure

Participants sat in a comfortable chair in a dimly-lit testing room, with a computer monitor in front of them. The participants heard a prime word and then made a lexical decision by looking at its target word. As the Figure 1 shows, each trial began with presentation of a fixation point at the center of the screen for 500ms. Afterwards, the participant heard a prime word. Each target word appeared on the screen for 500 ms. The participants pressed one of the two buttons (i.e., word or nonword) on a response box to decide whether the word is a real word or not. Each experimental list was divided into four blocks of 70 target words and 75 filler nonwords, each of which lasted for 10-15 minutes. Participants had a short break between the blocks.

![Figure 1. Procedure](image)

2.4 EEG recordings

Electroencephalograms (EEGs) were recorded from 30 Ag/AgCl electrodes, mounted in an electrode cap (Neuroscan Quikcap): 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 as well as on the left and right outer canthus to monitor eye movements. The EEG recordings were amplified by a SynAmps2 EEG amplifier, by
using a band-pass from 0.3 to 100 Hz with a sampling rate of 1 kHz. Electrode impedances were kept below 5 kΩ.

2.5 Data analysis

Trials with excessive eye-blink or movement artifacts were removed on the basis of visual screening prior to any further analysis. After artifact eliminating procedures, 89.4% of the initial total number of trials was saved for subsequent analysis. Averaging ERPs were based on 900 ms intervals, consisting of a 100 ms pre-stimulus baseline and a 800 ms post-stimulus interval. Grand average waveforms were filtered at a low-pass of 20 Hz.

For the ANOVA analyses, 18 electrodes were selected and divided into nine regions: left anterior (LA:F3, FC3), anterior midline (MA: FZ, FCZ), right anterior (RA:F4, FC4), left center (LC: C3, CP3), central midline (MC: CZ, CPZ), right center (RC: C4, CP4), left posterior (LP: P3, O1), posterior midline (MP: PZ, OZ), and right posterior (RP: P4, O2) in Figure 2. Repeated measures ANOVAs were performed for the factor of prime type (related vs. unrelated) and of region (LA, LC, LP, MA, MC, MP, RA, RC, RP), analysing each word type. For significant effects, the Greenhouse-Geisser correction was applied (Greenhouse and Geisser 1959), and uncorrected degrees of freedom and corrected p-values were reported.

At all words, ANOVAs were calculated based on mean voltages at the two different time intervals (324-400ms and 400-476ms). Additional analyses compared mean amplitude of the primed targets with mean amplitude of the unprimed targets for each condition at each region. And difference waves were also computed for the primed minus unprimed condition for each word type. In the analysis of priming effects for morphologically related words, mean amplitude measures were calculated and compared for each condition’s difference wave (related prime minus unrelated prime) using ANOVAs at the nine regions. The effects of semantic (+M+P: +M+P+S, +M+P−S, +M+P~S) and phonological (+M+P: +M+P+S, +M−P+S) relatedness then were evaluated.
3. Results

3.1 Behavior result

The accuracy of lexical decision is presented in Table 2. Accuracy data showed a main effect of word type, $F(5,108)=6.496$, $p<0.01$, but didn’t show any main effect of prime (primed vs. unprimed) nor any prime*word-type interaction effect. In each condition, no priming effect between primed and unprimed targets was found.

Reaction time of lexical decision is presented in Table 3. Incorrect responses and more extreme than ±2.5SD from the mean were removed. RT data that were submitted to two-way repeated measures ANOVAs (prime, word type) showed a main effect of prime, $F(1,41)=9.26$, $p<0.01$, and of word type, $F(5,205)=2.84$, $p<0.05$, but didn’t display any effect of prime*word type interaction. In each condition, priming effects between primed and unprimed targets were found in the three conditions: fully transparent $F_1(1,21)=11.88$, $p<0.01$, $F_2(1,48)=5.55$, $p<0.05$; partially transparent, $F_1(1,21)=30.51$, $p<0.01$, $F_2(1,44)=9.29$, $p<0.01$; and opaque, $F_1(1,21)=4.18$, $p<0.05$, $F_2(1,48)=1.13$, $p=0.3$.

Table 2. Accuracy rate (SD in parenthesis)

<table>
<thead>
<tr>
<th>condition relatedness</th>
<th>+M+P+S</th>
<th>+M-P+S</th>
<th>+M+P-S</th>
<th>+M+P~S</th>
<th>-M+P-S</th>
<th>-M-P+S</th>
</tr>
</thead>
<tbody>
<tr>
<td>primed</td>
<td>96 (6)</td>
<td>95 (5)</td>
<td>90 (7)</td>
<td>94 (7)</td>
<td>94 (6)</td>
<td>96 (6)</td>
</tr>
<tr>
<td>unprimed</td>
<td>98 (3)</td>
<td>94 (8)</td>
<td>90 (8)</td>
<td>93 (6)</td>
<td>94 (5)</td>
<td>94 (5)</td>
</tr>
<tr>
<td>F-value</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 3. Reaction time (SD in parenthesis)

<table>
<thead>
<tr>
<th>Condition</th>
<th>+M+P+S</th>
<th>+M-P+S</th>
<th>+M+P-S</th>
<th>+M+P~S</th>
<th>-M+P-S</th>
<th>-M-P+S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primed</td>
<td>377 (121)</td>
<td>414 (109)</td>
<td>427 (104)</td>
<td>405 (111)</td>
<td>420 (110)</td>
<td>420 (110)</td>
</tr>
<tr>
<td>Unprimed</td>
<td>420 (94)</td>
<td>469 (112)</td>
<td>457 (124)</td>
<td>423 (111)</td>
<td>439 (107)</td>
<td>424 (108)</td>
</tr>
<tr>
<td>Difference</td>
<td>43</td>
<td>55</td>
<td>30</td>
<td>18</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>F1-value</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2-value</td>
<td>**</td>
<td>***</td>
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</tr>
</tbody>
</table>

(* p<0.1; ** p<0.05; *** P<0.01)

3.2 ERP results

The grand average ERPs to primed and unprimed targets at the electrode CZ (A) and the central regions (B), together with topographical distribution of priming effects across the scalp based on the difference waveforms (primed minus unprimed) using isovoltage mapping, are shown in Figure 3.

3.2.1 N400 priming effect at time window 324–400ms

As shown at the electrode CZ and topographical distribution of Figure 3, there are reduced N400 effects in five conditions except the semantic condition at the 324–400ms interval. They can be understood as priming effects.

At the time window 324–400ms, the analysis for the fully transparent condition (+M+P+S) showed significant main effects of relatedness at the midline region, $F_{(1,21)}=4.07$, $p<0.05$, and of region, $F_{(2,42)}=9.56$, $p<0.01$, but no effect of relatedness*region interaction, $F_{(2,42)}=2.32$, $p=0.13$. Likewise, at the lateral region there were also significant main effects of hemisphere, $F_{(1,21)}=94.57$, $p<0.01$, and of region, $F_{(2,42)}=11.36$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=1.54$, $p=0.23$. 
Figure 3. Grand average ERP responses at the electrode CZ (A) and at the central region (B) and topographic scalp voltage maps:

- Primed: **blue**
- Unprimed: *gray*

[A]

<table>
<thead>
<tr>
<th>Description</th>
<th>Time Window</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully transparent</td>
<td>324-400 ms</td>
<td><img src="image1" alt="Image" /></td>
</tr>
<tr>
<td>Partially transparent</td>
<td>400-476 ms</td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>Opaque</td>
<td><img src="image3" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Quasi-regular</td>
<td><img src="image4" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Phonological</td>
<td><img src="image5" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Semantic</td>
<td><img src="image6" alt="Image" /></td>
<td></td>
</tr>
</tbody>
</table>

[B]

- Fully transparent (+M+P+S, successful-success)
- Partially transparent (+M-P+S, decision-decide)
- Opaque (+M-P-S, apartment-apart)
- Quasi-regular (+M-P-S, dresser-dress)
- Phonological (-M+P-S, planet-plan)
- Semantic (-M-P+S, fortune-wealth)
For the partially transparent condition (+M-P+S), at the midline region there were significant main effects of relatedness, $F_{(1,21)}=7.39, p<0.01$, and of region, $F_{(2,42)}=8.69, p<0.01$, but no effect of interaction, $F_{(2,42)}=2.0, p=0.16$. And at the lateral region there were also significant main effects of relatedness, $F_{(1,21)}=4.74, p<0.05$, of hemisphere, $F_{(1,21)}=63.01, p<0.01$, and of region, $F_{(2,42)}=7.84, p<0.01$.

The opaque condition (+M+P-S) showed significant main effects of relatedness, $F_{(1,21)}=8.35, p<0.01$, and of region, $F_{(2,42)}=15.93, p<0.01$, but no effect of interaction, $F_{(2,42)}=2.08, p=0.16$, at the midline region. And at the lateral region there were also significant main effects of relatedness, $F_{(1,21)}=6.14, p<0.05$, of hemisphere, $F_{(1,21)}=36.5, p<0.01$, and of region, $F_{(2,42)}=17.88, p<0.01$.

For the quasi-regular condition (+M+P~S), there were significant main effects of relatedness, $F_{(1,21)}=8.83, p<0.01$, and of region, $F_{(2,42)}=11.34, p<0.01$, but no effect of interaction, $F_{(2,42)}=1.35, p=0.27$, at the midline region. And at the lateral region there were also significant main effects of relatedness, $F_{(1,21)}=5.92, p<0.05$, of hemisphere, $F_{(1,21)}=72.29, p<0.01$, and of region, $F_{(2,42)}=11.69, p<0.01$.

For the phonological condition (-M+P-S), there were significant main effects of relatedness, $F_{(1,21)}=11.38, p<0.01$, and of region, $F_{(2,42)}=11.16, p<0.01$, but no effect of interaction, $F_{(2,42)}=0.21$, at the midline region. And at the lateral region there were also significant main effects of relatedness, $F_{(1,21)}=10.02, p<0.01$, of hemisphere, $F_{(1,21)}=40.18, p<0.01$, and of region, $F_{(2,42)}=11.61, p<0.01$.

### Table 4. Analysis of N400 priming effects across conditions and nine electrode regions: F-values for the ANOVAs for the comparison of primed vs. unprimed targets

<table>
<thead>
<tr>
<th>Electrode region condition</th>
<th>LA</th>
<th>LC</th>
<th>LP</th>
<th>MA</th>
<th>MC</th>
<th>MP</th>
<th>RA</th>
<th>RC</th>
<th>RP</th>
</tr>
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<tbody>
<tr>
<td>324-400ms</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trans-f (+M+P+S)</td>
<td>3.54*</td>
<td>3.66*</td>
<td></td>
<td></td>
<td>5.27***</td>
<td>6.64**</td>
<td></td>
<td>3.61*</td>
<td></td>
</tr>
<tr>
<td>Trans-p (+M+P+S)</td>
<td>5.98***</td>
<td>10.6**</td>
<td>12.7***</td>
<td>7.60***</td>
<td>4.83**</td>
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<td>3.27*</td>
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<td>Opaque (+M+P+S)</td>
<td>7.54***</td>
<td>8.66***</td>
<td>5.41***</td>
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<tr>
<td>Quasi (+M+P~S)</td>
<td>10.6***</td>
<td>12.7***</td>
<td>7.60***</td>
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<td>Trans-f (+M+P+S)</td>
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<td>Trans-p (+M+P+S)</td>
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<td>Opaque (+M+P+S)</td>
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<td>Quasi (+M+P~S)</td>
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<td>Phonoe (-M+P-S)</td>
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<td>Seman (-M-P+S)</td>
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<td>4.08*</td>
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Finally, for the semantic condition, at the midline region there were significant main effects of region, $F_{(2,42)}=8.69$, $p<0.01$, and of interaction, $F_{(2,42)}=3.49$, $p<0.05$, but no effect of relatedness, $F_{(1,21)}=1.67$, $p=0.21$. At the lateral region there were also significant main effects of hemisphere, $F_{(1,21)}=45.53$, $p<0.01$, and of region, $F_{(2,42)}=8.70$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=1.0$, $p=0.33$.

Additional priming effects of nine electrode regions at time window 324-400ms were shown in Table 4. N400 priming effects in each condition (primed vs. unprimed) were elicited at the right hemisphere rather than at the left hemisphere as shown in Figure 3. To compare the effects of N400 ERP priming to morphologically related conditions, in the case of +M+P (+M+P+S: fully transparent; +M+P-S: opaque; +M+P~S: quasi-regular), differences between conditions were analyzed by using differences between primed and unprimed waves. Although the amplitude of difference between primed and unprimed targets showed a bit difference as in Figure 4, there were no statistically significant differences between morphologically related conditions. That is, in comparing fully transparent and opaque conditions and in comparing fully transparent and quasi-regular conditions, there were no significant differences at any of the electrode regions. In the case of +M+S (+M+P+S: fully transparent; +M-P+S: partially transparent), there were no significant differences at any of the electrode regions, either.

**Figure 4.** N400 priming results: A. Difference waves (primed–unprimed) at the midline region (MC); B. Mean differences in amplitude (primed–unprimed) for all the conditions at the midline region (MC) in 324–400ms and 400–476ms time intervals.
To investigate the degree of effect of semantic (+M+P+S; +M+P-S; +M+P~S) and phonological (+M+P+S; +M+P+S) overlap at all the nine electrode regions, the F-values of repeated measures ANOVAs were compared by amplitudes of the differences between primed and unprimed targets across morphologically related conditions. The result of analysis showed a significant main effect of region, $F_{(8,168)}=5.29, p<0.01$, while there was no effect of relatedness, $F_{(3,63)}=2.12, p=0.12$, nor of interaction, $F_{(24,504)}=0.38, p=0.89$ as shown in Table 5.

As for semantic effects (+M+P+S; +M+P-S; +M+P~S), the analysis revealed a significant main effect of region, $F_{(8,168)}=4.56, p<0.01$, while there was no effect of relatedness, $F_{(2,42)}=2.0, p=0.15$, nor of interaction, $F_{(16,336)}=0.36, p=0.85$. In particular, at the MC region there was a marginal effect of semantic relatedness, $F_{(2,42)}=3.03, p=0.06$. To compare graded effects of semantic relatedness at each electrode region, the amplitude of priming effect was analyzed. In comparing fully transparent (+M+P+S) with opaque conditions (+M+P-S), there were significant effects at the midline (MC, $F_{(1,23)}=6.32, p<0.05$; MP, $F_{(1,23)}=4.23, p<0.05$), and marginal effects at RC region, $F_{(1,23)}=6.32, p=0.07$. In comparing opaque (+M+P-S) with quasi-regular conditions (+M+P~S), we saw marginal effects, $F_{(1,23)}=6.32, p<0.1$, at MC region. However, there was no significant difference between fully transparent (+M+P+S) and quasi-regular conditions (+M+P~S) at any of the regions.

To investigate the effects of phonological relatedness, the two +M+S conditions (+M+P+S and +M-P+S) were analyzed at each electrode region. The analysis showed significant effects at MA, $F_{(1,23)}=4.31, p<0.05$ and MP, $F_{(1,23)}=5.88, p<0.05$,
and marginal effects at MC, $F_{(1,23)}=3.33$, $p=0.82$, RA, $F_{(1,23)}=3.85$, $p=0.06$, and $F_{(1,23)}=2.94$, $p=0.1$.

3.2.2 N400 priming effect at time window 400–476ms

Within the 400-475ms time window, priming effects were found in fully transparent, partially transparent, and opaque conditions. The priming effects were detected at the central and posterior regions rather than at the anterior region.

At 400-476ms, the analysis for the fully transparent condition (+M+P+S) revealed significant main effects of region, $F_{(2,42)}=6.64$, $p<0.05$, and of relatedness*region interaction, $F_{(2,42)}=6.62$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=94.57$, $p=0.13$, at the midline region, while at the lateral region there were significant main effects of hemisphere, $F_{(1,21)}=20.02$, $p<0.01$, and of region, $F_{(2,42)}=7.06$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=1.34$, $p=0.30$. In the partially transparent condition (+M-P+S), at the midline region there was a marginal main effect of relatedness, $F_{(1,21)}=3.10$, $p=0.09$, of region, $F_{(2,42)}=8.21$, $p<0.01$, and of interaction, $F_{(2,42)}=7.75$, $p<0.01$. At the lateral region there were also marginal main effects of relatedness, $F_{(1,21)}=3.42$, $p=0.08$, of hemisphere, $F_{(1,21)}=36.95$, $p<0.01$, and of region, $F_{(2,42)}=7.13$, $p<0.01$.

The opaque condition (+M+P-S) showed marginal main effects of relatedness, $F_{(1,21)}=3.0$, $p=0.1$, and of region, $F_{(2,42)}=11.56$, $p<0.01$, but no effect of interaction, $F_{(2,42)}=0.48$, $p=0.53$, at the midline region. At the lateral region there were marginal main effects of relatedness, $F_{(1,21)}=3.33$, $p=0.08$, of hemisphere, $F_{(1,21)}=12.54$, $p<0.01$, and of region, $F_{(2,42)}=10.84$, $p<0.01$.

For the quasi-regular condition (+M+P~S) there were significant main effects of region, $F_{(2,42)}=6.39$, $p<0.01$, and of interaction, $F_{(2,42)}=11.17$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=0.32$, $p=0.58$ at the midline region. At the lateral region there were significant main effects of hemisphere, $F_{(1,21)}=12.87$, $p<0.01$, and of region, $F_{(2,42)}=5.01$, $p<0.05$, but no effect of relatedness, $F_{(1,21)}=0.22$, $p=0.64$.

For the phonological condition (-M+P-S), there was a significant main effect of region, $F_{(2,42)}=11.67$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=0.84$, $p=0.37$, nor of interaction, $F_{(2,42)}=1.96$, $p=0.16$, at the midline region. At the lateral region there were also significant main effects of hemisphere, $F_{(1,21)}=14.52$, $p<0.01$, and of region, $F_{(2,42)}=7.44$, $p<0.01$, but no effect of relatedness, $F_{(1,21)}=0.81$, $p=0.37$. 
Finally, for the semantic condition, at the midline region there were marginal main effects of region, $F(2,42)=3.38$, $p=0.07$, and of interaction, $F(2,42)=3.19$, $p=0.06$, but no effect of relatedness, $F(1,21)=2.35$, $p=0.14$. At the lateral region there were also significant main effects of hemisphere, $F(1,21)=82.5$, $p<0.01$, but no effect of relatedness, $F(1,21)=1.85$, $p=0.19$, nor of region, $F(2,42)=2.0$, $p=0.17$.

Additional priming effects of the nine electrode regions at time window 400-476ms were found in Table 4. N400 priming effects in each condition (primed vs. unprimed) were elicited at the central and posterior regions rather than at the anterior region, as shown in Table 4 and Figure 3.

To compare the effects of N400 ERP priming to morphologically related conditions, in the case of +M+P (+M+P+S: fully transparent; +M+P-S: opaque; +M+P~S: quasi-regular), differences between conditions were analyzed using differences between primed and unprimed waves. In comparing fully transparent with opaque conditions at each electrode region, there was no statistically significant differences at any of the electrode regions. In comparing fully transparent with quasi-regular conditions, there was significant differences at LP, $F(1,21)=7.77$, $p<0.05$, and marginal effects at MP, $F(1,21)=3.45$, $p=0.08$, and RP, $F(1,21)=2.83$, $p=0.10$. In the case of +M+S (+M+P+S: fully transparent; +M-P+S: partially transparent), there was no significant difference at any electrode regions.

To investigate the degree of effects of semantic (+M+P+S; +M+P-S; +M+P~S) and phonological (+M+P+S; +M-P+S) overlap at all the nine electrode regions, the $F$-values of repeated measures ANOVAs were compared by amplitudes of the differences between primed and unprimed targets across the morphologically related conditions. The result of analysis showed significant main effects of region, $F(8,168)=5.29$, $p<0.01$, and marginal effects of relatedness, $F(3,63)=2.73$, $p=0.07$, but no effect of interaction, $F(24,504)=0.51$, $p=0.58$ as shown in Table 5.

As for semantic effects (+M+P+S; +M+P-S; +M+P~S), the analysis revealed significant main effects of relatedness, $F(2,42)=4.13$, $p<0.05$, and of region, $F(8,168)=3.14$, $p<0.05$, but no effect of interaction, $F(16,336)=0.79$, $p=0.56$. In particular, there were significant effects of semantic relatedness at midline region (MC, $F(2,42)=3.48$, $p<0.05$; MP, $F(2,42)=3.19$, $p<0.05$) and at left region (LA, $F(2,42)=3.28$, $p<0.05$; LC, $F(2,42)=3.90$, $p<0.05$; LP, $F(2,42)=4.01$, $p<0.05$). To compare graded effects of semantic relatedness at each electrode region, the amplitude of priming effects was analyzed. In comparing fully transparent (+M+P+S) with opaque (+M+P-S)
conditions, there were significant effects at the midline regions (MA, $F_{(1,23)}=3.09$, $p=0.09$; MC, $F_{(1,23)}=3.70$, $p=0.07$; MP, $F_{(1,23)}=5.83$, $p<0.05$), at the left regions (LA, $F_{(1,23)}=5.83$, $p<0.05$; LC, $F_{(1,23)}=5.83$, $p<0.05$; LP, $F_{(1,23)}=5.83$, $p<0.05$), and at the right region (RP, $F_{(1,23)}=3.89$, $p=0.06$). In comparing fully transparent (+M+P+S) with quasi-regular (+M+P~S) conditions, there were significant effects at the midline regions (MC, $F_{(1,23)}=5.60$, $p<0.05$; MP, $F_{(1,23)}=3.20$, $p=0.09$), at the left regions (LA, $F_{(1,23)}=3.23$, $p=0.09$; LC, $F_{(1,23)}=7.66$, $p<0.05$; LP, $F_{(1,23)}=4.10$, $p<0.05$), and at the right region (RP, $F_{(1,23)}=3.60$, $p=0.07$). However, there was no significant difference between opaque (+M+P-S) and quasi-regular (+M+P~S) at any of the regions.

To investigate effects of phonological relatedness, the two conditions (+M+P+S and +M-P+S) were analyzed at each electrode region. The analysis showed marginal effects at the left regions (LA, $F_{(1,23)}=3.74$, $p=0.07$; LC, $F_{(1,23)}=2.88$, $p=0.10$).

To sum up, Table 5 shows effects of semantic and phonological overlap in the time window 324-400ms and 400-476ms.

Table 5. Effect of semantic and phonological overlap: comparing amplitudes of the difference waves (primed − unprimed)
4. Discussion

As pointed out in the introduction, there has been growing interest in using English derivationally complex words to look into the cognitive and brain bases of language representation. The previous researches on derivational morphology include a number of behavioral priming studies (Feldman et al. 2008; Marslen-Wilson et al. 2008) and functional neuroimaging (Bozic et al. 2007; Gold and Rastle 2007; Lehtonen et al. 2007). Many of these researches have found differences between morphologically decomposable and opaque words. The findings in these works point to a specialized mechanism for comprehending the morphological structure of words. On this view, morphologically transparent forms like *successful* are decomposed into a base word like *success* and bound morphemes like *-ful*. In contrast, morphologically opaque forms like *department* are stored as whole words in the lexicon such that they are lexically distinguished from the base forms. Furthermore, this decomposition theory assumes that morphological effects in priming are driven by morphological knowledge that is independent from phonological and semantic relatedness (Kempley and Morton 1982; Marslen-Wilson et al. 1994; 2008).

In the present study, we examined the validity of the alternative theory, which states that this dichotomy is due to differences in form and meaning relationships among words. Priming effects between derived words and stems may vary with the systematic phonological, orthographic and semantic relatedness between primes and targets (Rueckl et al. 1997; Rueckl and Aicher 2008). The thrust of this theory is that the degree of priming effects is proportionate to that of form or meaning similarity. On this theory, morphological regularities mirror cases where the mapping between sound and meaning is the strongest and most consistent. Nevertheless, these effects are taken to be relatively always present such that they can also occur for allegedly non-derived words.

The ERPs measured in the present study are instrumental in revealing a continuum of online changes in mental computation, which correspond to pre-decision stages of word analysis. In contrast to ERP, reaction time data in behavioral priming studies reflect the final output of multiple processes, and also this may obscure the full scope of processing and lead to a failure to examine differences in processing that resolve prior to response decision. Thus, phonologically related word pairs would produce the same magnitude of priming as morphologically related
pairs. ERP studies, on the other hand, help get over this problem by exposing separable cognitive mechanisms either temporally or spatially, thanks to the advantages of the ERP paradigm.

In our study, ERP priming effects of shared form and meaning were contrasted with those of either form or meaning. We employed a key feature of derivational morphology in English, such that derived forms differ with respect to their phonological and semantic transparency. The semantic dimension was examined by comparing ERP priming effects of semantically transparent derived words (+M+P+S: *successful*—*success*) with those of semantically opaque words (+M+P-S: *department*—*depart*) and quasi-regular word pairs that are not derived, but are nevertheless generally rated as sharing some degree of meaning (+M+P∼S: *dresser*—*dress*).

Similarly, the effect of phonological relatedness was examined for transparent forms by keeping semantic relatedness constant but varying only phonological similarity (e.g., +M+P+S: *successful*—*success* vs. +M-P+S: *decision*—*decide*). Besides, strictly meaning- and form-based priming were measured to examine the degree to which observed morphological effects are the results of either simple phonological or semantic similarity. This arrangement of stimuli of form and meaning overlap allowed us to observe an interactive contribution of semantic and phonological information to word recognition.

The results of the present study showed that phonological and semantic factors modulated the amplitude of N400 priming in the late time window (400-476ms). In this late time window, significant N400 priming effects were observed for both semantically transparent pairs (+M-P+S) and phonologically transparent pairs (+M+P-S). This amounts to showing that morphological priming effects were modulated by either phonological or semantic factors. In this late time window, the largest priming effect was obtained for words that are closely related in meaning (+M-P+S: *decision*—*decide*), compared to intermediate cases that overlapped more weakly with respect to phonology (i.e., opaque +M+P-S: *department*—*depart*; quasi-regular +M+P∼S: *dresser*—*dress*).

The time-varying pattern of the ERP priming effects in the present study suggests that the exact pattern of facilitation changes with the time course of word processing. In the early N400 time window (324-400ms), significant priming effects were observed for phonologically related words. The effect was the greatest for the only phonologically related pairs (-M+P-S), the in-between for the phonologically
related but semantically quasi-regular (+M+P-S) and phonologically related but semantically opaque targets (+M+P-S), which shared weaker semantic overlap and lacked semantic overlap, respectively. The effect was the weakest for the fully transparent word pairs (+M+P+S). Since in this early N400 time window, the phonological factor played a dominant role in inducing priming effects, effects of phonological relatedness arose between the fully transparent word pairs (+M+P+S) and the phonologically opaque word pairs (+M-P+S).

In the late time interval (400-476ms), the N400 priming effects showed up for fully transparent (+M+P+S), semantically related but phonologically opaque (+M-P+S), and phonologically related but semantically opaque (+M+P-S) targets, but were greatly attenuated for all other conditions. These results indicate that unlike phonologically induced prime effects found in the early N400 time window, increased processing time at this late time interval strengthened the influence of formal or semantic overlap for morphologically related targets in the late time interval. The fully transparent words (+M+P+S) consistently overlap on both semantic and formal dimensions, while the remaining prime-target pairs closely overlap on only one dimension, either meaning (+M-P+S) or sound (+M+P-S), but not both. However, though they are most pronounced for L1 native language speakers, morphological effects are most weakly manifested for Korean L2 learners of English when both form and meaning are strongly and consistently correlated. This weakens the view advanced on the basis of L1 processing that the word recognition system is sensitive to the degree of interaction between semantic and phonological codes. In fact, Korean L2 learners of English had difficulty in processing cumulative features of morphologically related target words. It is worth noting that for Korean L2 learners of English, one-dimensional priming effects were stronger for semantically related words (+M+P-S) than phonologically related words (+M-P-S), which is the same for L1 native speakers. Therefore, effects of semantic relatedness were found among the three conditions such as (+M+P+S), (+M+P-S), and (+M-P+S).

To summarize, unlike L1 native speakers, L2 learners of English start with processing both simple and derivationally complex words on the phonological level, as can be seen from the finding that only phonological overlap priming effects arose in the early N400 time window (324-400ms). But at the immediately following stage of processing they engage in processing derivationally complex words on the
semantic level, as can be seen from the finding that now semantic overlap priming effects arose in the late time interval (400-476ms). Since for L1 native speakers this semantic processing in fact starts early in the early N400 time window, L2 learners of English are taken to be a little slower than L1 native speakers in processing derivationally complex words. Furthermore, differently from L1 native speakers, the L2 learners are found to have difficulty in understanding cumulative features of semantic and formal properties in processing morphologically related words.

5. Conclusion

This paper studied L2 processing of derivationally complex words in English by using ERPs that were measured to lexical decisions in the context of a cross-modal priming paradigm. In particular, we concentrated on how sound and meaning are computed over time and how these factors contribute to the processing of morphological structure for Korean L2 learners of English. More specifically, we focused on how the differences in the degree of sound and meaning relatedness between derivationally related words are reflected in their ERP responses. The results of the experiment showed that L2 learners of English start with processing simple and derivationally complex words on the phonological level, as can be noted from the finding that only phonological/phonetic priming effects arose in the early N400 time window (324-400ms). But at the immediately next stage of processing they comprehend derivationally complex words on the semantic level, as can be learned from the finding that semantic priming effects showed up in the late time interval (400-476ms). Since for L1 native speakers this semantic processing in fact begins early in the early N400 time window, it follows that L2 learners of English are a little slower than L1 native speakers in comprehending derivationally complex words. In addition, unlike L1 native speakers, the L2 learners are found to have difficulty in processing cumulative features of semantic and phonological/phonetic properties in morphologically related words.
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Myung-Kwan Park
Department of English Language
Dongguk University
26 3-ga Phil-dong, Jung-gu,
Seoul 100-715, Korea
E-mail: parkmk@dgu.edu

Wonil Chung
Department of English Language
Dongguk University
26 3-ga Phil-dong, Jung-gu,
Seoul 100-715, Korea
E-mail: wonilchung@naver.com

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