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English Stop Production before a Nasal in Korean L2 Learners*

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Kang, Hyunsook. (2018). English stop production before a nasal in Korean L2 learners. *The Linguistic Association of Korea Journal*, *26*(1), 1-22. The present study examines the production forms of English stops before a nasal produced by Korean learners of English (L2). Korean L2 learners have to learn the phonetic and phonological properties of an English stop before a nasal as a stop is not allowed in this position in Korean. This study attempted first to investigate whether Korean L2 learners were able to establish an L2 phonological subsystem with distinct phonetic categories for English stops in this position, and then to uncover what acoustic values they exploited for these new categories depending on their L2 proficiency level. The results revealed that low-proficiency talkers showed considerable evidence of L1 interference; in some instances, they did not create a new category for a stop by substituting it with a nasal. In other instances, they inserted a vowel after it. They also realized voiceless stops with significantly longer voicing than those of native English talkers. In contrast, high-proficiency talkers realized voiced and voiceless stops with significantly longer stop closure than did native English talkers respectively. This paper showed that stop categories with different acoustic values were established by Korean learners of English compared to native English talkers and that the time of exposure to the L2 affected production forms as has been suggested in many previous studies.

Key Words: production forms of English stops before a nasal, an L2 phonological subsystem, L1 transfer, time of exposure to the L2

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1. Introduction

Many late foreign language (L2) learners produce the words of a foreign language with an “accent.” The “accented” L2 derives partly from phonological and phonetic differences between their native language (L1) and L2. That is, the L1 phonological system may interfere in the acquisition of L2 phonetic categories of L2 learners (Flege, 1995; Guion et al., 2000; Iverson et al., 2003; etc.). Even with the L1 interference, however, L2 learners may still perceive and create new phonetic categories regardless of their age of learning (cf. Flege, 1987; etc.).

In order to explain this L1 and L2 interaction, Flege (1995) proposed the Speech Learning Model (SLM) with two main mechanisms, i.e., assimilation and dissimilation between L1 sounds and L2 sounds. Due to the overall phonetic similarities, some L2 phones are considered as different realizations of a category in L1. In this case, a new category is not created by L1 speakers. For instance, English [t] is usually judged by Korean learners of English as different realizations of the same sound in Korean, [t^h], as they are phonetically similar to each other (cf. Schmidt, 1996). For such a case, SLM assumes that category assimilation has taken place and that no new category is created. This does not mean that the sounds in L1 and L2 have identical phonetic properties nor that L2 learners do not recognize certain acoustic differences between L1 and L2 sounds.

In contrast, a distinct category for an L2 phone can be sometimes established. L1 speakers may note the distinctive phonetic differences between L1 and L2 sounds and be able to create a new category for an L2 sound. This is a case of category dissimilation in SLM. Flege and Hillenbrand (1984) showed one such case. They showed that American speakers in their experiment were able to create a new category for a French vowel category /y/, as a French vowel /y/ was categorically different from the vowels in L1 English. Their newly created vowel /y/ showed F2 values equal to that of the French speakers.

The ability to perceive different phonetic properties between LI and L2 sounds, to judge whether they are members of the same category or not, and further to establish new phonetic categories for L2 sounds may be constrained by the time of exposure of language learners to the L2 (Baker & Trofimovich, 2005; etc.). Best and Strange (1992) showed that experienced Japanese listeners performed better than inexperienced Japanese listeners did when identifying English phoneme contrasts such as /r/ and /l/. The experience with target L2 in Best and Strange (1992) was measured in terms of the length of stay in the United States (less than 7 months vs. 18-48 months) and the experience of English conversation training. Flege and Hillenbrand (1984) also showed that relatively experienced L2 learners produced more native-like sounds than did inexperienced L2 learners: French vowel /u/s produced by the experienced Americans were identified better than those produced by the inexperienced Americans in a labeling task.

One goal of the present paper is to examine Korean speakers' production forms of stops before a nasal, focusing on L2 phonetic learning and the L1-L2 interaction. Production of a stop in this context presents a difficult task for Korean learners of English since Korean stops show different phonetic and phonological properties from English stops. In specific, English contrasts voiced and voiceless stops both in syllable-initial (e.g., 'bag' vs. 'pack'; 'tie' vs. 'die'; 'cap' vs. 'gap') and syllable-final positions (e.g., 'cap' vs. 'cab'; 'mat' vs. 'mad'; 'back' vs. 'bag'). In contrast, Korean establishes a three-way distinction in word-initial position, i.e. aspirated, tense, and lax (e.g., /t^{h}al/-->[t^{h}al]: 'mask', /Tal/-->[Tal]: 'daughter', and /tal/-->[tal]: 'moon', respectively), all voiceless. Though Korean stops do not show a voicing contrast, the voicing contrast of English stops in word-initial position is well perceived and judged by Korean speakers to be equivalent to an aspiration contrast (aspirated stops vs. lax or tense stops) in L1 Korean: English voiceless stops are perceived as Korean aspirated stops (e.g., top-->[t^{h}ap], pen-->[p^{h}en]) and English voiced stops as Korean lax or tense stops (e.g., date--> [teit^{h}ɨ], gum--> [Kəm]) in loanwords. This can be regarded as a case of category assimilation in SLM.

In word-medial intervocalic position, the three-way distinction of Korean stops is well maintained but somewhat differently. Korean lax stops are frequently voiced in intervocalic position such that a three-way distinction of Korean stops in this position is (voiceless) aspirated, (voiceless) tense, and (frequently voiced) lax. A voiceless vs. voiced stop contrast of English in this position is judged by Korean speakers to be equivalent to aspirated stop vs. lax stop contrast (cf. 'maker' --> [meik^{h}ə], candy --> [k^{h}enti]).

In syllable-final position, the three-way contrast of Korean stops is cancelled and all three types of a stop are neutralized to a voiceless lax stop (e.g., /puək^h/-->[puək] 'kitchen', /paK/-->[pak] 'outside', /hopak/-->[hopak] 'pumpkin'). Thus, the voicing contrast of English does not have an equivalent contrast at this position in Korean, raising a question on what kind of L1-L2 interaction will occur.

Another difference between Korean and English regarding the target stop is a different phonological property. English allows a stop-nasal sequence word-internally (e.g., 'picnic', 'signal', 'submit', '(Mr.) Chapman', '(Ms.) Whitney'). Just like in English, a stop may occur before a nasal [m n] by morpheme juxtaposition in Korean. However, this stop obligatorily undergoes a phonological process and changes into a nasal (e.g., /kuk-mul/--> [kuŋmul] 'soup', /əp-mu/-->[əmmu] 'task', /mak-næ/-->[maŋnæ] the youngest one), cancelling the contrast between a stop and a nasal in this position. Again, a question arises on how Korean learners of L2 English respond to a stop-nasal sequence in English.

Another difference between English and Korean stops is that English stops are optionally released, particularly at word-final position, while Korean stops are not. That this difference is well perceived by Korean speakers is evidenced by loanword adaptation (cf. Kim-Renaud, 1977; O. Kang, 1996; etc.). For instance, English words like 'coat' and 'mode' are respectively adapted as [k^{h}ot^{h}ɨ] and [motɨ] with a default vowel, indicating that stop release burst is perceived as onset cues by Korean speakers. Not only word-final stops, but it is also our observation that word-internal stops are often released before a nasal as in 'picnic' and 'technic'.

Some linguists have suggested that Korean speakers perceive voicing quality of stops (cf. Y. Kang, 2003) as well. This is also based on the observation of loanwords, namely that English words ending with a voiced stop are adapted with a final default vowel more often than those ending with a voiceless stop. Y. Kang (2003) argued that this is evidence for Korean speakers' awareness of voicing quality of English stops. This paper assumes that both stop release cues and voicing cues are perceived by Korean speakers and thus affect the production forms of English stops.

Given these phonetic and phonological differences of stops between English and Korean, the production forms of a stop before a nasal may show different acoustic values in two groups of different language talkers, a native English talker group (NE) and a native Korean talker group (NK) learning English as L2. An extensive body of research on stops between L1 and L2 (cf. Flege et al. 1992; Hayes-Harb et al., 2008; Lopez, 2012; etc.) reveals that the phonetic and phonological differences between L1 and L2 affect the acoustic values of the L2 stops produced by L2 learners.

For instance, in syllable-initial position Spanish shows a two-way contrast of stops, pre-voiced vs. voiceless, while English shows another two-way stop distinction, voiced vs. voiceless. Flege and Eefting (1987) examined the production forms of voiceless stops by native Spanish learners of L2 English and found out that they developed a “compromised” stop category for English voiceless stops. Voiceless stops in English words were produced with longer VOT values than those in Spanish words but VOT values in English words were shorter than those produced by English monolinguals of the same age group.

Another well-studied language is Mandarin. Mandarin shows a two-way voicing contrast of stops only in syllable-initial position while English shows a two-way voicing contrast of stops both in syllable-initial and syllable-final positions. Flege et al. (1992) showed that native Mandarin speakers do not adequately produce a voicing contrast for an English word-final stop. Rather, they tend to produce it as voiceless regardless of its voicing.

Hayes-Harb et al. (2008) further investigated the detailed acoustic values of English word-final stops produced by NE speakers and Mandarin learners of English. Two Mandarin HP (high-proficiency) and two Mandarin LP (low-proficiency) learners of English produced English words with final stops. The results showed that compared to NE talkers, their voiced stops were produced with less proportion of voicing during C closure when the stop is voiced and with more proportion of voicing during C closure when the stop is voiceless.

In addition to examining Korean speakers’ production forms of stops before a nasal, another goal of this paper is to look into whether phonological proficiency levels of speakers affect the formation of a new stop category and its acoustic values. As Korean talkers in this experiment are not highly proficient learners of English or bilinguals, we may find “compromised” or

"Korean-accented" phones for L2 stops depending on the proficiency levels of L2 learners.

2. Method

2.1. Talkers

For this experiment, we recorded three American English talkers and twelve Korean talkers. The native-speaking American talkers were all born, raised, and had spent their young adult lives in the United States until they came to Korea to teach. The twelve Korean talkers for this study were all born in Korea and spent all their adult lives in Korea except two talkers who spent three years of high school in the U.S. and returned to Korea for college. All twelve talkers were currently university students in Korea.

Among twelve talkers, six talkers had considerable time of exposure to English. They spent three years in environments where they had considerable English conversation training. Four talkers graduated from a foreign language high school in Korea, majoring in English, and two talkers spent three years of high school in the U.S. and returned to Korea for college. They also had private English conversation classes and are all currently English major students. They are not highly proficient speakers or bilinguals in English but proficient enough to make good conversation in English. Among these six talkers, three best talkers (all female talkers) were selected by one native speaker and the author for the acoustic measurements. They will be referred to as HP talkers in this paper.

The other six talkers were chosen among the candidates who did not have considerable time of exposure to English. They have taken only minimal English classes required at the university, have never taken private English conversation classes, and are majoring in subjects other than English. Among these six Korean talkers, three talkers in English were chosen as the LP talkers by the same judges. Not only their proficiency but their production forms including the preceding vowel sound were considered in the selection. They will be referred to as LP talkers in this paper.

2.2. Stimuli

The target sounds are stops in a stop-nasal sequence VCNV. The list contained word-medial [p,k-n], [p,k-m], [b,g-n], or [b,g-m]. The words in the list are 'submarine,' 'magma,' 'Hackman,' 'Hackney,' 'signal,' 'abnormal,' 'Chapman,' and 'Upni'. The talkers were advised to produce the words as one word. For words they did not know, they were instructed to guess the pronunciation. Each talker produced five repetitions of a set of English words in the list. From the speech samples, we selected two different tokens of each word for the acoustic measurements.

2.3. Procedures

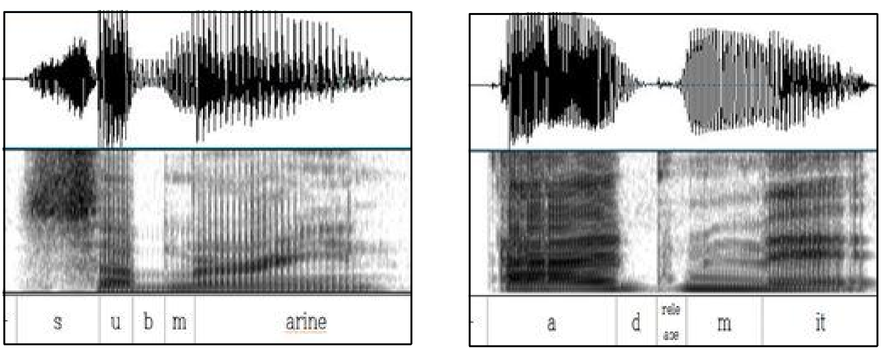
In order to understand various acoustic patterns of a stop produced by talkers with different proficiency in English, we first examined the stop targets and excluded those that were not pronounced as stops. Six voiced and eight voiceless stops were pronounced as nasals by Korean talkers due to L1 transfer, Korean stop nasalization process. For the remaining tokens, we performed acoustic analyses using waveform and spectrogram displays in Praat (Boersma & Weenink, 2016).

We analyzed each stimulus for the temporal-acoustic properties that were shown to be important for a voicing contrast of a stop in perception and production. Absolute temporal-acoustic properties of stops have been suggested to be related with the voicing contrast of a stop by many linguists (e.g., Hillenbrand et al., 1984; Nittrouer, 2004; Smith et al., 2003) such as the first vowel duration V1, final consonant (C2) closure duration, C2 voicing duration, and C2 burst duration. For example, vowel is longer before voiced stops than before the voiceless stops and the closure durations of stops were longer if the stops are voiceless than are voiced.

Further, relative temporal-acoustic properties were also argued to be important for the voicing contrast of a word-internal stop. Port and Dalvy (1982) suggested that relative temporal properties like the ratio of the preceding vowel duration to the following consonant duration play an important role in perception and production of a voicing contrast for the word-internal stop. Hayes-Harb et al. (2008) also noted the importance of relative acoustic values in a voicing contrast and measured four relative acoustic properties such as relative V duration (V duration/(V duration + C2 closure duration)), relative C2 closure duration (C2 closure duration/(V duration + C2 closure duration)), proportion voicing during C2 closure (C2 voicing duration/C2 closure duration), and relative C2 burst duration (burst duration/C2 closure duration) for a voicing contrast of word-final stops.

In this paper, following Hayes-Harb (2008) we measured three absolute measures such as the first vowel duration V, stop C closure duration, C voicing duration, and three relative measures such as relative V duration (V duration/(V duration + C closure duration)), relative C closure duration (C closure duration/(V duration + C closure duration)), and proportion voicing during C closure (C voicing duration/C closure duration). We did not measure the relative consonant closure duration to vowel (C closure duration/V1 duration) as this is implicated in the measures of relative V duration and relative C closure duration. We also did not measure C burst duration and relative C burst duration but we will mention whether the stop is released or not in the proper contexts.

The waveforms and the spectrograms of the tokens produced by NE talkers are shown in Figures 1a and 1b. Figure 1a shows the voiced stop without release burst before a nasal and Figure 1b shows the voiced stop with the following release burst before a nasal.



(a) (b)

Figure 1. Waveforms and spectrograms of 'submarine' (NE3) and 'admit'(NE2)

In Figure 1a, we can observe different formant patterns between a voiced stop and a nasal: Unlike a voiced stop which shows mainly a voicing bar, a nasal shows formant patterns that resemble vowel formants. Figure 1b shows the voiced stop followed by a release burst. The closure duration of voiced stops is measured for the closing duration before the nasal or before the release.

3. Results and Discussion

3.1. Acoustic Values of Voiced Stops

The acoustic values of voiced stops produced by NE talkers and NK talkers (HK and LP talkers together) are shown in Table 1. Mann-Whitney U tests were performed to compare differences in acoustic values between stops in NE talkers' speech and those in Korean talkers's speech while accommodating unequal variances between them. The data were averaged across place of articulation. With each of the six acoustic measures (the three absolute measures and the three relative measures) as the dependent variables, the results for the voiced stop before a nasal revealed that between NE talkers and NK talkers there were significant differences in stop C closure duration ($U = 123$, $p < .002$, Korean talkers showed significantly longer stop closure duration), and proportion voicing during C closure ($U = 184.5$, $p < .04$, Korean talkers showed significantly shorter relative voicing duration).

In short, compared to those in NE talkers' speech, the acoustic values of voiced stops in Korean talkers' speech were *more* voiceless-like in that they showed longer stop closure duration and shorter proportion voicing during C closure duration.

In order to examine whether all Korean talkers show the same tendency regardless of their proficiency level in English, we performed separate Mann-Whitney U tests between stops in NE talkers' speech and those in LP talkers' speech, and between the stops in NE talkers' speech and those in HP talkers' speech. The results showed that there was no significant difference between NE talkers and LP talkers for any of the absolute measures ($p > .05$ for all) and the relative measures ($p > .05$ for all). In short, LP talkers showed no significant difference from NE talkers in terms of temporal-acoustic properties of a voiced stop.

Table 1. A: Mean absolute acoustic measures (in ms) for voiced stops
B: Mean relative acoustic measures (in ms) for voiced stops

(A) Talker group	Target consonant	V duration	stop *C* closure duration	*C* voicing duration
NE	b	89.4(24.4)	54(11.5)	49.6(15.1)
	g	126.2(66.8)	58.5(15.4)	38.3(21.5)
HP	b	97.8(17.5)	91.8(38.0)	30.4(11.3)
	g	107.4(29.6)	88.4(35.8)	34.0(9.7)
LP	b	98.0(18.9)	68.3(35.6)	42(9)
	g	95.0(19.6)	54.4(12.2)	41(13)
(B) Talker group	**Target consonant**	**Relative V duration[a]**	**Relative *C* closure duration[b]**	**Proportion voicing[c]**
NE	b	.62(.08)	.38(.08)	.92(.20)
	g	.65(.13)	.35(.13)	.71(.38)
HP	b	.53(.13)	.47(.13)	.36(.12)
	g	.56(.12)	.44(.12)	.44(.21)
LP	b	.60(.10)	.39(.10)	.70(.30)
	g	.64(.04)	.36(.04)	.78(.24)

One standard deviation was presented in parentheses.
a. V duration/(V duration+C Closure duration).
b. C Closure duration/(V duration+C closure duration).
c. C voicing duration/C closure duration

In contrast, the results between the stops in NE talkers' speech and those in HP talkers' speech revealed that there were significant differences in stop C closure duration (U = 347.5, p < .001, HP talkers showed significantly longer stop closure duration), C voicing duration (U = 347.5, p < .02, HP talkers showed significantly shorter C voicing duration), relative V duration (U = 171, p < .02, HP talkers showed significantly shorter relative vowel duration), relative C closure duration (U = 171, p < .02, HP talkers showed significantly longer relative stop closure duration), and proportion voicing during C closure (U = 84, p < .001, HP talkers showed significantly shorter relative voicing proportion of C). No significant difference between the two groups was observed in first vowel duration V (p > .05). In short, HP talkers showed significant differences in all the acoustic measures from NE talkers except first vowel duration V.

3.2. Discussion for Voiced Stops

The results in this section revealed that surprisingly, LP talkers, not HP talkers, showed close similarities to NE talkers in the acoustic values of a word-internal voiced stop before a nasal. As such, LP talkers' speech might be interpreted as showing little L1 transfer in producing an L2 voiced stop, contra to the expectation. To find out whether other factors might have twisted the results, we further examined the waveform and spectrogram displays of stop-nasal sequences.

A close examination of the voiced stops before a nasal by NE talkers showed some variant forms: Some were released while others were not. All unreleased stops were fully voiced while released stops did not necessarily show full voicing. Only one token by an NE2 talker seemed to show clear vowel-like waveform after the release of a voiced stop (37 ms). Table 2 shows the number of tokens for each type of voiced stop produced by NE, HP, and LP talkers.

Ladefoged and Johnson (2015) note that when a stop-nasal sequence occurs across the word boundary, English word-final stops are generally unreleased when the following word begins with a nasal. It is interesting to observe that NE talkers in this experiment produced released voiced stops as often as unreleased voiced stops when a stop-nasal sequence occurs within a word.

Table 2. Surface realizations of voiced stops by NE, HP, and LP talkers

	non-released stop	released stop	stop with an inserted V	nasal
NE	8	15	1	
HP	8	8	8	
LP	3		15	6

An examination of the stop-nasal sequences in LP talkers' speech, however, revealed that apparent similarities in acoustic values between their voiced stops and those of NE talkers were in fact due to their low level of English proficiency.

As mentioned earlier, six voiced stops in native Korean talkers' speech were produced as nasals. These six nasal tokens were all produced by LP talkers.

These tokens showed that LP talkers did not establish a distinct stop category for an English stop in these instances, suggesting that a Korean stop vs. a nasal contrast in coda position might not be as distinctive as it is in English.[1)]

Another fifteen target stops by LP talkers were produced with the following vowel. These tokens showed that LP talkers distinctively perceived the voicing contrast of an English stop and attempted to create a new category for a voiced stop, but were unable to produce it correctly. Rather, they created a new incorrect category, CV, in order to reflect the voicing contrast. The stop closure duration of these forms was measured and used for the results in Table 1. Note that these forms constitute the majority of the voiced tokens (79%) of LP talkers submitted for the Mann-Whitney U tests.

As we noted in the Introduction, the stops in VCV forms in Korean were mostly fully voiced due to an L1 Korean phonological process. Since voiced stops were shorter than voiceless stops, the closure duration of the stops in VCV forms were relatively short. Based on these facts, we suggest that acoustic values of the voiced stops in LP talkers' speech were similar to those in NE talkers' speech because LP talkers produced most of the English voiced stops as CV forms in which C occurs as voiced, just like the target English voiced stop.

In contrast, the voiced stops in HP talkers's speech did not show any nasal variant form, showing that HP talkers created a new stop category for an English stop in this position in all instances. Eight tokens were produced with a following inserted vowel, another eight tokens with a release burst, and the other eight tokens as unreleased. Voiced stops by HP talkers showed longer stop closure duration than those by NE talkers (92 ms vs 54 ms for [b]; 88 ms vs 59 ms for [g]). In particular, the mean closure duration of the unreleased voiced stops of HP talkers was 127 ms, quite long compared to 54 ms for the unreleased voiced stops of NE talkers. We conjecture that HP talkers placed a long closure duration before the nasal possibly to minimize the articulatory pressure of consonant nasalization or the vowel insertion due to L1 transfer.

In short, the LP talker group and HP talker group produced stop categories with different acoustic values from each other. LP talkers mostly used CV form

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1) This may imply that perceptual distance between a stop and a nasal if placed before a nasal may differ between LP and NE talkers, and possibly between LP and HP talkers. This issue will be discussed in the future paper.

to represent the voiced quality of a stop and to avoid stop nasalization process. In doing so, they produced a typical "Korean-accented" English. HP talkers used the longer stop closure duration to avoid stop nasalization process and the insertion of an extra vowel, producing a voiced stop with *more* voiceless-like acoustic values.

3.3. Acoustic values of Voiceless Stops

This section compared the six acoustic measures of voiceless stops produced by an NE talker group and a NK talker group. The acoustic values of voiceless stops produced by NE talkers and NK talkers are shown in Table 3. Mann-Whitney U tests were conducted to the data averaged across place of articulation.

Table 3. A: Mean absolute acoustic measures (in ms) for voiced stops
B: Mean relative acoustic measures (in ms) for voiced stops

(A) Talker group	Target consonant	V duration	stop *C* closure duration	*C* voicing duration
NE	p	86.9(20.2)	146.2(36.1)	15.3(5.0)
	k	100.2(21.2)	87.9(18.7)	9.8(6.4)
HP	p	92.3(24.4)	186.1(74.9)	18.0(9.9)
	k	77(17)	147.2(63.8)	19.2(11.7)
LP	p	84.8(25.6)	124(38)	43.0(5.4)
	k	67.9(13.7)	86(25)	40.7(14.8)
(B) Talker group	**Target consonant**	**Relative V duration**	**Relative *C* closure duration**	**Proportion voicing**
(B)NE	p	.11(.04)	.62(.08)	.09(.04)
	k	.12(.07)	.47(.07)	.12(.06)
HP	p	.36(.15)	.64(.15)	.10(.06)
	k	.37(.13)	.63(.13)	.15(.11)
LP	p	.38(.07)	.59(.08)	.32(.06)
	k	.45(.07)	.55(.07)	.50(.18)

One standard deviation was presented in parentheses.
a. V duration/(V duration+C Closure duration).
b. C Closure duration/(V duration+C closure duration).
c. C voicing duration/C closure duration

The results revealed that there were significant differences in first vowel duration V ($U = 308$, $p < .017$, Korean talkers showed significantly shorter vowel duration), C voicing duration ($U = 215$, $p < .001$, Korean talkers showed significantly longer voicing duration), relative V duration ($U = 318$, $p < .025$, Korean talkers showed significantly shorter relative vowel duration), relative C closure duration ($U = 318$, $p < .025$, Korean talkers showed significantly longer relative C closure duration), and proportion voicing during C closure ($U = 286.5$, $p < .008$, Korean talkers showed significantly shorter relative vowel duration). No significant difference was observed in stop C closure duration ($p > .05$).

The results look contradictory: Compared to those of NE talkers, the acoustic values of voiceless stops of Korean talkers look *more* voiced-like in that they showed relatively longer voicing duration but at the same time look *more* voiceless-like in that they showed significantly shorter relative V duration and significantly longer relative C closure duration. These contradictory acoustic values led us to question whether the results were distorted due to the inclusion of speakers with different L2 proficiency in the same group. Thus, we compared the acoustic values of voiceless stops in the NE talker group with those in each of two Korean talker groups separately using Mann-Whitney U tests.

The results revealed that there were significant differences between NE talkers and LP talkers in first vowel duration V ($U = 95.5$, $p < .008$, LP talkers showed significantly shorter vowel duration), C voicing duration ($U = 17$, $p < .001$, LP talkers showed significantly longer voicing duration), and proportion voicing during C closure ($U = 3$, $p < .001$, LP talkers showed significantly longer relative voicing proportion). No other significant differences were observed. In short, compared to voiceless tokens produced by NE talkers, LP talkers seemed to produce voiceless stops with temporal-acoustic values that were *more* voiced-like; long voicing duration of C and longer proportion voicing during C closure.

In contrast, test results between voiceless stops in NE talkers' speech and those in HP talkers' speech revealed that there were significant differences in stop C closure duration ($U = 171.5$, $p < .017$, HP talkers showed significantly longer stop C closure duration than NE talkers), relative V duration ($U = 172$, $p < .017$, HP talkers showed significantly shorter relative vowel duration than NE talkers), and relative C closure duration ($U = 172$, $p < .017$, HP talkers showed significantly longer relative C closure duration than NE talkers). However, no significant differences in first vowel duration V, V voicing duration, and proportion voicing during C closure ($p > .05$ for all) were observed. In short, the significant differences in acoustic values between NE and HP talker groups in this experiment seemed to come from the long stop C closure duration among other things. This long stop closure duration induced relative shortness of the vowel and the relative longness of the consonant closure. In short, different production forms of voiceless stops were observed between LP talkers and HP talkers.

3.4. Discussion for Voiceless Stops

The results in this section showed that different voiceless stop categories were formed depending on the proficiency levels of Korean talkers: LP talkers produced a voiceless stop variant with relatively long C voicing duration and relatively long proportion voicing during C closure compared to that produced by NE talkers. HP talkers produced a voiceless stop variant category with longer stop closure duration among other properties than the one produced by NE talkers.

The inspection of voiceless stop tokens in NE talkers' speech showed that some tokens were released while others were unreleased. The average closure duration of the stops was 117 ms and that of unreleased ones was 151.8 ms. The unreleased stops showed longer stop closure duration. Table 4 shows the number of tokens for each type of a voiceless stop produced by NE, HP, and LP talkers.

Note that NE talkers in this experiment produced released voiceless stops more often than unreleased voiceless stops. In Section 3.2, we also showed that NE talkers in this experiment produced voiced released stops as often as voiced unreleased stops. That is, regardless of the voicing of the stops, NE talkers in this experiment have produced English word-internal stops before a nasal differently from the way word-final stops before a nasal were generally produced (cf. Ladefoged and Johnson, 2015). It seems that depending on the prosodic position, a stop could be differently realized in the same phonological context.

Table 4. Surface realizations of voiceless stops by NE, HP, and LP talkers

	non-released stop	released stop	stop with an inserted V	nasal
NE	10	14	0	0
HP	17	7	0	0
LP	5	3	8	8

LP talkers produced eight voiceless stops as nasals. As mentioned earlier, the nasal variant form shows that LP talkers have not yet created a distinct stop category in this position, showing a considerable influence of L1. These tokens were excluded from Mann-Whitney U tests as they were not obstruents. Among the remaining sixteen tokens, eight tokens were followed by inserted vowels. These tokens showed 49% proportion voicing during C closure, quite a large ratio considering that they were intended to be voiceless stops. In addition, the average closure duration of the target stops in LP talkers' speech was significantly shorter than that in NE talkers' speech. In short, the acoustic values in LP talkers' speech suggest that their voiceless stops are *more* voiced-like in acoustic values than those in NE talkers's speech.

In HP talkers' speech, no voiceless stop occurred as a nasal. As was argued earlier, this shows that HP talkers were able to form a new stop category for an L2 stop before a nasal. Five tokens were produced with the following vowel, another five tokens with a release burst, and the remaining fourteen tokens with no vowel insertion and no visible release burst. The voiceless stops showed longer stop closure duration than that by NE talkers. For instance, the mean closure durations of the unreleased tokens were 211.8 ms (HP) vs. 151.8 ms (NE). Note that HP talkers produced most stops with no clear release burst unlike NE talkers and LP talkers. We speculate that this has contributed to the longer closure duration of voiceless stops produced by HP talkers compared to those by NE talkers and LP talkers. The long closure duration of the stops induced relatively short vowel duration and relatively long stop closure duration as well. We speculate that HP talkers in this experiment placed a stop with a long closure between a preceding vowel and the following nasal in order to minimize L1 phonological transfer, namely, the influence of the following nasal.

In short, LP talkers and HP talkers produced different voiceless stop categories. Specifically, LP talkers in some instances did not establish a new category for a voiceless stop before a nasal. In other instances, they created a voiceless stop category with *more* voiced-like acoustic values than those of NE talkers. Korean HP talkers on the other hand created a stop category in all instances. A stop category established by HP talkers showed *more* voiceless-like acoustic values than that produced by NE talkers.

3.5. Comparison between Voiceless and Voiced Stops

In the previous sections, it was noted that LP talkers' voiceless stops showed *more* voiced-like acoustic values than those produced by NE talkers. As such, the question arises whether LP talkers distinctively contrast voiceless stops with voiced stops in their speech. In order to investigate this issue, Mann-Whitney U tests were performed on the acoustic values of voiced and voiceless stops produced by LP talkers.

The Mann-Whitney U tests showed that there were significant differences between voiceless and voiced stops produced by LP talkers, i.e., in first vowel duration V (U = 41.5, p < .001, voiceless stops showed significantly shorter vowel duration), stop C closure duration (U = 46, p < .001, voiceless stops showed significantly longer stop C closure duration), and relative V duration (U = 8 p < .001, voiceless stops showed significantly shorter relative vowel duration), relative C closure duration (U = 8, p < .001, voiceless stops showed significantly longer relative consonant duration), and proportion voicing during C closure (U = 51, p < .001, voiceless stops showed significantly shorter relative voicing proportion). However, C voicing duration (U = 135, p > .05) did not show any significant difference. In short, LP talkers seemed to well discriminate voiced stops from voiceless stops in five out of six acoustic properties we measured in this paper, showing that they attempted to reflect their acoustic differences in production.

However, the question still remains whether the voiceless stops in LP talkers' speech were distinctively perceived as such in perception. Since their voiceless stops showed *more* voiced-like acoustic values than those in NE speech, future perception tests should be conducted to verify this matter.

The results in the previous sections also revealed that voiced stops in HP talkers' speech showed *more* voiceless-like acoustic values than those in NE talkers' speech. Another set of Mann-Whitney U tests were performed to examine whether voiced stops and voiceless stops in HP talkers' speech were distinctively produced.

The Mann-Whitney U tests on voiced stops and voiceless stops in HP talkers' speech showed that there were significant differences in first vowel duration V (U = 160.5, p < .009, voiceless stops showed significantly shorter vowel duration V), C voicing duration (U = 108, p < .001, voiceless stops showed significantly shorter voicing duration), stop C closure duration of C (U = 104.5, p < .001, voiceless stops showed significantly longer obstruent closure duration), relative V duration (U = 102, p < .001, voiceless stops showed significantly shorter relative vowel duration), relative C closure duration (U = 102, p < .001, voiceless stops showed significantly longer relative consonant duration), and proportion voicing during C closure (U = 25.5, p < .001, voiceless stops showed significantly shorter relative voicing proportion). In short, HP talkers in this experiment accurately discriminated voiced stops from voiceless stops and reflected the differences in production. Again, however, the question still remains whether the voiced stops in HP talkers' speech were distinctively perceived as such in perception since their voiced stops showed *more* voiceless-like acoustic values than those in NE talkers' speech. Future perception test will be conducted to examine this matter.

4. Conclusion

This study examined the acoustic values of an English stop before a nasal produced by NE speakers and NK speakers who are learning English as their L2. The goals of the present study were to find out if Korean learners of English have created an L2 phonological subsystem with distinct phonetic categories and if they did, what acoustic values were exploited for the newly created categories. Furthermore, this paper investigated whether stops with different acoustic values were established depending on the L2 proficiency levels of Korean speakers.

The results obtained in this experiment showed that there were clear differences between the acoustic values of the stops in NE talkers' speech and those in Korean talkers' speech. Korean talkers realized less authentic ranges of acoustic values than NE talkers. In addition, the extent of L1 interference differed depending on the proficiency levels of language learners in L2: As expected, L1 interference on LP talkers' speech was considerable while HP talkers with the increased L2 experience showed some evidence of overcoming L1 interference (Guion et al., 2000; Majors, 2001; Hayes-Harb et al., 2008; etc.).

Specifically, LP talkers often substituted a stop with a nasal, showing that a new stop category was not formed in some instances: The stop was category-assimilated to a nasal (cf. SLM). There was another variant form of a stop with an inserted vowel in LP talkers' speech, a typical English loanword form in L1 Korean. This variant form again showed that LP talkers were under considerable influence of L1 Korean. On the other hand, the voiceless stop in LP talkers' speech revealed *more* voiced-like acoustic values such as the long C voicing duration compared to those in NE talkers' speech.

In contrast, HP talkers produced no nasal substitute for a stop. This shows that HP talkers were able to distinctively perceive the phonetic difference between a stop and a nasal in coda position and control the articulatory gestures to suppress the phonological process of L1. The newly formed voiced and voiceless stops in their speech were *more* voiceless-like in acoustic values compared to the voiced stops in NE talkers' speech, showing longer C closure duration among other things. Based on this, we may assume that as Korean learners of English become more proficient in it, they first attempt to avoid the stop nasalization process in L1 phonology, and then vowel insertion by exploiting the stop closure duration.

Finally, this paper also showed that both LP talkers and HP talkers attempted to reflect the voicing contrast of English stops in their own speech. However, whether the stops will be perceived as they were intended to be remains to be seen since their acoustic values showed somewhat different ranges of values than those in NE talkers' speech.

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