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**Multinomial regression modeling of vowel insertion patterns: adaptation of coda stops from English to Korean**

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**Abstract:** When an English word ending in a stop is adapted to Korean, a vowel is variably inserted after the final stop. Vowel insertion in this position is surprising because voiceless stops are permissible in coda position in Korean and it is not motivated by Korean native phonology. This study examines five factors that have been hypothesized to affect the likelihood of vowel insertion, i.e., tenseness of the pre-final vowel, voicing and place of the English final stop, word size and final stress. These possibilities were tested using a corpus of Korean loanwords whose source word ends in a stop. Patterns of vowel insertion were classified as no vowel insertion, vowel insertion, or optional vowel insertion, and analyzed using multinomial regression modeling. The results confirmed that all the relevant factors significantly increased the likelihood of vowel insertion and optional vowel insertion patterns relative to no vowel insertion patterns compared with the reference condition rates. These findings suggest that particular features indeed impact production patterns in loanword phonology. My Results support the need for further research into how other possible auditory factors such as stop release may shape speech perception in loanword adaptation.

**Keywords:** Korean; loanword adaptation; multinomial regression; vowel insertion patterns

1 Introduction

Words that are adopted from one language and incorporated into another generally undergo modification processes to conform to the phonological restrictions of the borrowing language. While the L1 structures truly play a role in altering foreign words in adaptation, many other patterns are not accounted for by the requirements

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of L1 phonology alone. The unexpected emergent patterns in loanword adaptation include unnecessary repair (Golston and Yang 2001; Kang 2003; Peperkamp 2005), differential faithfulness (Broselow 2009; Davidson and Noyer 1997; Ito and Mester 2001), retreat to the unmarked (Kenstowicz 2005; Kenstowicz and Suchato 2006; Shinohara 2000), and ranking reversals (Broselow 2009; Kenstowicz 2005; Peperkamp et al. 2008), among others (for a review, see Kang 2011).

This study involves one of the puzzling examples, which is the variable adaptation of English word-final stops into Korean (see Table 1). Vowel epenthesis in this position has been considered seemingly unmotivated since Korean native words can end in a stop and an English word-final stop would be entirely legal in L1. Korean has a three-way laryngeal contrast in stops, i.e., voiceless unaspirated, voiceless aspirated, and voiceless tense. Only voiceless unaspirated stops are allowed in final position, with all categories realized as voiceless unaspirated unreleased in this context (e.g., /pæp/ [pæp] ‘meal’, /patʰ/ [пат] ‘field’, /pak/ [пак] ‘outside’). Because voiceless unaspirated stops may occur word-finally in Korean, we would expect that words borrowed from English that end in a voiceless stop to be adapted into Korean with a voiceless unaspirated stop, a legal Korean structure. It is therefore surprising to find that loanwords frequently depart from the English structure in two ways, i.e., the English final stop is realized as aspirated, and a vowel is inserted after the final stop (e.g., rope → [lopʰi], knit → [nitʰi], peak → [pʰikʰi]).

Several factors have been proposed to influence the likelihood of vowel insertion in this environment (Hirano 1994b; Jun 2002; Kang 2003; Kim 2018; Ku 1999; Kwon 2017; Rhee and Choi 2001), as summarized in Table 2. First, the effect of preceding tense and lax vowels has been argued to be correlated with that of release of the English final stop (Kang 2003). In the TIMIT corpus of American English, 58% of final stops following a tense vowel are released, but only 41% of final stops following a lax vowel are released (Kang 2003: 241). This difference is reflected in the Korean loanword vowel insertion pattern, with more epenthesis when the pre-final vowel is tense (89%) than when it is lax (28%) (Kang 2003: 232).

Second, stop voicing is relevant since English final voiced stops are frequently adapted with an inserted vowel (e.g., tube → [tʰjubʰi], pad → [pʰædʰi],

Table 1: Vowel insertion patterns of English words ending in a stop.

| No vowel insertion (NVI) | Vowel insertion (VI) | Optional vowel insertion (OVI) |
|-------------------------|----------------------|-------------------------------|
| lab → [læp]             | loop → [lupʰi]       | type → [tʰæplʰi]              |
| hot → [hɔtʰ]            | brand → [pʰirændɪ]   | flute → [pʰɪlluθʰi]           |
| book → [pʊkʰ]          | peak → [pʰikʰi]      | tag → [tʰækgʰi]               |
smog → [simogi]). Because the only position in which voiced stops can occur in Korean is between sonorants, where voiceless unaspirated stops are allophonically voiced (e.g., [mok] /mok/ ‘neck’, [mogi] /mok-i/ ‘neck-NOM’), vowel insertion after a voiced obstruent can maintain perceptual similarity between English and Korean forms by placing the voiced stop in a context in which voicing is legal in Korean (Kang 2003).

Third, the place of the final stop has also been suggested to affect the frequency of vowel insertion in Korean loanwords borrowed from English as well as the frequency of release by English speakers (Kang 2003). The release frequency of insertion after dorsal stops was 83%, which is greater than after labial stops, at only 51% (Kang 2003: 250). Although Kang’s claim concerning the relationship between release and vowel insertion was supported in the case of dorsal versus labial stops, it was not supported for coronal stops. Even though the frequency of vowel insertion in loanwords was highest for coronals (72%), final coronal stops in the TIMIT corpus were the least likely to be released (37%) (Kang 2003: 232–250). Kang claims that the surprisingly high frequency of vowel insertion after coronal stops arises from the fact that in Korean surface forms, final [t] in nouns is generally derived from underlying /s/, which is neutralized to [t] in final position, but which surfaces as [s] before vowel-initial suffixes. She proposes that vowel insertion after English final [t] in nouns protects the form from undergoing the normal [t-s] alternation.

### Table 2: Factors affecting the possibility of vowel insertion after English final stops.

| Factors       | Observations                                                                 | Examples                                                                 |
|---------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Vowel tenseness | Vowel insertion is more likely when the vowel preceding the English final stop is tense than when it is lax. | Lax: step→sitʰɛpʰ  
Tense: state→sit⁰ɛtʰi |
| Stop voicing  | Vowel insertion is more likely when the English final stop is voiced than when it is voiceless. | Voiceless: plot→pʰɪlloptʰ  
Voiced: plug→pʰɪlloptʰ |
| Stop place    | Vowel insertion is more likely when the English final stop is coronal than when it is labial or dorsal. | Labial/Dorsal: cap/bag→kʰæpʰ  
pækʰ  
Coronal: bat→pætʰi |
| Word size     | Vowel insertion is more likely when the English word is monosyllabic than when it is polysyllabic. | Monosyllabic: light→laitʰ  
Polysyllabic: moonlight→munlaitʰ |
| Final stress  | Vowel insertion is more likely when the English final syllable is stressed than when it is unstressed. | Unstressed:ˈhandbag→hændibækʰ  
Stressed: handˈmade→hændimɛidə́
In addition to the factors discussed by Kang (2003), other researchers have identified two additional factors that affect the likelihood of vowel insertion by Korean speakers adapting English words: word size and final stress. Rhee and Choi (2001: 157) found that vowel insertion is more likely in monosyllabic than in polysyllabic borrowed words in their loanword corpus (1 syllable 64%, 2 syllables 34%, 3 syllables 33%, 4–5 syllables 29%). This finding agrees with the vowel insertion patterns in Kang’s loanword list, where the frequency of final vowel insertion for monosyllabic words is higher than that of polysyllabic words (68 versus 36%, Kang 2003: 227). Moreover, in an experiment where Korean participants heard auditory stimuli and wrote what they had heard on a response sheet, Jun (2002) found that vowel insertion was more likely when the final syllable was stressed (55%) than when it was unstressed (52%). This finding is also consistent with Kang’s loanword list, where the frequency of vowel insertion in polysyllabic words with final postvocalic stops was higher when the final syllable was stressed than when it was unstressed (51 versus 14%, Kang 2003: 227).

To investigate how these linguistic factors influence word-final vowel insertion, the present study examined the production patterns of English final stops based on corpus data consisting of Korean loanwords from English whose source word ends in a stop. The corpus was built by collecting loanword lists published by the National Academy of the Korean Language (2001, 2002, 2007a, 2007b, 2010). A strength of this corpus study is the construction of a new database of Korean loanwords from English containing more extensive and recent loanwords than prior studies. This study also employed statistics that have been widely recognized as a powerful method for analyzing linguistic patterns in natural language corpus data. Multinomial logistic regression modeling was notably used in the present study to examine three different adaptation patterns. Since no study had utilized multinomial modeling in this specific context of Korean loanwords adopted from English, another contribution of this study is that it provides a methodology to predict an adaptation pattern given a great deal of corpus data comprising established loanwords.

2 Method

This study reports on a study of vowel insertion after a word-final stop in Korean loanwords borrowed from English and describes vowel insertion patterns in this environment based on material compiled in publications of the National Academy of the Korean Language (2001, 2002, 2007a, 2007b, 2010). The analysis of the corpus data was based on 540 Korean loanwords from English whose source word ends in a stop. One previous major study, Kang (2003), used a loanword list
published in 1991 by the National Academy of the Korean Language where the list contained 447 English words with a final postvocalic stop gathered from books published in 1990. The corpus compiled for the current study has been improved compared to Kang’s as the present data are more recent and extensive containing a large number of newly added technology-related terms like Internet, gigabit, cloud, website, upload, hybrid, and netiquette (see the supplemental file for an in-depth comparison of the two corpora). Several words contained in Kang’s study have not been included in the current study such as brinkmanship, ascorbic, polyphonic, sextet, and videotape, indicating that their use was considerably less frequent in the 2000s than in 1990. In particular, many words belonging to the category of vowel insertion in Kang (2003) have now been moved to the transition class, optional vowel insertion; these words include catalogue, dot, eight, and unit. The present study collected 540 loanwords from sources published in the 2000s. Out of 540 English words with a final stop, 264 were consistently adapted with final vowel insertion, and 214 were always adapted without final vowel insertion, while 62 were variably adapted both with and without vowel insertion.

The adaptation patterns of vowel insertion were modeled using a series of mixed-effects logistic regression models, implemented in the MCMCglmm package (Hadfield 2010) in R (R Development Core Team 2021). The vowel insertion pattern was calculated by building ten different models where the dependent variable was the adaptation pattern (NVI, VI, OVI) and the five context predictors were vowel tenseness (lax or tense), stop voicing (voiceless or voiced), final stress (unstressed or stressed), word size (monosyllabic or polysyllabic), and stop place (labial or coronal or dorsal). This study employed multinomial logistic regression since the analysis involved more than two dependent variable categories. Two-way interactions of the five factors (vowel tenseness, stop voicing, final stress, word size, and stop place) were included in the models to examine the interplay of those factors in loanword adaptation. Each model includes a two-way interaction, i.e., (i) vowel tenseness * stop voicing, (ii) vowel tenseness * final stress, (iii) vowel tenseness * word size, (iv) vowel tenseness * stop place, (v) stop voicing * final stress, (vi) stop voicing * word size, (vii) stop voicing * stop place, (viii) final stress * word size, (ix) final stress * stop place, and (x) word size * stop place. All fixed factors were coded using treatment coding with the reference level for the intercept being set to the lax, voiceless, unstressed, monosyllabic, and labial. The models included random effects consisting of random intercepts by item (English word).

Since the MCMCglmm package utilizes Bayesian modeling as well as Markov chain Monte Carlo (MCMC) algorithms to implement model fits, a statistical model requires the specification of prior probabilities and posterior probability estimates (Hadfield 2010). Fixed effect priors were set at 0.667 for all diagonal terms and 0.333 for all off-diagonal terms. In addition, a burn-in period of 50,000 with
500,000 iterations and a thinning interval of 250 were used (see Supplemental files for statistical information). Output estimates of posterior probabilities by the Bayesian \textit{MCMCglmm} statistical implementation include a posterior mean given in log-odds and a 95% credibility interval. Type I error rates were estimated using \textit{MCMC} methods and quantified as \textit{pMCMC}, which is analogous to \textit{p}-values (see Tables 3, 5, 7, and 9 for statistical outputs).

3 Results

Figure 1 plots the frequency of the three vowel insertion patterns in the corpus. For a complete list of loanwords, see the xlsx data file in the “Supplementary material” section. All the statistical models built for the corpus analysis found significant effects for all the given factors, i.e., tenseness of pre-final vowel, voicing of English final stop, final syllable containing stress, word size, and place of English final stop. The outputs of all ten regression models are summarized in Tables 3, 5, 7, and 9.

3.1 Tenseness of pre-final vowel and other predictors

The output of the model given in Table 3a shows that both VI and OVI patterns were predicted to be significantly less common than NVI patterns (referent category) at baseline (i.e., items ending in voiceless stops with lax pre-stop vowels), as shown by the significant negative mean logit values (post.mean = $-2.118$, $p < 0.001$ for NVI versus OVI; post.mean = $-3.752$, $p < 0.001$ for NVI versus VI). Importantly, the output shown in Table 3a indicates that tense pre-final vowels significantly increased the likelihood of each pattern relative to NVI patterns, compared with the reference likelihood (post.mean = 5.146, $p < 0.001$ for NVI versus OVI; post.mean = 10.434, $p < 0.001$ for NVI versus VI). As displayed in Figure 2, the current loanword corpus showed that VI took place in a greater percentage of words with tense pre-final vowels (89% = 176 out of 198) than in words with lax vowels (26% = 88 out of 342).

Concerning interaction terms, there were no significant interactions between vowel tenseness and other variables including stop voicing, final stress, and word size on relative rates of any pattern (VI or OVI), compared with rates in reference conditions (see Table 3a–c). Only the model given in Table 3d found a significant interaction between items with tense vowels and those with coronal stops for each adaptation pattern (post.mean = $-13.922$, $p < 0.001$ for NVI versus OVI; post.mean = $-24.182$, $p < 0.001$ for NVI versus VI). That is, tense pre-final vowels did
Table 3: The outputs of logistic mixed-effects models of vowel tenseness and other variables for the multinomial distribution of NVI (no vowel insertion), VI (vowel insertion), and OVI (optional vowel insertion). NVI was the reference level. Fixed factors are vowel tenseness (lax vs. tense), stop voicing (voiceless vs. voiced), final stress (unstressed vs. stressed), word size (monosyllabic vs. polysyllabic) and stop place (labial vs. coronal vs. dorsal), with lax, voiceless, unstressed, monosyllabic and labial set as the baseline levels.

| Comparison to baseline | Pattern | Posterior mean | 95% CI       | pMCMC |
|------------------------|---------|----------------|--------------|-------|
| Intercept              | OVI     | −2.118         | (−2.970, −1.373) | <0.001*** |
| Intercept              | VI      | −3.752         | (−6.495, −1.820) | <0.001*** |
| Tenseness = Tense      | OVI     | 5.146          | (1.911, 8.985)  | <0.001*** |
| Tenseness = Tense      | VI      | 10.434         | (4.848, 16.972) | <0.001*** |
| Voicing = Voiced       | OVI     | 2.082          | (−0.515, 4.643) | 0.086 |
| Voicing = Voiced       | VI      | 6.543          | (2.817, 10.920) | <0.001*** |
| Tenseness = Tense:Voicing = Voiced | OVI | −1.817         | (−7.117, 3.037) | 0.399 |
| Tenseness = Tense:Voicing = Voiced | VI | −3.002         | (−7.732, 2.290) | 0.192 |

Table 3a: The output of a logistic mixed-effects model of vowel tenseness and stop voicing

| Comparison to baseline | Pattern | Posterior mean | 95% CI       | pMCMC |
|------------------------|---------|----------------|--------------|-------|
| Intercept              | OVI     | −2.146         | (−3.181, −1.305) | <0.001*** |
| Intercept              | VI      | −4.147         | (−7.600, −1.862) | <0.001*** |
| Tenseness = Tense      | OVI     | 2.180          | (−1.832, 6.646) | 0.381 |
| Tenseness = Tense      | VI      | 10.560         | (4.523, 19.022) | <0.001*** |
| Stress = Stressed      | OVI     | 1.046          | (−0.185, 2.716) | 0.100 |
| Stress = Stressed      | VI      | 3.081          | (0.862, 5.933)  | <0.001*** |
| Tenseness = Tense:Stress = Stressed | OVI | 4.083          | (0.416, 8.300)  | 0.023 |
| Tenseness = Tense:Stress = Stressed | VI | 0.486          | (−3.960, 4.653) | 0.746 |

Table 3b: The output of a logistic mixed-effects model of vowel tenseness and final stress

| Comparison to baseline | Pattern | Posterior mean | 95% CI       | pMCMC |
|------------------------|---------|----------------|--------------|-------|
| Intercept              | OVI     | −0.900         | (−2.101, 0.312) | 0.183 |
| Intercept              | VI      | −1.448         | (−4.580, 0.410) | 0.091 |
| Tenseness = Tense      | OVI     | 6.666          | (2.068, 12.527) | <0.001*** |
| Tenseness = Tense      | VI      | 13.404         | (4.141, 28.391) | <0.001*** |
| Size = Polysyllabic    | OVI     | −1.261         | (−3.193, 0.380) | 0.081 |
| Size = Polysyllabic    | VI      | −3.661         | (−9.143, −0.758) | <0.001*** |
| Tenseness = Tense:Size = Polysyllabic | OVI | −2.436         | (−5.585, 1.081) | 0.153 |
| Tenseness = Tense:Size = Polysyllabic | VI | 1.074          | (−3.037, 7.476) | 0.709 |

Table 3c: The output of a logistic mixed-effects model of vowel tenseness and word size

| Comparison to baseline | Pattern | Posterior mean | 95% CI       | pMCMC |
|------------------------|---------|----------------|--------------|-------|
| Intercept              | OVI     | −10.613        | (−18.009, −4.525) | <0.001*** |
| Intercept              | VI      | −24.119        | (−38.593, −9.822) | <0.001*** |
significantly alter pattern rate distributions compared with reference rates of patterns for items ending in coronal stops. As shown in Table 4, Tukey’s HSD post-hoc comparisons of the interaction between vowel tenseness and stop place indicated that the stop place effect was significant only for items with lax pre-final vowels (see also Figure 3): vowel insertion was significantly most frequent following coronal final stops and least frequent following labial stops when the pre-final vowel was lax ($z = -7.006$, $p < 0.001$ for coronals versus dorsals; $z = 3.149$, $p < 0.05$ for labials versus dorsals) whereas the difference between labial versus

**Table 3d:** The output of a logistic mixed-effects model of vowel tenseness and stop place

| Comparison to baseline | Pattern | Posterior mean | 95% CI | pMCMC  |
|------------------------|---------|----------------|--------|--------|
| Tenseness = Tense      | OVI     | 16.997         | (5.446, 31.081) | <0.001*** |
| Tenseness = Tense      | VI      | 34.032         | (14.837, 57.392) | <0.001*** |
| Place = Coronal        | OVI     | 12.187         | (4.555, 22.559)  | <0.001*** |
| Place = Coronal        | VI      | 25.940         | (10.858, 42.825) | <0.001*** |
| Place = Dorsal         | OVI     | 7.040          | (1.871, 12.963)  | <0.001*** |
| Place = Dorsal         | VI      | 16.972         | (6.814, 28.031)  | <0.001*** |
| Tenseness = Tense:Place = Coronal | OVI | -13.922 | (-24.556, -4.708) | <0.001*** |
| Tenseness = Tense:Place = Coronal | VI | -24.182 | (-40.349, -9.766) | <0.001*** |
| Tenseness = Tense:Place = Dorsal  | OVI     | 15.522         | (-2.167, 35.432) | 0.084 |
| Tenseness = Tense:Place = Dorsal  | VI      | 11.810         | (-11.673, 36.861) | 0.459 |

Type I error rates are pMCMC values with ***$p < 0.001$.

**Figure 1:** Overall frequency of each adaptation pattern of English words ending in a stop. VI (vowel insertion); NVI (no vowel insertion); OVI (optional vowel insertion).

**Figure 2:** Percentage and counts of vowel insertion patterns of words ending in a stop with a lax versus tense pre-final vowel classified as VI (vowel insertion), NVI (no vowel insertion), or OVI (optional vowel insertion).
coronal/dorsal stops was not significant when the pre-final vowel was tense ($p = 1.000$ for coronals versus dorsals; $p = 1.000$ for labials versus dorsals).

### 3.2 Voicing of English final stop and other predictors

The output of the model given in Table 5a shows that items ending in voiced stops significantly altered relative rates of both VI and OVI patterns in relation to items ending in voiceless stops. There was a significant increase in the relative rates of each pattern in items ending in voiced stops, compared with the reference condition rates (post.mean = 6.651, $p < 0.001$ for NVI versus OVI; post.mean = 13.312, $p < 0.001$ for NVI versus VI). As shown in Figure 4, the percentage of words with

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**Table 4:** Tukey’s HSD test of vowel tenseness and stop place.

| Comparisons                        | Estimate | St.Error | z-value | Pr($>|z|)$ |
|------------------------------------|----------|----------|---------|-----------|
| Tense:labial – lax:labial          | 7.194e+00| 1.438e+00| 5.002   | <0.001*** |
| Lax:coronal – lax:labial          | 5.183e+00| 1.023e+00| 5.069   | <0.001*** |
| Lax:dorsal – lax:labial           | 3.239e+00| 1.029e+00| 3.149   | <0.05*    |
| Tense:cor – tense:labial          | -4.256e-02| 1.090e+00| -0.039  | 1.000     |
| Tense:dorsal – tense:labial       | 2.653e+01| 4.250e+05| 0.000   | 1.000     |
| Tense:coronal – lax:coronal       | 1.969e+00| 4.055e-01| 4.855   | <0.001*** |
| Lax:dorsal – lax:coronal          | -1.944e+00| 2.775e-01| -7.006  | <0.001*** |
| Tense:dorsal – tense:coronal      | 2.657e+01| 4.250e+05| 0.000   | 1.000     |
| Tense:dorsal – lax:dorsal         | 3.048e+01| 4.250e+05| 0.000   | 1.000     |

Levels of significance were *$p < 0.05$ and ***$p < 0.001$.

**Figure 3:** Vowel insertion rate for three adaptation patterns in lax versus tense conditions.
Table 5: The outputs of logistic mixed-effects models of stop voicing and other variables for the multinomial distribution of NVI (no vowel insertion), VI (vowel insertion), and OVI (optional vowel insertion). NVI was the reference level. Fixed factors are stop voicing (voiceless vs. voiced), final stress (unstressed vs. stressed), word size (monosyllabic vs. polysyllabic) and stop place (labial vs. coronal vs. dorsal), with voiceless, unstressed, monosyllabic and labial set as the baseline levels.

Table 5a: The output of a logistic mixed-effects model of stop voicing and final stress

| Comparison to baseline | Pattern | Posterior mean | 95% CI        | pMCMC |
|------------------------|---------|----------------|---------------|-------|
| Intercept              | OVI     | -2.430         | (-4.012, -1.310) | <0.001*** |
| Intercept              | VI      | -4.420         | (-6.956, -1.416) | <0.001*** |
| Voicing = Voiced       | OVI     | 6.651          | (1.833, 11.509)  | <0.001*** |
| Voicing = Voiced       | VI      | 13.312         | (4.607, 20.037)  | <0.001*** |
| Stress = Stressed      | OVI     | 3.310          | (0.921, 5.878)   | <0.001*** |
| Stress = Stressed      | VI      | 6.835          | (2.502, 10.487)  | <0.001*** |
| Voicing = Voiced:Stress = Stressed | OVI | -7.061         | (-11.650, -2.600) | <0.001*** |
| Voicing = Voiced:Stress = Stressed | VI | -9.358         | (-15.264, -2.934) | <0.001*** |

Table 5b: The output of a logistic mixed-effects model of stop voicing and word size

| Comparison to baseline | Pattern | Posterior mean | 95% CI        | pMCMC |
|------------------------|---------|----------------|---------------|-------|
| Intercept              | OVI     | 1.954          | (-0.005, 4.454) | 0.077 |
| Intercept              | VI      | 3.530          | (0.720, 6.345)  | <0.01** |
| Voicing = Voiced       | OVI     | 0.212          | (-2.571, 3.053) | 0.961 |
| Voicing = Voiced       | VI      | 6.223          | (0.821, 11.983) | <0.01** |
| Size = Polysyllabic    | OVI     | -4.017         | (-7.244, -1.521) | <0.001*** |
| Size = Polysyllabic    | VI      | -9.529         | (-15.372, -2.795) | <0.001*** |
| Voicing = Voiced:Size = Polysyllabic | OVI | 7.861          | (3.498, 13.420)  | <0.001*** |
| Voicing = Voiced:Size = Polysyllabic | VI | 14.308         | (3.147, 23.950)  | <0.001*** |

Table 5c: The output of a logistic mixed-effects model of stop voicing and stop place

| Comparison to baseline | Pattern | Posterior mean | 95% CI        | pMCMC |
|------------------------|---------|----------------|---------------|-------|
| Intercept              | OVI     | -5.870         | (-9.409, -2.633) | <0.001*** |
| Intercept              | VI      | -12.054        | (-19.794, -5.266) | <0.001*** |
| Voicing = Voiced       | OVI     | -62.980        | (-104.298, -12.703) | <0.001*** |
| Voicing = Voiced       | VI      | 2.188          | (-7.850, 13.894) | 0.679 |
| Place = Coronal        | OVI     | 9.700          | (3.115, 15.491)  | <0.001*** |
| Place = Coronal        | VI      | 17.219         | (7.761, 28.599)  | <0.001*** |
| Place = Dorsal         | OVI     | 2.559          | (-0.329, 5.875)  | 0.067 |
| Place = Dorsal         | VI      | 5.852          | (0.681, 11.697)  | <0.05* |
| Voicing = Voiced:Place = Coronal | OVI | 69.785         | (14.357, 113.456) | <0.001*** |
| Voicing = Voiced:Place = Coronal | VI | 15.357         | (1.595, 28.115)  | <0.01** |
| Voicing = Voiced:Place = Dorsal | OVI | 71.771         | (17.213, 115.097) | <0.001*** |
| Voicing = Voiced:Place = Dorsal | VI | 12.516         | (-1.792, 26.416) | <0.05* |

Type I error rates are pMCMC values with *p < 0.05, **p < 0.01 and ***p < 0.001.
voiced final stops undergoing VI (82% = 104 out of 127) was much higher than that of words with voiceless stops (39% = 160 out of 413). In addition to the voicing effect, there were significant interactions between stop voicing and other variables including final stress, word size, and stop place on relative rates of both VI and OVI patterns compared with rates in reference conditions. First, as shown in Table 5a, voiced stops significantly changed pattern rate distributions compared with reference rates of patterns for stressed items (post.mean = −7.061, \( p < 0.001 \) for NVI versus OVI; post.mean = −9.358, \( p < 0.001 \) for NVI versus VI). Table 6a summarizes Tukey’s HSD post-hoc comparisons of the interaction between stop voicing and final stress, indicating that the final stress effect was only shown in the voiceless condition (see also Figure 5A): vowel epenthesis was significantly more likely after final stressed syllables than after unstressed syllables when voicing was not present (\( z = 7.342, p < 0.001 \)) whereas the difference between unstressed versus stressed syllables was not significant in voiced stops (\( p = 0.428 \)).

There was also a significant interaction of stop voicing and word size (post.mean = 7.861, \( p < 0.001 \) for NVI versus OVI; post.mean = 14.308, \( p < 0.001 \) for NVI versus VI), as shown in Table 5b. Table 6b summarizes Tukey’s HSD post-hoc comparisons of the interaction between the two predictors, suggesting that the word size effect was found only in voiceless stops (see also Figure 5B); namely, vowel insertion was significantly more likely in monosyllabic words than in polysyllabic words when the final stop was voiceless (\( z = 7.342, p < 0.001 \)) whereas there was no significant difference between monosyllabic versus polysyllabic words in the voiced condition (\( p = 0.237 \)). Further, Table 5c shows that voiced final stops also significantly altered pattern rates for items ending in coronal stops (post.mean = 69.785, \( p < 0.001 \) for NVI versus OVI; post.mean = 15.357, \( p < 0.01 \) for NVI versus VI and for those ending in dorsal stops (post.mean = 71.771, \( p < 0.001 \) for NVI versus OVI; post.mean = 12.516, \( p < 0.05 \) for NVI versus VI). As shown in Table 6c, Tukey’s HSD post-hoc comparisons of the interaction between stop voicing and stop place indicated that the coronal place effect was significant only in voiceless stops (see also Figure 5C): coronal stops induced more vowel insertion than dorsal stops with no significant difference between labial versus dorsal stops.

**Figure 4:** Percentage and counts of vowel insertion patterns of words ending in a voiceless versus voiced stop classified as VI (vowel insertion), NVI (no vowel insertion), and OVI (optional vowel insertion).
when voicing was absent ($z = -7.166, p < 0.001$ for coronals versus dorsals; $p = 0.193$ for labials versus dorsals) while coronal stops were not significantly more likely than dorsal stops in the voiced condition with significant difference between labial versus dorsal stops ($p = 0.114$ for coronals versus dorsals; $z = 3.352, p < 0.01$ for labials versus dorsals).

### 3.3 Final syllable containing stress and other predictors

The output of the model given in Table 7b shows that both VI and OVI patterns were predicted to be significantly less common than NVI patterns at baseline (i.e., unstressed final syllables with labial stops), as shown by the significant negative mean logit values (post.mean = $-48.119, p < 0.001$ for NVI versus OVI;
post.mean = −25.115, p < 0.001 for NVI versus VI). The two models given in Table 7 found a significant effect of final stress (unstressed versus stressed); Table 6b shows that there was a significant rise in the relative rates of VI and OVI patterns in words ending in stressed syllables compared to the reference condition rates (post.mean = 44.790, p < 0.001 for NVI versus OVI; post.mean = 14.007, p < 0.05 for NVI versus VI). As outlined in Figure 6, the percentage of words with stressed final syllables undergoing VI (63% = 185 out of 292) was higher than that of words with unstressed syllables (32% = 79 out of 248). There were also significant interactions between final stress and other variables including word size and stop place. First, the model in Table 7a found a significant interaction between items ending in stressed syllables and polysyllabic items for each adaptation pattern (post.mean = −117.306, p < 0.05 for NVI versus OVI; post.mean = −308.854, p < 0.01 for NVI versus VI). As shown in Table 8a, however, Tukey’s HSD post-hoc comparisons of the interaction between final stress and word size indicated that there was no significant effect of word size in both unstressed and stressed conditions (see also

Figure 5: Vowel insertion rate for three adaptation patterns in voiceless versus voiced conditions. a: Upper left; b: Upper right; c: Down.
Table 7: The outputs of the logistic mixed-effects model of final stress and other variables for the multinomial distribution of NVI (no vowel insertion), VI (vowel insertion), and OVI (optional vowel insertion). NVI was the reference level. Fixed factors are final stress (unstressed vs. stressed), word size (monosyllabic vs. polysyllabic) and stop place (labial vs. coronal vs. dorsal), with unstressed, monosyllabic and labial set as the baseline levels.

Table 7a: The output of a logistic mixed-effects model of final stress and word size

| Comparison to baseline | Pattern | Posterior mean | 95% CI | pMCMC   |
|------------------------|---------|----------------|--------|---------|
| Intercept              | OVI     | −118.411       | (−302.561, 2.956) | <0.05*  |
| Intercept              | VI      | −310.553       | (−704.097, 0.748) | <0.01** |
| Stress = Stressed      | OVI     | 118.172        | (−1.727, 303.240) | <0.05*  |
| Stress = Stressed      | VI      | 312.495        | (1.508, 707.323)  | <0.01** |
| Size = Polysyllabic    | OVI     | 116.665        | (−4.555, 300.710) | <0.05*  |
| Size = Polysyllabic    | VI      | 309.227        | (−1.654, 702.243) | <0.01** |
| Stress = Stressed:Size = Polysyllabic | OVI | −117.306 | (−301.504, 3.573) | <0.05* |
| Stress = Stressed:Size = Polysyllabic | VI | −308.854 | (−701.583, 2.903) | <0.01** |

Table 7b: The output of a logistic mixed-effects model of final stress and stop place

| Comparison to baseline | Pattern | Posterior mean | 95% CI | pMCMC   |
|------------------------|---------|----------------|--------|---------|
| Intercept              | OVI     | −48.119        | (−77.701, −14.447) | <0.001*** |
| Intercept              | VI      | −25.115        | (−38.999, −12.595) | <0.001*** |
| Stress = Stressed      | OVI     | 44.790         | (12.395, 74.829)  | <0.001*** |
| Stress = Stressed      | VI      | 14.007         | (0.713, 25.959)   | <0.05*   |
| Place = Coronal        | OVI     | 50.463         | (16.648, 82.576)  | <0.001*** |
| Place = Coronal        | VI      | 28.023         | (14.715, 44.173)  | <0.001*** |
| Place = Dorsal         | OVI     | 42.745         | (10.658, 72.202)  | <0.001*** |
| Place = Dorsal         | VI      | 8.648          | (−2.504, 20.567)  | 0.136    |
| Stress = Stressed:Place = Coronal | OVI | −40.334 | (−68.507, −7.759) | <0.001*** |
| Stress = Stressed:Place = Coronal | VI | 0.350 | (−11.670, 12.739) | 0.962   |
| Stress = Stressed:Place = Dorsal | OVI | −37.944 | (−65.538, −5.647) | <0.001*** |
| Stress = Stressed:Place = Dorsal | VI | 5.918 | (−8.040, 20.170) | 0.429   |

Type I error rates are pMCMC values with *p < 0.05, **p < 0.01 and ***p < 0.001.

Figure 6: Percentage and counts of vowel insertion patterns of words ending in an unstressed versus stressed syllable classified as VI (vowel insertion), NVI (no vowel insertion), and OVI (optional vowel insertion).
This result can possibly be attributed to the fact that all monosyllabic words are typically considered to hold lexical stress and hence there was no case of unstressed monosyllabic items in the current corpus data.

Figure 7: Vowel insertion rate for three adaptation patterns in unstressed versus stressed conditions. a: Left; b: Right.

Figure 7a: \( p = 0.986 \) for unstressed syllables; \( p = 0.988 \) for stressed syllables. This result can possibly be attributed to the fact that all monosyllabic words are typically considered to hold lexical stress and hence there was no case of unstressed monosyllabic items in the current corpus data.
Besides the significant interaction of final stress and word size, the present study found a significant interaction between items ending in stressed syllables and items ending in coronal/dorsal stops for OVI patterns (see Table 7b; post.mean = −40.334, p < 0.001 for stressed*coronal; post.mean = −37.944, p < 0.001 for stressed*dorsal). As shown in Table 8b, Tukey’s HSD post-hoc comparisons of the interaction between the two predictors indicated that a coronal place effect was significant in both unstressed and stressed syllables (see also Figure 7b); when the final syllable lacked stress, vowel insertion was significantly more likely after coronal stops than dorsal stops while there was no significant difference between labial versus dorsal stops (z = −6.693, p < 0.001 for coronals versus dorsals; p = 0.465 for labials versus dorsals). When the final syllable was stressed, on the other hand, the difference between labials versus coronals/dorsals was statistically significant (z = −4.664, p < 0.001 for coronals versus dorsals; z = 4.034, p < 0.001 for labials versus dorsals). This result can probably be attributed to the fact that all monosyllabic words are typically considered to hold lexical stress and hence there was no case of unstressed monosyllabic items in the current corpus data (see Figure 7a).

3.4 Word size and stop place

In the last model given in Table 9, NVI patterns were predicted to be significantly more common than both VI and OVI patterns at baseline (monosyllabic items ending in labial stops), i.e., post.mean = −3.199, p < 0.01 for NVI versus OVI; post.mean = −12.116, p < 0.01 for NVI versus VI. The model found a significant effect

| Comparison to baseline | Pattern | Posterior mean | 95% CI | pMCMC |
|------------------------|---------|----------------|--------|-------|
| Intercept              | OVI     | −3.199         | (−5.780, −0.836) | <0.01** |
| Intercept              | VI      | −12.116        | (−22.079, −4.131) | <0.01** |
| Size = Polysyllabic    | OVI     | −48.396        | (−84.497, −9.124) | <0.001*** |
| Size = Polysyllabic    | VI      | −19.460        | (−36.544, −5.079) | <0.01** |
| Place = Coronal        | OVI     | 11.105         | (3.337, 18.574)  | <0.001*** |
| Place = Coronal        | VI      | 32.944         | (16.299, 53.246) | <0.001*** |
| Place = Dorsal         | OVI     | 4.607          | (0.569, 9.229)   | <0.01** |
| Place = Dorsal         | VI      | 15.617         | (5.000, 28.593)  | <0.01** |
| Size = Polysyllabic:Place = Coronal | OVI | 43.351 | (4.059, 78.219) | <0.01** |
| Size = Polysyllabic:Place = Coronal | VI | 4.347 | (−10.979, 18.215) | 0.520 |
| Size = Polysyllabic:Place = Dorsal | OVI | 42.128 | (2.905, 76.994) | <0.01** |
| Size = Polysyllabic:Place = Dorsal | VI | −0.054 | (−16.071, 15.747) | 0.977 |

Type I error rates are pMCMC values with **p < 0.01 and ***p < 0.001.
of word size (monosyllabic versus polysyllabic); polysyllabic words significantly decreased the likelihood of VI and OVI patterns relative to NVI patterns compared with the reference likelihood (rates of VI and OVI patterns to NVI patterns for monosyllabic words), i.e., post.mean = −48.396, \( p < 0.001 \) for NVI versus OVI; post.mean = −19.460, \( p < 0.01 \) for NVI versus VI). As shown in Figure 8, the percentage of monosyllabic words undergoing VI (62% = 153 out of 247) was higher than that of polysyllabic words (38% = 111 out of 293). This model also found a significant effect of stop place (labials versus coronals; labials versus dorsals). That is, there was a significant increase in the relative rates of VI and OVI patterns in items ending in coronal and dorsal stops, compared with the reference rates (rates of VI and OVI patterns to NVI patterns for items ending in labial stops), i.e., labials versus coronals: post.mean = 11.105, \( p < 0.001 \) for NVI versus OVI; post.mean = 32.944, \( p < 0.001 \) for NVI versus VI; labials versus dorsals: post.mean = 4.607, \( p < 0.01 \) for NVI versus OVI; post.mean = 15.617, \( p < 0.01 \) for NVI versus VI). Figure 9 shows that vowel insertion was more likely when the final stop was coronal than when it was dorsal, and more likely when the final stop was dorsal than when it was labial. Fewer words with labial final stops (5% = 5 out of 94) underwent vowel insertion than words with dorsal stops (33% = 50 out of 150), which in turn were less likely to show vowel insertion than words with coronal stops (68% = 200 out of 296).

**Figure 8:** Percentage and counts of vowel insertion patterns of monosyllabic versus polysyllabic words ending in a stop classified as VI (vowel insertion), NVI (no vowel insertion), or OVI (optional vowel insertion).

**Figure 9:** Percentage and counts of vowel insertion patterns of words ending in a labial versus coronal versus dorsal stop classified as VI (vowel insertion), NVI (no vowel insertion), or OVI (optional vowel insertion).
In addition to the significant effects of each factor, there was a significant interaction between polysyllabic items and items ending in coronal/dorsal stops for OVI patterns, i.e., post.mean = 43.351, \( p < 0.01 \) for polysyllabic*coronal; post.mean = 42.128, \( p < 0.01 \) for polysyllabic*dorsal. As shown in Table 10, Tukey’s HSD post-hoc comparisons of the interaction between word size and stop place indicated that there was a significant effect of coronal place in both monosyllabic and polysyllabic words while the difference between labial versus dorsal final stops was only significant in monosyllabic words, i.e., monosyllabic words: \( z = -4.572, p < 0.001 \) for coronals versus dorsals; \( z = 3.524, p < 0.01 \) for labials versus dorsals; polysyllabic words: \( z = -7.084, p < 0.001 \) for coronals versus dorsals; \( p = 0.154 \) for labials versus dorsals (see also Figure 10).

**Table 10:** Tukey’s HSD test of word size and stop place.

| Comparisons                        | Estimate | St.Error | z-value | Pr(>|z|) |
|------------------------------------|----------|----------|---------|----------|
| Polysyllabic:labial – monosyllabic:labial | -2.274   | 0.783    | -2.905  | <0.05*   |
| Monosyllabic:coronal – monosyllabic:labial | 3.447    | 0.470    | 7.339   | <0.001***|
| Monosyllabic:dorsal – monosyllabic:labial | 1.392    | 0.395    | 3.524   | <0.01**  |
| Polysyllabic:coronal – polysyllabic:labial | 4.016    | 0.746    | 5.386   | <0.001***|
| Polysyllabic:dorsal – polysyllabic:labial | 1.817    | 0.768    | 2.365   | 0.154    |
| Polysyllabic:coronal – monosyllabic:coronal | -1.705   | 0.405    | -4.208  | <0.001***|
| Monosyllabic:dorsal – monosyllabic:coronal | -2.054   | 0.449    | -4.572  | <0.001***|
| Polysyllabic:dorsal – polysyllabic:coronal | -2.199   | 0.310    | -7.084  | <0.001***|
| Polysyllabic:dorsal – monosyllabic:dorsal | -1.849   | 0.366    | -5.049  | <0.001***|

Levels of significance were *\( p < 0.05 \), **\( p < 0.01 \) and ***\( p < 0.001 \).

**Figure 10:** Vowel insertion rate for three adaptation patterns in monosyllabic versus polysyllabic conditions.
4 Discussion

As mentioned in Section 3, the statistical analysis of the current loanword data showed that there were significant effects of all five factors in the rate of vowel epenthesis, i.e., tenseness of pre-stop vowel, voicing and place of English final stop, final syllable containing stress, and word size. These results confirmed that specific phonological factors affected the possibility of vowel insertion; that is, vowel epenthesis was more frequent after (i) stops following a tense vowel than those following a lax vowel, (ii) voiced stops than voiceless ones, (iii) coronal stops than labial or dorsal stops, (iv) stops in stressed syllables than those in unstressed syllables, and (v) monosyllabic than polysyllabic forms.

First of all, the influence of vowel tenseness on vowel epenthesis was evident in how Korean adapts English words ending in a stop. The vowel tenseness effect was significantly greater in words with tense pre-final vowels than in words with lax pre-final vowels in this study (see Figure 2). Addressing Kang’s (2003) argument may serve as a good starting point for a discussion about the tenseness of the pre-stop vowel. She correlates the effect of preceding tense and lax vowels in English with the likelihood that an English final stop is released. Kang (2003) argues that Korean speakers insert a vowel in their production to maintain perceptual similarity between the English and Korean forms because a sequence of a stop followed by an epenthetic vowel is the perceptually closest Korean structure to an English final released stop. According to her, the principal reason for the vowel tenseness effect is its influence on the relative likelihood of release. For example, although /aʊ/ is a tense diphthong, it is phonotactically very impoverished unlike other tense vowels in terms of what can follow the vowel; that is, only /t/ and /d/ are the plosives that occur word-finally following /aʊ/, where release is not an important cue. Therefore, it essentially behaves like a lax vowel in release and adaptation even though phonetically it is a long vowel like other tense diphthongs. In sum, the reason why vowel tenseness correlates with vowel insertion in Kang (2003) is that it can increase the likelihood of release in English pronunciation.

However, Kwon (2017) provides evidence where the tense vowel effect cannot be fully accounted for only by the greater likelihood of release in English pronunciation after tense vowels. She probed Korean speakers’ perception of nonce forms by asking Korean speakers to choose the appropriate allomorph of suffixes that have two allomorphs, one used after stems ending in a vowel and the other after stems ending in a consonant. In an experiment where Korean participants listened to English non-words ending in a plosive and selected an appropriate suffix after each stimulus, Kwon controlled the presence/absence of stop release
by excising the release portion of released items. The effect of tense vowels preceding the stem-final consonant was still found in unreleased items, i.e., about 40% of vowel insertion in unreleased tense items for near monolingual speakers (Kwon 2017: 11).

Although Kwon (2017) found the surprising effect of tenseness when release was controlled for, the tenseness effect might have been confounded with a word size effect in her study since all the experimental items were monosyllabic. Hirano (1994b) argues that Korean tends to adapt English monosyllabic words as disyllabic forms since Korean prefers disyllabic prosodic word structure. As discussed in Hirano (1994a), only 0.76% of words in the Korean pronunciation dictionary of the Korean Broadcasting System (1993) are monosyllabic. This suggests that a word size preference could motivate Korean speakers to change the word size of English monosyllables to a structure more consistent with Korean. Although Kwon (2017) investigated only four factors (release, voicing and place of coda consonant, and pre-coda vowel tenseness) and word size was not a factor she considered in her study, it is still possible that word size as well as vowel tenseness affected the high rate of vowel insertion for unreleased tense monosyllables. In order to separate the possible word size effect from the effect of vowel tenseness, polysyllabic items were examined separately in the current study and the corpus analysis revealed that vowel insertion in loanwords still took place in a considerably higher percentage of words with tense vowels than in words with lax vowels in polysyllabic words (see Figure 11). The statistical results showed that there was no significant interaction between vowel tenseness and word size, i.e., \( p = 0.153 \) for NVI versus OVI; \( p = 0.709 \) for NVI versus VI (see Table 3c).

This outcome would require an alternative motivation for the vowel tenseness effect, i.e., a factor other than a tendency to be associated with release of the English final stop. The effect of pre-stop vowel tenseness is consistent with the fact that vowel duration is a cue to open versus closed syllables in Korean. Han (1964) claims that vowels in Korean are longer when they occur in open syllables than in closed syllables, and this was confirmed in studies of vowel duration by Koo (1998) and Chung and Huckvale (2001). Koo (1998), for example, found a mean duration of 180.9 ms for vowels in CV syllables versus 87.9 ms in CVC syllables. Thus, the

![Figure 11: Percentage and counts of vowel insertion patterns of polysyllabic words ending in a stop with a lax versus tense pre-final vowel classified as VI, NVI, or OVI.](image-url)
pre-final vowel in ‘feet’ [fiːt], for example, may have a duration more consistent with a syllable-final vowel, leading to the production of this word as [fi.ɾi]. In addition, data analyses showed that obvious diphthongs in English whose nuclei contain two places such as /ai/ and /au/ were more likely to have final vowel insertion in Korean than long single nuclei like /iː/ and /uː/. The frequency of vowel epenthesis in loanwords was much higher for obvious diphthongs than for single long tense vowels in the current study (72 versus 28%). This result may be attributed to the fact that Korean does not allow diphthongs within a single syllable and Korean speakers tend to analyze diphthongs as two syllables (Kim 2021).

In addition, current findings also demonstrate the potential impact of stop voicing on vowel insertion in loanword adaptation. The stop voicing effect was significantly greater in words ending in voiced stops than in words ending in voiceless stops in the study (see Figure 4). There are two possible motivations for a greater likelihood of vowel insertion after voiced than voiceless final stops in Korean loanwords borrowed from English. One motivation is phonotactic, i.e., in Korean, voiced stops occur only between sonorants, never in final position. The second possible motivation has to do with the acoustic cues to voicing in English, where vowels are typically longer before voiced than before voiceless consonants. The phonotactic approach predicts that Korean speakers will be more likely to insert a vowel when an English final stop is voiced than when it is voiceless because Korean allows voicing to occur only between sonorants. However, this prediction appears to hold only for English unreleased final stops; Kwon (2017) reported more frequent epenthetic responses from L2 speakers in a voiced condition than in a voiceless condition, but this stop voicing effect disappeared in her study when the codas were released.

The latter hypothesis, the cue-based view, provides an alternative explanation for the stop voicing effect. This approach predicts that Korean speakers will be more likely to insert a vowel when an English final stop is voiced than when it is voiceless since English vowels tend to be longer before voiced consonants. It has been reported that vowels in English have a tendency to be shorter before voiceless consonants; for example, the vowel in bed is phonetically longer than that in bet (Chen 1970; Crystal and House 1988; House and Fairbanks 1953; Kingston and Diehl 1994; Klatt 1973; Naeser 1970; Peterson and Lehiste 1960; Raphael 1972). The vowel duration cue of the English source form is tied to the phonetics of Korean vowels. As discussed before, Korean vowels tend to be longer in an open syllable than in a closed syllable in Korean (Chung and Huckvale 2001; Han 1964; Koo 1998). Hence, a primary cue to whether a final stop in English is voiced or voiceless is the duration of the preceding vowel, and the longer vowel before a voiced stop in English can make it easier for Korean speakers to hear CVC as CVCC when the final stop is voiced.
Experimental work confirms that Korean speakers are sensitive to English vowel length differences. Chang and Idsardi (2001) reported that Korean participants correctly heard durational differences of vowels in minimal pairs such as *bad* and *bat* and that they used the vowel-length cue employed by English native speakers when identifying English final stops. Chang (2006) carried out a set of experiments to investigate whether Korean learners can use the vowel duration cue to distinguish voicing in English word-final consonants. First, Korean and English listeners responded ‘same’ or ‘different’ to each auditory stimulus consisting of minimal pairs exhibiting a voicing contrast. The overall result showed no difference between Korean and English speakers, although when the correct response rates were separated for stops versus fricatives, Korean speakers were better than English speakers with stops and marginally worse than English speakers with fricatives. Second, in an identification task, Chang’s participants listened to pairs of stimuli and were asked to identify which word they heard. His results showed that although Korean speakers had a lower rate of correct responses than English speakers, their correct response rate was far above chance level, which indicates that they did use the vowel duration cue of English in this task. Third, he reported that in a production task, Korean speakers pronounced longer vowels before voiced consonants just as English speakers did, although there were duration differences between the groups. The three different tests confirm that the vowel length cue is used by Korean speakers in both production and perception of English word-final voiced and voiceless consonants.

Concerning the place effect of the English final stop, the current results showed that vowel epenthesis was most frequent after coronal stops, followed by dorsal stops, then by labial stops (see Figure 9). One of the new findings with respect to the stop-place effect is that the difference between labial versus dorsal final stops turned out to be statistically significant (see Table 9 for statistical results). Kang (2003) reported that the difference between labial versus dorsal stops missed significance although the difference between coronal and dorsal stops was statistically significant. Her findings were based on a loanword list compiled from books published in 1990, while the present corpus dataset contains more recent loanwords collected from materials published in the twenty-first century. As discussed in Section 3, this study also found significant interactions between stop place and two other important factors. The interaction of stop place and vowel tenseness was significant, showing that the effect of stop place was found only in a lax condition (see Table 4), and the additional significant interaction was found in stop place and stop voicing where the difference between coronal versus dorsal stops was significant only in the voiceless condition (see Table 6c). These results suggest a more robust vowel-tenseness effect than stop-place effect in that the effect of stop place was found only when tenseness was
absent. The effect of coronal place in turn appears to be less powerful than the voicing effect since the coronal place effect was found only when voicing was not present. There might be a sort of factor competition here, i.e., the vowel tenseness factor could be more important in the loanword adaptation than the stop-place factor, causing the tenseness effect to veil the place effect; moreover, the stop-voicing factor might be stronger than the coronal-place factor, which could be ineffective due to its competitor.

The findings regarding the final syllable containing stress were consistent with prior studies, showing that vowel insertion was more frequent after stops in stressed syllables than those in unstressed syllables (see Figure 6). The result shown in Figure 6, however, could be confounded with the potential effect of monosyllabicity since all monosyllabic lexical words are generally believed to be stressed. To separate the stress effect from the monosyllabicity effect, polysyllabic items were examined separately in this study and the data analysis revealed that the percentage of polysyllabic words with final stress undergoing vowel insertion was still higher than that of words ending in unstressed syllables (see Figure 12). Statistical results revealed that there was a significant interaction of final stress and word size, showing that the final stress effect was significant only in polysyllabic items ($z = 3.780$, $p < 0.001$, see Table 8a), which indicates that the stress effect could be more salient than the size effect when the two factors are competing.

This study also found significant interactions between final stress and other predictors including stop voicing and stop place. First, the interaction of final stress and stop voicing does not seem so clear since the stress effect was shown only in a voiceless condition and the voicing effect was also found only in a stressless condition (see Table 6a). It is not so obvious which effect could be more powerful in the adaptation of English words into Korean because both predictors had their own significant effects only when their competitive effects were absent. The additional interaction between final stress and stop place also does not appear so unambiguous since the coronal place effect was significant in both unstressed and stressed conditions (see Table 8b). Thus, it is not entirely clear that we can say
one variable ranks above the other if there is something like a ranking hierarchy involving the two.

Finally, as for the effect of word size, vowel insertion was more frequent following monosyllabic items than polysyllabic items (see Figure 8), which corresponds to previous studies. In addition to the significant effect of word size, the present study found significant interactions of word size and other variables including stop voicing and stop place. The interaction of word size and stop voicing was significant showing that the word size effect was found only when the final stops were voiceless and that the stop voicing effect was shown even with polysyllabic items (see Table 6b). This result clearly indicates that the stop-voicing effect is more important than the word-size effect when the two predictors are competing in the loanword adaptation. The interaction between word size and stop place was also significant but this relationship did not appear as clear as that between word size and stop voicing in that vowel insertion was significantly more likely following coronal final stops in both monosyllabic and polysyllabic words (see Table 10), which suggests that the possible ranking of the two factors might not be crystal clear.

Furthermore, concerning the word size effect, prior studies have little to say as to why monosyllabic words have more frequent epenthetic vowels than polysyllabic words. As previously mentioned in this section, Hirano (1994b) argues that a possible reason why Korean adapts many English monosyllabic words as disyllabic forms is that Korean prefers disyllabic prosodic word structure. Hirano (1994a) reports that monosyllabic words comprise only 0.76% of the total words contained in the Korean pronunciation dictionary of the Korean Broadcasting System (1993). This strongly indicates that a word size preference can motivate Korean to change English monosyllabic words to a structure more preferable to Korean.

There are other cases where word size has been shown to be a factor in loanword adaptation and foreign language learning. Wang (1995) reported that Mandarin-speaking English learners were more likely to insert a vowel following a final obstruent in pronouncing monosyllabic than disyllabic nonce forms (72 versus 18%). Similarly, Kao (2015) shows that in Indonesian loanwords from English, vowel insertion is observed only when a lexical root is monosyllabic while coalescence occurs when it is polysyllabic. In addition, Cardoso (2007) found that speakers of Brazilian Portuguese inserted a vowel more frequently in monosyllabic English words than in polysyllabic ones (accuracy of monosyllables versus polysyllables for intermediate learners was 16 versus 37%). Thus, the greater frequency of vowel epenthesis in monosyllabic forms than in polysyllabic ones does show up among second language learners of different language backgrounds. This
word-size effect is often referred to as a phonological markedness effect because a certain word size is preferred (Blust 1979; Breiss and Hayes 2020; Martin 2011).

Another possible reason for the Korean speakers’ tendency toward vowel insertion in English monosyllables could be the influence of Japanese loanwords in Korean, as Hirano (1994b) argues. Because of the Japanese prohibition on final obstruents, many English monosyllabic words are adapted into Japanese as disyllables with open final syllables (e.g., *bed* → *beddo*, *cut* → *katto*, *ink* → *inku*), and it is assumed that Korean borrowed these loanwords from Japanese (e.g., *beddo* → *bed*, *katto* → *kati*, *inku* → *inki*). Previous studies list a large number of words that were borrowed into Korean through Japanese (Kang et al. 2008; Kay 1995; Kim 1998). Although there was indeed an effect of Japanese English-to-Korean adaptation, as Hirano (1994b) acknowledges, it is not easy to quantify precisely how many borrowings came into Korean through Japanese.

In sum, the current study provided the statistical analysis of the Korean loanword data where English source words end in a stop. A series of mixed-effects multinomial logistic regression models revealed that all the relevant phonological factors turned out to affect the likelihood of vowel insertion following the English final stop. The regression models built in the study showed significant effects of all five factors. Each of the given predictors including vowel tenseness, stop voicing, final stress, word size and stop place significantly increased the likelihood of VI and OVI patterns relative to NVI patterns compared with the reference condition rates. One strength of the present study is that it has constructed a new database that constitutes a great improvement both quantitatively and qualitatively over previous studies, resulting in new findings such as the difference between labial versus dorsal final stops and significant interactions of different context predictors. The interplay of these factors suggests a possible hierarchy of conditions/factors that could be modeled with weighted constraint grammars. The current findings suggest that the effects of vowel tenseness and stop voicing seem most important in this specific position, followed by the stop-place effect, followed by word size; in the meanwhile, the final-stress effect ranks above the word-size effect while the relative ranking between stop voicing and final stress is unclear, i.e., tenseness, voicing, ?stress ?place, ?stress size. That is, all the factors related to stop release along with stop voicing appear to rank higher in Korean loanword phonology than the word-size effect. As mentioned earlier, the vowel tenseness effect is correlated with the stop release effect in that English stops with tense pre-final vowels are more likely to be released than those with lax vowels (cf. Kwon 2017). Stop place and final stress also correlate with stop release since they can contribute to the likelihood that English final stops are released; namely, dorsal final stops (or final stressed syllables) are more likely to be released than labial final stops (or final unstressed syllables) by English speakers (Kang 2003).
The current findings, therefore, support the need for further research into how relevant other possible auditory factors such as stop release would be in this specific position although the present study sheds light on adaptation patterns associated with important phonological implications. Future research may involve a behavioral test using auditory stimuli to address whether the particulars of these effects can contribute to the perception of L2 learners and to compare L2 perception patterns between production forms that have already entered the L1 lexicon shown in the current results.

**Supplementary file**

The experimental data from the current analysis as well as R scripts are available as supplementary materials at https://osf.io/5z8fh/.

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