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Production of pre-fortis clipping in English by Korean and English speakers*

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Cho, Hyesun. 2015. Production of pre-fortis clipping in English by Korean and English speakers. *Studies in Phonetics, Phonology and Morphology* 21.1. 115-141. The term pre-fortis clipping refers to the phenomenon in English of vowels being shorter before voiceless obstruents than before voiced ones. This paper examines whether ratios of duration for vowels before voiceless versus voiced obstruents are affected by speakers' L1 and segmental properties such as consonantal manner of articulation, vowel height, and phonemic vowel length. Nine Korean speakers and four native speakers of English were recorded reading 30 minimal pairs consisting of English monosyllabic CVC words differing in coda voicing. The mean ratio of duration for vowels preceding voiceless and voiced obstruents respectively was greater for Korean speakers than for English speakers, but mixed-effects model analyses with speaker and item random effects indicate that the effect of L1 was not significant, though there was greater variation for Korean speakers than for English speakers. The ratio of vowel duration significantly differs between Korean and English speakers only before fricatives. Vowels before voiced fricatives are not sufficiently long for Korean speakers as compared to English speakers. It is suggested that, due to their lack of experience with released fricatives, Korean speakers fail to vary vowel durations sufficiently depending on the consonant manner, before stops and fricatives. **(Dankook University)**

Keywords: Pre-fortis clipping, vowel duration, voicing contrast, L1, consonant manner

1. Introduction

In English, the voicing contrast in word-final consonants is realized by several acoustic properties: duration of the vowel preceding the word-final consonant, F1 offset frequency, closure voicing, and closure duration (Flege et al. 1992). Among these, vowel duration is a strong cue to the perception of consonant voicing (Raphael 1972, Hogan and Rozsypal 1980, Flege et al. 1992, Crowther and Mann 1992). Flege et al. (1992: 132) show that even when the closure portion is entirely edited out, native speakers of English can perceive consonant voicing of /t/- or /d/- final words almost as accurately as when all cues are present, solely depending on the vowel duration (with full cues, 82% and 65%, for /t/ and /d/ respectively; with closure cues removed, 72% and 61%).

This paper focuses on the duration of vowel in English varying depending on the voicing of the following consonant produced by English and Korean

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speakers. Traditionally, 'pre-fortis clipping (hereafter PFC)' refers to a phenomenon where a vowel is shorter before a voiceless consonant than before a voiced consonant within the same syllable, without changing the quality of the vowel (e.g. *beat* vs. *bead*) (House and Fairbanks 1953, Chen 1970, Lisker 1973: 229, Peterson and Lehiste 1960, Keating 1985, Gimson 1989: 96-97, Wells 1990, Roach 2010: 28). English has a 'long' and 'short' phonemic vowel length contrast (such as /i:/ and /ɪ/). The long and short contrast involves not only the vowel length, but the vowel quality as well, whereas pre-fortis clipping involves the vowel quantity exclusively, rather than the vowel quality (Wells 1990). PFC occurs in diphthongs (*plate* vs. *played*) as well, and is triggered by a consonant in the same syllable, e.g. it occurs in *feet* but not in *tea-kettle* (Wells 1990).

The present study examines the duration and ratio of vowels preceding voiceless vs. voiced consonants produced by English vs. Korean speakers. According to Gimson (1989: 96), the vowel in *beat* is about 'half' the vowel in *bead* (before voiced). Vowel duration shows further variation depending on manner of the contextual consonant, i.e. vowels are longer before fricatives than before stops (Peterson and Lehiste 1960, Gimson 1989: 96-97). Vowels before nasals are shorter than those before voiced obstruents and longer than voiceless obstruents. To illustrate, vowel duration of /i:/, which varies with the context in which it occurs, is shown below (Gimson 1989: 97) (csecs. means centiseconds):

(1)	36 csecs.	(before voiced fricative)
	28.5 csecs.	(before voiced stop)
	19.5 csecs.	(before nasal)
	13 csecs.	(before voiceless fricative)
	12.3 csecs.	(before voiceless stop)

The above shows that vowels are longer before voiced than voiceless obstruents, and longer before fricatives than before stops. The ratio of vowel durations before voiceless and voiced stops is 0.43 (=12.3/28.5) and for fricatives, it is even smaller, 0.36 (13/36). More generally, the ratio is known to be greater – a little more than 60% (the ratio of voiceless /voiced). House and Fairbanks (1953) reported the ratio of 68.8%. According to Peterson and Lehiste (1960:700), the ratio of the vowels before voiceless vs. voiced consonant is about 2:3 (=0.66) (19.3csec./29.1csec.) in American English. Umeda (1975) reported the ratio of 0.71 in American English. The ratio is 0.62 (=133/214) in Fruin (1982: 192).

Speakers' L1 may affect the production of the target language. In general, the voicing effect is known to be smaller (i.e. greater ratio values) in L2 speakers. Flege et al. (1992: 134-135) examined the production of words with final /t/ and /d/ by English, Mandarin, and Spanish speakers. In the results, Mandarin and Spanish speakers show a similar pattern of variation in vowel duration as native speakers of English, i.e. vowels are shorter before

/t/ than /d/. However, the duration contrast is weaker in nonnative speakers than in native speakers. The ratios of vowel durations (voiceless to voiced) are: English speakers (0.66), Spanish speakers (0.74, 0.81 – experienced vs. inexperienced), Mandarin speakers (0.79, 0.8 – experienced vs. inexperienced) (converted from the reported ratios of voiced to voiceless, by taking the inverse of the ratio). The ratios of experienced (high proficiency) speakers were not significantly different from native speakers, but those of the inexperienced were significantly different from native speakers. More specifically, the difference between vowel duration mainly came from the difference in the production of vowels before voiced, rather than voiceless, obstruents. The vowel duration before /t/ was not significantly different across all speaker groups, whereas vowels before /d/ were much longer in native speakers of English than in speakers of the other two languages, regardless of proficiency level.

Flege et al. (1992) examined Spanish and Mandarin because the two languages are different from English in that stops are rarely or never allowed in word-final position. Stops cannot appear word-finally in Spanish, with very few exceptional words with voiced final stops (some loanwords or proper names), which are usually produced as fricatives. In Mandarin, only sonorants can occur in word-final position.

Several other studies also report greater ratios in L2 speakers. Crowther and Mann (1992) show that Japanese and Mandarin speakers have substantially smaller vowel duration contrast (*pod* and *pot*) than native speakers of American English. The ratio of vowel duration before voiceless to voiced obstruents are as follows: American English: 0.62, Japanese: 0.82, Mandarin Chinese: 0.91 (computed from mean durations) (Crowther and Maun 1992: 714). French monolingual speakers show a greater ratio (0.72) than English monolingual speakers (0.54) (Mack 1982: 175). Interestingly, the ratio becomes similar in bilingual speakers of French and English: French bilinguals (0.74), English bilinguals (0.78), similar to French monolinguals.

Cho (2003: 216-222) showed that Korean speakers have different ratios of vowel duration from English speakers. For *pat* vs. *pad*, Korean speakers' ratio of vowel duration was 0.67 and English speakers' ratio was 0.57 (converted inversely from his data), thus the voicing effect is weaker in Korean speakers, as expected. He also noted that English speakers use a wider range of vowel duration depending on the voicing and manner of the coda consonant (comparing *seat, cease, seen, seed, sea, and seize* - the duration increases in this order) than Korean speakers (English: 1~2.45, Korean: 1~1.90, setting *seat* as 1).

In the present paper, PFC will be examined with a larger variety of vowels (varying height and phonemic length, including diphthongs) and places of articulation within the same manner. In general high vowels are shorter than non-high vowels ('intrinsic duration' Lehiste 1970, Westbury and Keating 1980). Changes in vowel duration caused by stress and speech rate affect the ratio of vowel duration (Crystal and House 1982), but the influence of intrinsic vowel duration on PFC has not been examined. Another difference from the previous work is that mixed-effects models are fitted treating speakers and items as random effects, instead of just comparing mean values. With these factors included, the current research questions are summarized as below.

(1) Do Korean learners of English apply pre-fortis clipping? Do Korean speakers show the same ratio of vowel durations as English speakers?
(2) Is pre-fortis clipping influenced by segmental properties, i.e. consonant manner, vowel height, or vowel length?

The Korean language does not have voicing contrast, like Mandarin. Unlike Mandarin, Korean allows stops word-finally, though always unreleased (like Cantonese (Edge 1991: 379)). In this regard, Korean speakers are expected to exhibit a weaker voicing effect as Mandarin and Spanish speakers in Flege et al. (1992).

A production experiment is conducted to investigate the above research questions. Section 2 describes the speech materials and experimental procedure, and reports the results. Section 3 is the discussion and Section 4 concludes the paper.

2. Experiment

2.1 Speech materials

The speech materials are 30 minimal pairs of CVC monosyllabic English words. Each minimal pair differs in the voicing of coda consonant (e.g. *beat-bead*). The total list of words is shown in Table 1. The pronunciation of the vowels follows the CMU pronouncing dictionary for North American English by Carnegie Mellon University[1].

There was one minimal pair of CVC words under each combination of the following conditions: consonant manner (stop, fricative, affricate), vowel height (high vs. non-high), and phonemic vowel length[2] (short vs. long) (Gimson 1989). In addition, there were minimal pairs with diphthongs in each manner of consonant.

1 http://www.speech.cs.cmu.edu/cgi-bin/cmudict#about
2 To avoid confusion with the word ‘duration’, the word ‘length’ is used to indicate only phonemic vowel length.

Table 1. Speech materials. The rows indicate manner of coda consonants: (a) stop, (b) fricative, and (c) affricate. The columns indicate different categories of vowels: high vs. non-high, long vs. short vowels, and diphthongs.

		High		Non-high		Diphthong
		Long /iː/	Short /ɪ/	Long /ɑː/,/ɔː/	Short /æ/	
(a)	p-b	beep-beeb	rip-rib	cop-cob /ɑː/	cap-cab	rope-robe
	t-d	beat-bead	bit-bid	cot-cod /ɑː/	bat-bad	coat-code
	k-g	leak-league	pick-pig	clock-clog /ɑː/	sack-sag	broke-brogue
(b)	f-v	leaf-leave	riff-riv	off-of /ɔː/-/ʌ/	half-have	safe-save
	s-z	peace-peas	hiss-his	sauce-saws /ɔː/	ass-as	place-plays
(c)	ts-dz	beats-beads	bits-bids	cots-cods /ɑː/	pats-pads	coats-codes

Some of these minimal pairs were selected referring to Hogan and Rozsypal (1980: 1765) and Roach (2010: 174-175). For fricatives, only the labiodental and alveolar fricatives were included. Post-alveolar fricatives [ʃ, ʒ] were not included because there was no minimal pair that sounds natural. For affricates, only the alveolar place was included, because there were few minimal pairs with [tʃ, dʒ] across a range of vowels. The pair *off-of* has different vowels according to the CMU dictionary (/ɔː/-/ʌ/), but this pair was used in Hogan and Rozsypal (1980) because in citation form both *of* and *off* are pronounced /ɐv/ in Canadian English. Though these are not a perfect minimal pair in some dialects, they share the same manner and place of consonant and the same height (non-high), but differ only in phonemic vowel length. Statistical analyses with and without this pair were conducted but the results were not substantially different, so only the results including this pair is reported. All the affricates and some of the fricatives items are morphologically complex, with the plural marker attached (used in the previous literature). This could have some influence in the realization of vowel duration, but we will ignore this factor in the present paper, as with the previous literature.

A frequent mistake by Korean speakers was the pronunciation of *half* as [hælf], pronouncing the silent /l/. Some Korean speakers pronounced the vowel spelt ‘o’ as [o] or diphthong [oʊ] (*cob*, *cot*, *cod*, *cods*). The subjects were not corrected for these mistakes, but natural readings were recorded for the analysis.

2.2 Participants and recording procedure

The participants in this experiment are 9 native speakers of Korean and 4 native speakers of English (North American). The Koreans were five males (K5-K9) and four females (K1-K4), all university students. All speakers major in English language and literature except one female speaker (K2) whose major is Japanese language and literature. The TOEIC scores of all the Korean speakers were controlled above 700 in order to obtain homogeneity of speakers. The current study did not intend to test PFC according to English proficiency, but merely aim to compare native and nonnative speakers. The TOEIC scores were set to recruit Korean speakers whose English proficiency was moderate to advanced level. It is assumed that such speakers would have had enough English input and thus had a chance to learn PFC naturally. None of the Korean speakers have lived in English-speaking countries more than two months.

The two English speakers came from the United States (Indianapolis, Upstate New York) (E1, E2) and the other two were from Canada (Toronto, Manitoba) (E3, E4). The English speakers were all male, and three of them (E1, E3, E4) were professors at the College English department. Although our English speakers came from different regions, it is reported that these regions have more or less similar vowel duration ratios. According to Tauberer and Evanini (2009), the regions close to our speakers' exhibit the following ratios: NYC: 1.13, Midland (Indianapolis): 1.21, Canada: 1.19 (The numbers are voiced/voiceless ratio. The numbers correspond to 0.88, 0.86, and 0.83 respectively), all of which are not significantly different. None of the participants reported any disorders in hearing and speaking.

Before the recording speakers had a chance to go over the words and check whether they are aware of all the words to read. Most speakers (both Korean and English speakers) were not familiar with *riv* and *beeb*. They were told that *riv* is short for *river* (Hogan and Rozsypal 1980) and *beeb* is slang for BBC (British Broadcasting Corporation).

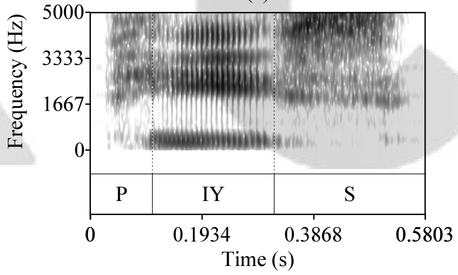
The participants were recorded reading the speech materials in Table 1 three times at a normal, self-selected speaking rate. The words were all randomized so that none of the words comprising a minimal pair can come in a sequence. The words were presented on a sheet of paper, and read without a carrier phrase. Three English speakers and four Korean speakers were recorded in a sound-treated recording studio. The sounds were recorded on a PC through a mastering device, using Sound Forge (with sampling frequency 44.1kHz, sampling size 16bit). Other five Korean speakers were recorded using TASCAM HD-P2 Portable Stereo Audio Recorder in the same sound-treated recording studio (44.1kHz, 24bit). One English speaker (E2) was recorded using Sony IC recorded (ICD-PX312) in a quiet room.

The recordings were analyzed using Praat (version 5.3.22, Boersma and Weenink 1992-2012). Vowel duration for each token was manually measured. The total number of tokens was 2340 (=60 words x 3 repetitions x 13 speakers). The ratio between the vowel duration before voiceless obstruent and the vowel duration before voiced obstruent was computed for each minimal pair with the one before voiced obstruent as denominator.

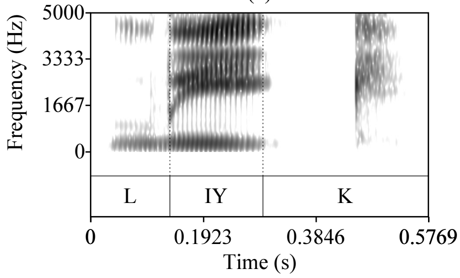
2.3. Measurement

Measuring vowel duration involves determining the onset and the offset of a vowel, which is sometimes difficult depending on the surrounding consonants. It is necessary to have consistent criteria throughout the measurement. The onset of a vowel was determined under following criteria: When the syllable onset is a voiceless stop, the beginning of voicing is determined based on the first formant (following Peterson and Lehiste 1960), though higher formants are blurred by aspiration (Figure 1(a)). As for the onset /l/, there was almost always a clear boundary between the /l/ and the following vowel (Figure 1(b)). Onset /r/ does not have a clear boundary with the vowel. The third formant is a clue to /r/, but the formants were continuous into the vowel, so the boundary is not clear. In such case the point was taken where the formants begin to move fast as the start of the vowel (Figure 1(c)). As for the offset of a vowel, the point where all the major formants (F1,F2,F3) were visible was taken (as in (a) and (b)), even though there were some weak voicing bars in the low frequency band as in (c).

(a)



(b)



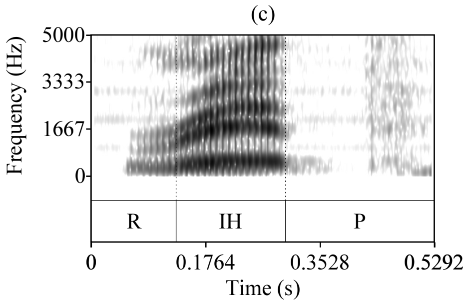
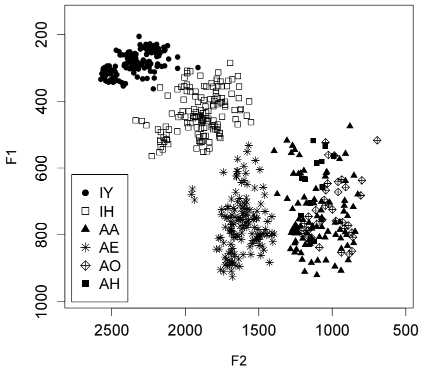


Figure 1. Illustrations of vowel segmentation for the words (a) *peace*, (b) *leak*, and (c) *rip*. Spoken by the same speaker E1. (IY=[i:], IH=[ɪ]).

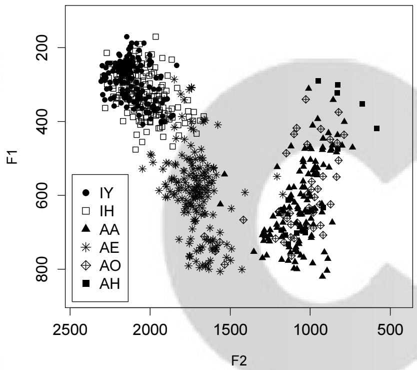
2.4 Results

2.4.1 Vowel quality (F1, F2)

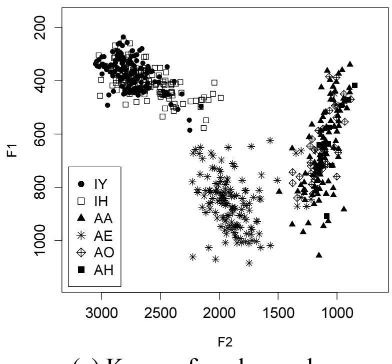
It is well-known that the long-short vowel contrast is hard to produce by Korean speakers because Korean does not have the long vs. short vowel contrast (Yang 1996, Koo 2000, Lee 2001, Cho 2003, Kang 2007, Yang 2008). The long vs. short vowel contrast involves differences in vowel quality, rather than just length difference (Gimson 1989). Vowel formants (F1, F2) were examined in order to check how Korean speakers produced the vowel quality. The first and second format values were collected automatically using Praat scripts (Lennes 2003), which collect formant values at the midpoint of the vowel. After automatic collection, some obvious outliers were checked and their formant values were measured manually. These were mostly the data from K5, whose F1 and F2 were often so close that sometimes the formant tracker recognizes only one formant (f1) in the region of F1 and F2, and treated F3 as F2. As a result, F2 values often came out as too high. The errors mostly occurred with the vowels /ɑ:/ (*cop, cob, cots, cods*), and sometimes with /æ/ (*cab*). Similar errors came from /ɔ:/ (*off*) and /ʌ/ (*of*). For K5, all instances of vowels in *of, cop* and one instance of vowels in *cod, cots, cods, cab* and *cap* were hand-measured. One instance of *of* in K6, and one instance of *cop* in K8 were hand-measured.



(a) English speakers



(b) Korean male speakers



(c) Korean female speakers

Figure 2. F1 and F2 values by speaker group: (a) English speakers (all male) (b) Korean male speakers (c) Korean female speakers. (IY=[i:], IH=[ɪ], AA=[ɑ:], AE=[æ], AH=[ʌ])

Figure 2 shows F1 and F2 values by speaker group. We can see that the vowels /i:/ and /ɪ/ are well separated out by formants in native speakers of English. It is well-known that because the contrast /i:/ and /ɪ/ does not exist in Korean, Korean speakers have difficulty in pronouncing these vowel quality differences (Yang 1996, Koo 2000, Lee 2001, Cho 2003, Kang 2007, Yang 2008). As expected, these two vowels are not distinguished by formants in Korean speakers. The positions of these vowels in Korean speakers almost completely overlapped, as shown in Figure 2(b) and 2(c).

Korean speakers also have difficulties in producing English non-high back vowels /ɑ:/, /ɔ:/ and /ʌ/ (as previously noted in Lee (2001: 235), Koo (2000: 106)). Korean speakers produce these vowels with higher tongue position (lower F1) than English speakers. For Koreans speakers F1 values of these vowels start from as low as about 300 Hz. One source of this difference is that some speakers pronounce the spelling 'o' as [o] (as in *cop, cob, cot*..), which is /ɑ:/ for native speakers ([o], a mid-high vowel, has a lower F1 than [ɑ:], a low vowel).

2.4.2 Duration

2.4.2.1 Overall duration

Figure 3 shows overall vowel duration for each individual speaker, combining vowels across conditions (voiceless and voiced). Among the English speakers, E4 has the longest vowel duration. Korean male speaker K6 has the shortest vowel duration among the speakers. Other than these two speakers, most speakers have more or less similar vowel duration.

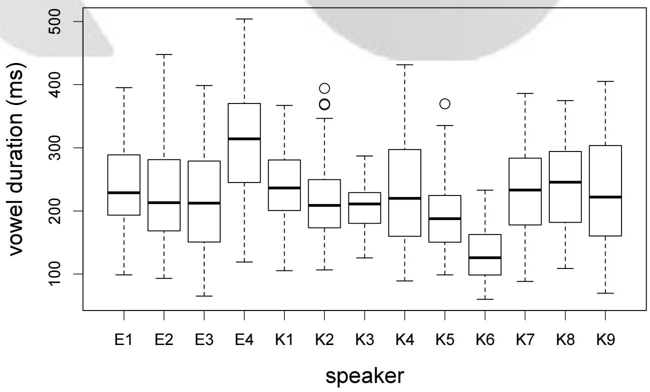


Figure 3. Vowel duration across voicing conditions by individual speaker (E1~E4: English speakers, K1~K4: Korean female speakers, K5~K9: Korean male speakers)

A mixed-effects linear regression model was fitted to the data in order to test the effects of various factors (L1, voicing, consonant manner, vowel height, vowel length) on overall vowel duration. A statistic software R (version 2.15.1) was used (the *lme4* package (Bates and Maechler 2010)). These five factors were fixed effects, and speakers and items (the words in Table 1) were treated as random effects (Baayen et al. 2008), allowing random slopes for speakers and items. The model with speakers and items as random effects was better than the model with only speakers as random effects ($\chi(1)=384.57$, $p<0.0001$). The dependent variable was vowel duration.

(3) Model summary for overall vowel duration across voicing conditions

	Coefficient	Std.Error	t value (p value)
(Intercept)	275.9	21.8	12.6 (p<0.0001) ***
voicingVOICELESS[3]	-74.9	7.8	-9.7 (p<0.001) **
mannerFRIC	25.8	11.6	2.2 (p<0.05) .
mannerSTOP	-13.9	11.0	-1.3 (p<0.05) .
heightNONHIGH	26.9	7.7	3.5 (p=0.2)
lengthSHORT	-15.5	7.7	-2.0 (p<0.0001) ***
L1KOREAN	-37.4	22.3	-1.7 (p=0.1)

The above shows the results of model fitting. All factors other than L1 and vowel height were significant in determining vowel duration (the manner factors are marginally significant). The grand mean of vowel duration is 275.9 ms. Vowel is shorter by 74.9 ms before voiceless obstruent than before voiced obstruent, as expected by PFC. Vowel is longer before fricative by 25.8 ms, shorter before stops by 13.9 ms (compared with affricates, which is the base). The effect of vowel height was not significantly different from zero, but the coefficient was in the expected direction: non-high vowels were longer than high vowels by 26.9 ms. The effect of phonemic vowel length was significant: short vowels were shorter than long vowels, as expected, by 15.5 ms. As for L1, overall vowel duration was shorter in Korean speakers than in English speakers by 37.4 ms, but this difference was not significantly different from zero ($t(1872)=-1.7$, $p=0.1$). This means that overall vowel duration was not significantly different in Korean and English speakers when random effects of speakers and items were factored out.

2.4.2.2 Basic statistics of vowel duration

Our focus is variation in vowel duration depending on voicing condition in Korean vs. English speakers. Figure 4 shows vowel duration for each speaker, voiced and voiceless contexts separately. This clearly shows that in all speakers, vowels preceding voiced obstruent are longer than those preceding voiceless obstruent, though the differences vary among speakers. This difference is significant in both Korean and English speakers, as shown in Table 2. The difference between voiced vs. voiceless conditions is greater in

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[3] Here and below, small letters are factors, capital letters are levels in a factor. 'height' is vowel height, 'length' is phonemic vowel duration. The condition that is not shown in the model summary is the base (reference level).

English than in Korean speakers (98ms, 67ms), suggesting greater durational contrast in English speakers in general. The ratios (voiceless/voiced) are 0.67 for English speakers, and 0.73 for Korean speakers.

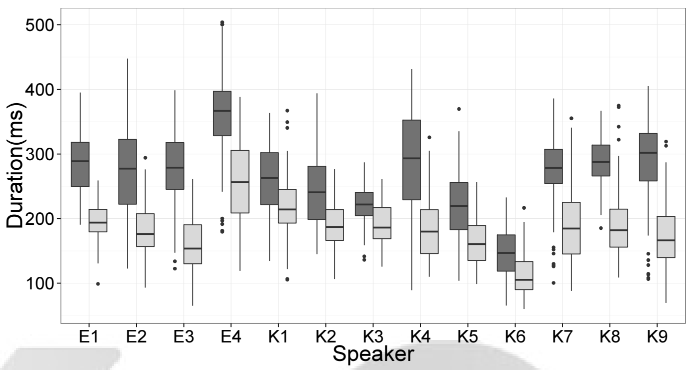


Figure 4. Duration of vowels preceding voiced (dark gray) vs. voiceless (light gray) obstruents for each individual speaker

Table 2. Mean duration of vowels comparing voiced and voiceless environments. The numbers in the parentheses are standard deviation.

L1	(a)Voiced	(b)Voiceless	(a)-(b)	Ratio(b/a)	t-test
English	297 ms (72)	199 ms (70)	98ms	0.67	$t(684)=20.25$ $p<0.0001$
Korean	247 ms (57)	180 ms (52)	67ms	0.73	$t(1483)=21.94$ $p<0.0001$

Table 3 shows the mean duration of the vowel in each word across speakers, Koreans and English speakers separately. Each cell shows the mean vowel duration of the words in the minimal pairs from Table 1, voiceless (left) and voiced (right) final words separately. It can be easily seen that a voiceless-final word always has a shorter vowel than a voiced-final word in the same minimal pair in both Korean and English speakers. English speakers show longer mean vowel durations than Korean speakers, often above 300 ms, whereas none of the vowels produced by Korean speakers are over 300 ms. English speakers also have very short vowels, as short as 118 ms (*pick*). None of the Korean vowels are this short. This means that English speakers use a larger range of vowel duration than Korean speakers, making the length contrast more distinct. In both speaker groups, we can also see that fricatives and diphthongs occur with long vowels.

Table 3. Mean duration of vowels in each word (corresponding to each cell in Table 1, each cell divided into voiceless (left) vs. voiced (right) final words) across speakers (Korean speakers (above), English speakers (below))

Korean speakers		High				Non-high				Diphthong	
		Long /iː/		Short /ɪ/		Long /ɑː/,/ɔː/		Short /æ/			
(a)	p-b	173	212	135	148	143	184	154	192	196	262
	t-d	177	290	142	233	134	242	194	295	183	273
	k-g	174	248	124	224	170	246	167	237	176	258
(b)	f-v	204	273	183	238	212	245	201	265	222	291
	s-z	187	247	181	190	250	287	232	274	224	251
(c)	ts-dz	175	276	162	236	169	256	161	261	183	271

English speakers		High				Non-high				Diphthong	
		Long /iː/		Short /ɪ/		Long /ɑː/,/ɔː/		Short /æ/			
(a)	p-b	166	236	145	189	187	287	199	279	209	328
	t-d	210	319	153	237	216	294	263	353	202	315
	k-g	176	263	118	178	188	298	228	328	170	262
(b)	f-v	205	346	180	278	255	303	234	333	213	346
	s-z	195	361	156	279	260	377	278	391	220	356
(c)	ts-dz	184	289	160	211	209	292	205	306	191	284

The patterns in Table 3 can be more easily seen in Figures 5 and 6. Figure 5 shows the plot of vowel duration by L1. Vowel duration is greater in English speakers than in Korean speakers, and the difference appears to be greater in voiced context rather than in voiceless context. This is similar to Flege et al. (1992)'s finding mentioned in Section 1, where the difference between English speakers and Mandarin/Spanish speakers lies in vowels before voiced obstruents rather than before voiceless obstruents. Vowels preceding voiced obstruents were much longer in English speakers.

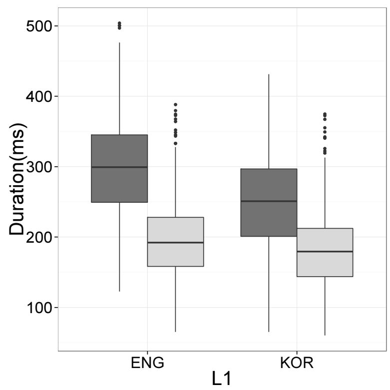
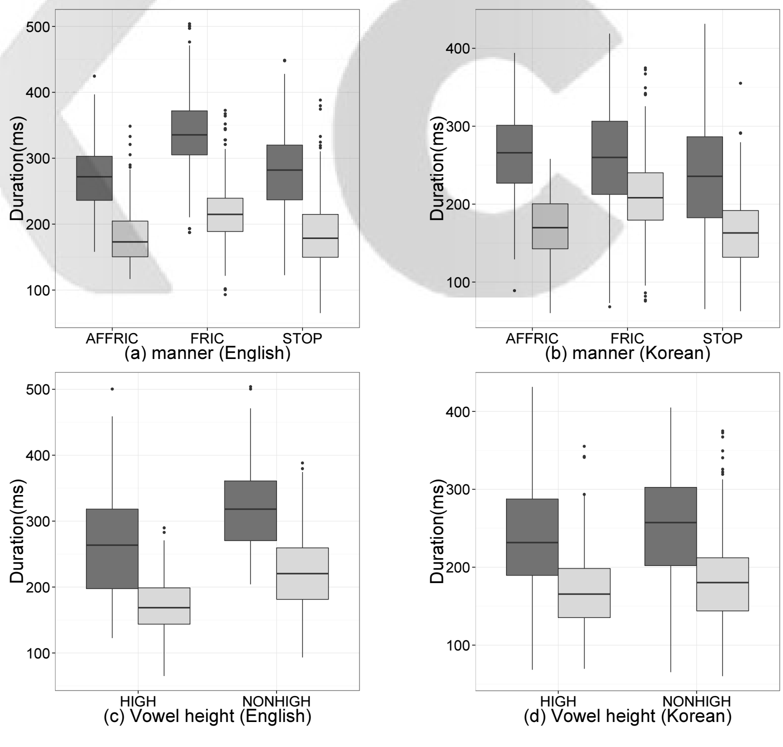


Figure 5. Overall vowel duration before voiced (dark gray) vs. voiceless (light gray) by English and Korean speakers



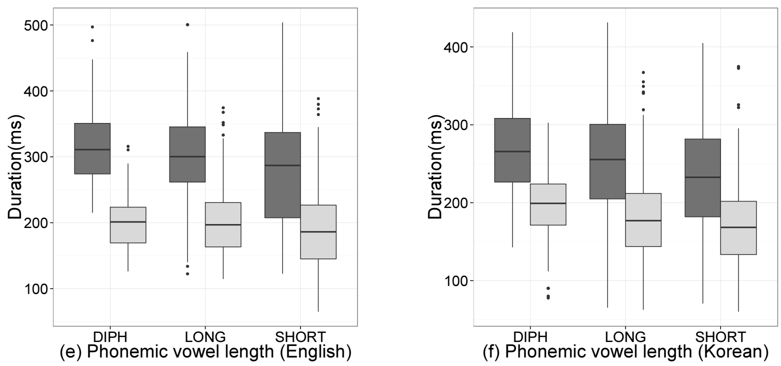


Figure 6. Duration of vowels preceding voiced (dark gray) and voiceless (light gray) consonants depending on varying segmental properties: manner (a, b), vowel height (c, d), phonemic vowel length (e, f). In each rows, English and Korean speakers data are separately presented (English: left, Korean: right).

Figure 6 shows durations of vowels before voiced and voiceless obstruents, plotted according to consonant manner (a, b), vowel height (c, d), and phonemic vowel length (e, f). To compare, English and Korean speakers are plotted separately. The following tendencies are observed in both Korean and English speakers: vowels are longer before fricatives than before affricates or stops (6(a, b)). Vowels before affricates tend to have duration between stops and fricatives (except Koreans affricates vs. fricatives in voiced context). Vowels are longer in non-high condition than high condition (6(c)). Vowels are longer in the order of diphthong>long>short vowels (6(d)), unsurprisingly. All these patterns occur along with PFC. In all varying conditions, vowels before voiced obstruents are longer than those before voiceless obstruents. This means that PFC is a robust phenomenon across various types of consonants and vowels.

In most conditions English speakers have greater differences between vowels before voiced and voiceless obstruents than Korean speakers. In most cases, the ‘boxes’ in the boxplots (showing the first quartile to the third quartile) do not overlap for vowels before voiced and voiceless obstruents in English speakers. The difference is the greatest in the case of vowels before fricatives.

2.4.2.3 Mixed effects modeling

Let us now examine whether and how PFC statistically differs in Korean vs. English speakers depending on segmental properties. To examine the effect of PFC in different L1, a mixed-effects model with the interaction terms with L1 and VOICING was fitted to the data. The model includes two-factor interaction terms (with L1) (i.e. VOICING × L1, MANNER × L1, VOWEL

HEIGHT × L1, and VOWEL LENGTH × L1) and three-factor interaction terms (with L1 and VOICING) (i.e. MANNER × L1×VOICING, VOWEL HEIGHT × L1×VOICING, and VOWEL LENGTH × L1×VOICING) in addition to single terms in the previous simple model in (3). Speakers and items were treated as random effects and the dependent variable was vowel duration, as before. The fitted model with the interaction terms was significantly better than the previous model without any interaction terms ($\chi(13)=205.77$, $p<0.0001$), so the current model describes the data more accurately. The results are shown in (4).

(4) Mixed-effects model with L1×VOICING interaction terms

	Coefficient	Std. Error	t value	
(Intercept)	259.8	25.1	10.36	(p<0.0001)***
(a) Single terms				
voicingVOICELESS	-92.6	24.0	-3.9	p<0.001 **
mannerFRIC	59.0	18.0	3.2	p<0.01 *
mannerSTOP	-2.9	17.0	-0.2	p=0.86
heightNONHIGH	54.5	12.0	4.5	p<0.0001***
lengthSHORT	-25.0	12.0	-2.1	p=0.04
L1KOREAN	-0.8	23.6	-0.0	p=0.97
(b) Interaction terms with two factors				
voicingVOICELESS:lengthSHORT	14.1	17.0	0.9	p=0.4
voicingVOICELESS:mannerFRIC	-28.4	25.5	-1.1	p=0.3
voicingVOICELESS:mannerSTOP	0.3	24.0	0.0	p=0.9
heightNONHIGH:L1KOR	-40.2	5.8	-6.9	p<0.0001 ***
heightNONHIGH:voicingVOICELESS	1.7	17.0	0.1	p=0.9
L1KOR:voicingVOICELESS	-1.2	11.6	-0.1	p=0.9
L1KOR:lengthSHORT	7.1	5.8	1.2	p=0.2
L1KOR:mannerFRIC	-63.8	8.7	-7.3	p<0.0001 ***
L1KOR:mannerSTOP	-25.1	8.2	-3.1	p<0.01 *
(c) Interaction terms with three factors				
heightNONHIGH:L1KOR:voicingVOICELESS	-1.8	8.2	-0.2	p=0.8
L1KOR:voicingVOICELESS:lengthSHORT	-7.2	8.2	-0.9	p=0.4
L1KOR:voicingVOICELESS:mannerFRIC	72.7	12.3	5.9	p<0.0001***
L1KOR:voicingVOICELESS:mannerSTOP	18.1	11.6	1.6	p=0.1

The grand mean was 259.8ms. (4a) shows the single terms. The effects (coefficient estimates) of voicing, manner (fricatives), and vowel height were significantly different from zero. Vowels are shorter before voiceless consonant (-92.6ms), longer before a fricative (59ms). Non-high vowels are longer than high vowels (54.5 ms). Among the two-factor interaction terms in (4b), three were significantly different from zero: non-high and Korean (-

40ms), Korean and fricatives (-63ms), Korean and stops (-25ms).

The three-factor interaction terms show an L1-dependent PFC effect. Only one interaction (Korean, voiceless, fricative) turns out to be significantly different from zero. That is, the vowels are longer by 72.7 ms if L1 is Korean *and* the vowel is followed by a voiceless fricative. This longer duration in the voiceless context yields a smaller difference between the vowels in different voicing condition for Korean speakers. As a result, Korean speakers have a smaller PFC effect in *fricative* environment than English speakers. This can also be seen in Figure 6(a) vs. (b).

2.4.3 The ratios of vowel duration

The previous section showed the ratio of mean duration of vowels preceding voiceless and voiced obstruents for English and Korean speakers (Table 2). Those values were computed from the mean durations for each group of speakers. In this section, the ratio of vowel duration is calculated for every minimal pair of the same repetition. As mentioned, speakers read the speech materials three times. The ratio was calculated by dividing the vowel duration preceding a voiceless consonant with the vowel duration preceding a voiced consonant. Thus for each speaker, there are 90 ratio values (=30 minimal pairs × 3 repetitions) computed from 180 words (=60 words × 3 repetitions). The total number of tokens is 1170 (90 ratio values × 13 speakers)

Figure 7 shows the ratios of vowel duration preceding voiceless and voiced consonants for each individual speaker. English speakers show a similar range of ratio values. Korean speakers show wider variation across and within speaker. K6 shows the widest variation in the ratio values. Note that the overall, absolute vowel duration (Figure 3) is not much related to the ratio of vowel durations (weak positive correlation, r=0.33). E4, who had the longest vowel duration among English speakers, has the ratio value that is similar to that of other English speakers. K6 has the shortest duration in general, but he has the greatest variation in the ratio values.

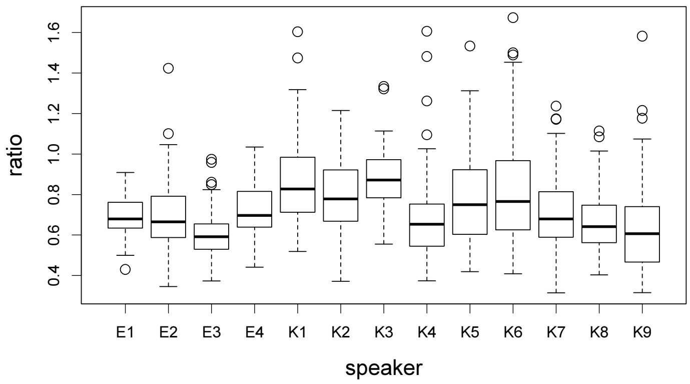


Figure 7. Ratios of vowel duration for each speaker

The mean values computed from individual ratio values are shown in Table 4. Korean speakers have a greater ratio (0.76) than English speakers (0.68). These ratio values are different from those in the previous section (Table 2) where the ratio was computed simply dividing two mean durations. The ratios came out as different when computed from each minimal pair, which appears to be more accurate (PFC is a relation within a minimal pair, e.g. *beat*-*bead*).

Table 4. The ratio of vowels (mean and standard deviation) for English and Korean speakers

	English	Korean	t-test
voiceless/voiced ratio	0.68 (0.14)	0.76 (0.22)	$t(675)=11.15$, $p<0.0001$

Table 5 shows the mean ratio for each condition, comparing English and Korean speakers. T-test values are provided, but these are only tentative, because the ratio values are from different speakers. The results in Table 5 show that in all conditions except manner 'affricate' the ratio of vowel duration was smaller in English speakers than in Koreans speakers. In the case of affricates, English speakers show a slightly higher ratio than Korean speakers, but this difference is not significant (p=0.4). Figure 8 shows the plots of ratios corresponding to the data in Table 4 and 5. Figure 8(a) shows that Korean speakers have greater ratios than English speakers. Figure 8(b) to 8(d) show the distribution of ratios depending on manner, vowel height, and vowel length, comparing English (dark gray) and Korean (light gray) speakers.

Table 5. The mean ratios of vowels for English and Korean speakers

		English speakers	Korean speakers	t-test
Manner	Stop	0.69	0.73	t(512)=-2.8, p<0.01
	Fricative	0.66	0.85	t(343)=-10.9, p<0.0001
	Affricate	0.69	0.67	t(151)=0.85, p=0.4
Vowel height	High	0.67	0.76	t(418)=-5.2, p<0.0001
	Non-high	0.71	0.76	t(423)=-3,4, p<0.001
Vowel length	Short	0.70	0.77	t(437)=-4.4, p<0.0001
	Long	0.68	0.75	t(398)=-4.3, p<0.0001
	Diphthong	0.64	0.76	t(219)=-6.5, p<0.0001

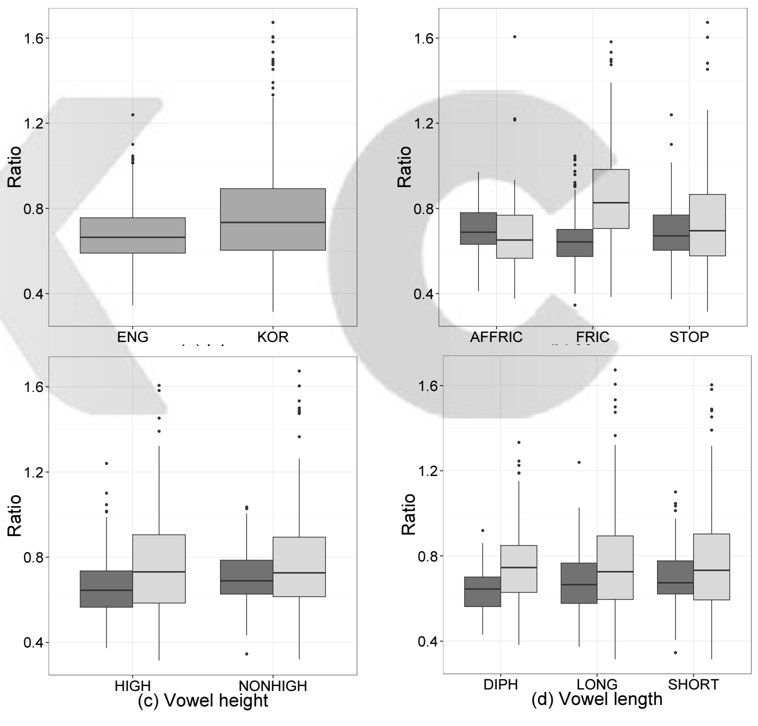


Figure 8. The ratios of vowel duration depending on (a) L1, (b) manner, (c) vowel height, (d) vowel length. In (b), (c), and (d), the dark gray boxes indicate English speakers, and the light gray boxes indicate Korean speakers.

As briefly mentioned, the t-tests presented in Table 4 and 5, however, cannot be very accurate, because the ratio values are from different speakers (in addition to the multiple comparisons problem, which could be corrected by Bonferroni correction). In order to factor out random effects by speaker, a mixed-effect model was fitted to the data with speaker as random effects.

In the mixed-effects model, the dependent variable was the ratio values. Fixed effects were L1, MANNER, VOWEL HEIGHT, VOWEL LENGTH. In addition, the interaction terms with L1 was added for all the factors (i.e. MANNER × L1, VOWEL HEIGHT × L1, VOWEL LENGTH × L1). Random effects were speakers and items. The model with the interaction terms were significantly better than the model without the interaction terms ($\chi^2(4)$= 49.9, $p<0.0001$). The model with speaker and item random effects were better than the model with only speaker random effect ($\chi^2(1)$=91.9, $p<0.0001$). The model summary in (5) shows the effect of each factor.

(5) Model summary for the ratios of vowel duration with L1 interaction terms

	Coefficient	Std.Error	t value (p value)
(Intercept)	0.67	0.07	10.0 (p<0.0001)***
L1KOR	-0.01	0.06 -	0.2 (p=0.9)
mannerFRIC	-0.03	0.06	-0.6 (p=0.6)
mannerSTOP	0.00	0.05	0.0 (p=0.9)
lengthSHORT	0.02	0.04	0.4 (p=0.7)
heightNONHIGH	0.04	0.04	1.1 (p=0.3)
L1KOR:mannerFRIC	0.22	0.04	6.0 (p<0.0001)***
L1KOR:mannerSTOP	0.06	0.03	1.8 (p=0.1)
L1KOR:lengthSHORT	-0.00	0.02	-0.0 (p=0.9)
L1KOR:heightNONHIGH	-0.04	0.02	-1.5 (p=0.1)

It can be seen that only the interaction term L1(Korean) × Manner(Fricative) had a significant effect. If the speaker is Korean and if the consonant is fricative, then the ratio significantly increases (0.85 = 0.67-0.01-0.03+0.22) (adding up all relevant terms in (5)). Other than that, the ratio is invariably 0.67 (the intercept), because none of the factors, including the single term L1, had a significant effect on the ratio of vowel duration.

The results suggest that the ratio of vowel durations preceding voiceless vs. voiced is not significantly different in English vs. Korean speakers in the current experiment. Table 6 shows the random intercepts for speakers. English speakers show less variation (intercepts ranging from -0.081 to +0.039) from the mean than Korean speakers (intercepts ranging from -0.122 to 0.114). Though some Korean speakers show wider variations from the mean (K1, K3, K8, K9, in both plus and minus directions), more Korean speakers stay close to the grand mean, in the range of native speakers of English (e.g. K2, K5, K7). Figure 9 is a quantile-quantile (q-q) plot (Johnson 2008: 19-23) for the random intercepts of the speakers. This reveals why there is statistically no significant difference between English and Korean speakers. A q-q plot compares given data with theoretical quantiles and tests whether the given data are from the same group with a normal distribution. English speakers are relatively close to mean, but Korean speakers show wider variations. Koreans speakers, despite wide variations among subjects, cluster around the mean value of the two groups.

Table 6. Random intercepts for individual speakers

English speakers		Korean (female)		Korean (male)	
E1	0.005	K1	0.089	K5	0.018
E2	0.036	K2	0.044	K6	0.064
E3	-0.081	K3	0.114	K7	-0.042
E4	0.039	K4	-0.063	K8	-0.101
				K9	-0.122

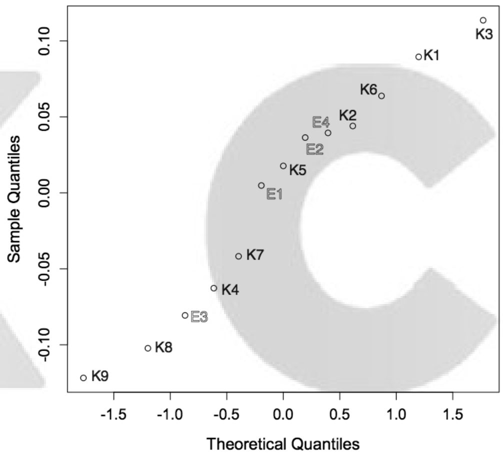


Figure 9. A quantile-quantile (q-q) plot for random intercepts of speakers

Although the results so far indicate that there is no statistically significant effect by the factor L1 alone, we can still find some evidence pointing to the differences between English and Korean speakers. Returning to Figure 7, we can see that the ratio values are below 1 for almost all instances of English speakers (except very few outliers), whereas there are substantial instances of ratio values which are above 1 for almost all Korean speakers. This is not an ignorable difference. The ratio above 1 means that a vowel is longer before *voiceless* than voiced obstruents, the reverse of PFC[4]. To analyze this pattern quantitatively, a logistic regression analysis was carried out. The dependent variable was BELOW for ratios below 1, ABOVE for ratios above 1. Fixed

[4] I thank the anonymous reviewer who pointed this out.

effects were L1, consonant manner, vowel height and length. The model without the interaction terms was better (AIC=601) than the one with the interaction terms (AIC=608) (the lower the AIC, the better the model). The results are shown in (6).

(6) Logistic regression analysis for the ratio values below vs. above 1

	Coefficient	Std.Error	t value (p value)	
(Intercept)	5.4	0.7	7.8 (p<0.0001)	***
L1KOREAN	-1.9	0.4	-5.1 (p<0.0001)	***
mannerFRIC	-2.6	0.6	-4.3 (p<0.0001)	***
mannerSTOP	-1.7	0.6	-2.9 (p<0.01)	*
lengthSHORT	-0.2	0.2	-1.0 (p=0.3)	
heightNONHIGH	0.5	0.2	2.2 (p<0.05)	.

All factors except phonemic vowel length were significant. We can see that the probability of the ratio below 1 decreases when L1 is Korean (indicated by negative values of coefficients), manner is fricative or stop, with fricatives stronger (-2.6) than stops (-1.7). This means that PFC is less accurately produced by Korean speakers and before fricatives and stops. The probability of the ratio below 1 increases for non-high vowels. This means that PFC is more accurately realized for non-high vowels. To summarize, we can see that though Korean speakers reach the mean ratio values of English speakers, there are wide variations, and the ratio values above 1 was significantly much more in Korean speakers than in English speakers.

The results in (6) are in line with the results so far, in that the reverse of PFC is most likely in the fricative environment for Korean speakers. In fact, this is the only condition that shows a significant difference in vowel ratios between Korean and English speakers, according to the model summary in (5). A further discussion on this follows in the next section.

3. Discussion

3.1 Discussion of the results

The present study aimed at investigating whether a sub-phonemic difference like contextual vowel duration is manifested in non-native speakers (Korean). The results show that PFC is not significantly affected by L1, i.e. neither vowel duration nor vowel ratio was not significantly different between Korean and English speakers. The only context where PFC turns out to be significantly different between two groups was fricatives: the duration ratio was greater in Korean speakers than in English speakers.

This is primarily because the vowel before a voiced fricative is shorter in Korean speakers than in English speakers (compare Figure 6(a) and 6(b)). English speakers produce more distinct vowel duration differences in this context than Korean speakers. As mentioned in Section 1, in English, vowel duration is longer before fricatives than before stops. This effect of consonant manner is apparently smaller in Korean speakers, i.e. Korean speakers do not produce the vowel duration long enough in the fricative context as English speakers do.

Stops require time for a complete closure before release, whereas fricatives do not require such a silent interval. Vowel duration changes by the timing of the initiation of the onset of the closing gesture of a coda consonant (de Jong 1991). For stops the closing gesture comes early. On the other hand, there is no complete closure interval for fricatives, so the vowels before fricatives can lengthen more compared with those before stops in the case of English.

Whereas in English the constriction for word-final obstruents can be released, in Korean no obstruents can be released in coda position. Fricatives are neutralized to an unreleased stop (e.g. /s/→[t˺]), so Korean speakers are not familiar with released fricatives in coda position in their L1. It can be suggested, therefore, that due to this lack of experience with word-final fricatives in L1, Korean speakers initiate the consonant closure gesture without differentiating stops and fricatives when they speak English, which yields less distinct vowel duration differences before stops and before fricatives.

Except in the fricative environment, the PFC ratio is not significantly affected by speakers' L1. This does not suggest that the Korean speakers have mastered PFC like English speakers, but merely suggests that the Korean mean values zero in on the native speakers' mean. Korean speakers show greater variations in the duration ratios than English speakers, quite a few cases showing the ratio over 1. Thus we can say that PFC is less stable in Korean speakers than in English speakers, especially when the coda is fricative.

It should also be noted that we controlled for the proficiency level of Koreans speakers (TOEIC score of above 700). Varying the proficiency levels could yield greater differences between Korean and English speakers (cf. Flege et al. 1992).

3.2 Learnability of phonetic details

One might ask whether phonetic details like PFC ratios can be mastered by L2 speakers. PFC is not always taught in school, and even when it is taught, the exact ratio of vowel duration is not explicitly taught, nor are students trained at such a level of elaboration. For this reason, the presence or absence of explicit teaching does not seem directly related to the mastery of PFC. Many of the speakers had not learned PFC in school, but produced distinctive vowel duration. Speaker K5, whose ratio was the closest to the group mean among Korean speakers (Figure 9), said that he had not learned PFC in school but was aware of it, when asked after the experiment. Speaker K4 gave the same answer. Speaker K2 had learned PFC in school, but her ratio value was somewhat farther from the mean than that of K5. Speaker K8 said he was not aware of PFC, but he produced the vowel duration quite distinctively depending on the voicing, even more so than K2 (Figure 4). For those Koreans whose ratio values are close to the mean, it can be suggested that they naturally picked up the relative vowel duration quite accurately just by listening.

Alternatively, it could mean that PFC is universal, so learners of English would automatically apply PFC without any explicit training or sufficient input. In early works of generative phonology (Chomsky and Halle 1968), it was considered that phonetic details are supplied by universal phonetic rules. However, although there is a preferred direction of tendency, languages do show variations in the fine-grained phonetic properties (Chen 1970). Keating (1985) argues that language-specific rules are needed to account for phonetic details such as intrinsic vowel duration, extrinsic vowel duration (PFC), and voicing timing (VOT).

Languages have a different ratio of vowel duration in different voicing contexts. The ratio of voicing-dependent vowel durations appears to be a parameter across languages. As mentioned in Section 1, French speakers have a greater ratio of vowel duration than English speakers (Mack 1982), and French monolinguals and bilinguals show a longer ratio of vowels than English speakers, as an influence of L1. This shows that there is a language-specific 'ratio'. Furthermore, in Arabic (Ammani-Jordanian), voicing effects are inconsistent (de Jong and Zawaydeh 2002), and in Saudi Arabic vowel duration was not significantly different before voiced and voiceless stops (Flege 1979).

Japanese L1 speakers show a greater ratio of vowels than English speakers, but closer to the English ratio than Mandarin speakers (Crowther and Mann 1992). Crowther and Mann suggested that this is because Japanese has a long and short vowel contrast in their phonemic inventory, so they are more experienced with durational property of vowels (Unlike French, Japanese does not allow word-final obstruents, so Japanese cannot have an L1-specific ratio). Unlike Japanese or French, there is no voicing or durational contrast in Korean[5] – thus there could not be any L1 grammar or parameter for the voicing-dependent vowel duration. In other words Korean speakers do not have their own 'ratio'. It is plausible that since such a parameter is left blank in L1 grammar, the ratio in English is relatively easier for Koreans speakers to acquire.

4. Conclusion

In this paper, two research questions were investigated: (i) whether and how Korean speakers differ from English in the production of vowel duration depending on the voicing of the following obstruents, and (ii) whether and

[5] Vowel duration contrast exists only in the prescriptive grammar.

how PFC is affected by segmental factors (consonant manner, vowel height, phonemic vowel length). In general Korean speakers exhibit a smaller vowel duration contrast than English speakers, but the effect of L1 turns out not to be significant. Nevertheless, all Korean speakers showed quite a few ratio values greater than 1, i.e. vowel duration is even longer in voiceless environment than in voiced environment. One significant difference between Korean and English speakers is found in the fricative environment, where Korean speakers lack experience in their L1.

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