Articulatory and Acoustic Correlates of Korean /l/

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<Contents>

<Abstract>

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This study investigated the articulatory and acoustic correlates of Korean /l/. In particular, direct comparison between Korean /l/ and English /l/ was made to evaluate the current assumption about Korean /l/ such that Korean /l/ is phonetically similar to English clear /l/. The present study revealed that Korea /l/ is different from English /l/ in several properties. First, F2 for Korean /l/ is around 600-700 Hz higher than F2 for English /l/. The overall higher F2 for Korean /l/ is attributed to the fact that Korean /l/ involves tongue body raising while it lacks a dorsal gesture. Second, F3 value for Korean /l/ becomes significantly lower when the preceeding vowel is a back vowel. This kind of variable F3 pattern was not observed in English /l/. The current study relates the F3 lowering to the retroflexion of Korean /l/ in the back vowel context.

* Keywords: Korean lateral, Acoustic analysis, Articulatory and acoustic correlates, Retroflexion.

1. Introduction

It has been generally assumed that Korean /l/[1)] is an alveolar lateral, which is analogous to English clear /l/. For instance, Park[16] states that Korean /l/, which occurs in syllable-final and intervocalic position, is invariably realized as a clear alveolar lateral. Sung[24] makes a similar statement: "The lateral [l] is always 'light' (the tongue tip touching the alveo-dental area) in Korean" (p.14).[2)]

In contrast to the description of Korean /l/ in these previous studies, phonetic experimental literature on Korean /l/[10][25][26] indicates that articulatory and acoustic characteristics of the Korean lateral are more complicated than warrant the simple labeling of it as an alveolar lateral or a clear lateral.

In terms of articulation, the findings of Lee[10], Tsuzuki[25], and Umeda[26] all demonstrate that the articulatory point or articulatory manner of the Korean lateral varies a great deal depending on the quality of the preceding vowels. For instance, Umeda[26] observed that articulatory point of syllable-final /l/ in Korean changes according to the preceding vowels. That is, the articulatory point of /l/ occurs at or before alveolar when the preceding vowel is a front vowel, while it occurs after alveolar when the preceding vowel is a back vowel. Based on these results, Umeda[26] concluded that syllable-final /l/ in the back vowel context is retroflexed. In a similar vein, Lee[10] found that /l/ in syllable-final position is realized as a retroflex lateral when the preceding vowel is /a/.

Tsuzuki[25], in his dissertation, investigated the articulatory configuration of Korean /l/ in more detail. He found that Korean /l/ is realized as an alveolar lateral when the preceding vowel is /i/ or /e/, whereas it is realized as a retroflex lateral when the preceding vowel is /o/, /a/, or /u/. Note that Lee[10], Tsuzuki[25], and Umeda[26] all employed an eletro-palatographic analysis which shows the tongue-palate contact of sound in production.

Recently, Gick, Campbell and Oh[3] (cited in [14]) found that Korean /l/ involves two gestures, tongue tip raising and tongue body raising, while in English /l/, tongue tip raising pairs with tongue dorsal gesture. In terms of timing relation, the Korean

1) Throughout the paper, a phonemic notation for Korean /l/ was used to emphasize the fact that the Korean lateral is realized either as an alveolar lateral or as a retroflex lateral depending on the vowel context (phonetic notation [l] cannot capture this distinction). However, when it comes to the citation from other studies, the notation from the original study was used. In addition, Korean /l/ in intervocalic position indicates a geminate /ll/.

2) In loanword phonology literature, the Korean lateral is also termed as "alveolar lateral", "dental lateral"[9] or "bright (or clear) lateral"[6].

lateral is not distinguished by a timing lag between tongue tip and tongue body gesture, while English /l/ has a considerable timing lag between tongue tip and tongue dorsal gesture in a syllable-final position.3)

In terms of acoustics, there also exist differences in Korean /l/ and English /l/. Previous studies on the acoustics of Korean /l/ showed that the formant frequencies (especially F2) are quite different from those of English /l/. <Table 1> demonstrates the formant frequencies of English /l/ from Lehiste[11] and Stevens[18], and <Table 2> is the formant frequencies of Korean /l/ from Tsuzuki[25].4)

<Table 1> Mean formant frequencies of English /l/ in previous studies

Source	Gender	F1	F2	F3	F2-F3
Lehiste[11] (American English)	Male	295	980	2600	1620
Stevens[18] (American English)	Male Female	360 350	900 1180		

<Table 2> Formant frequencies of Korean /l/ by a male Korean speaker (Tsuzuki[25])

Stimuli	F1	F2	F3	F2-F3
/il/	347	1916	2670	754
/el/	642	1590	2395	805
/al/	642	1468	2589	1121
/ol/	306	1233	1682	449
/ul/	306	1458	2028	570
Average	448	1535	2272	737
Stimuli	F1	F2	F3	F2-F3
/illi/	347	1896	2742	846
/elle/	561	1692	2823	1131
/alla/	561	1335	2691	1356
/ollo/	387	1172	2691	1519
/ullu/	387	1376	1753	377
Average	449	1494	2540	1046

Note that F2 for Korean /l/ is around 400-500 Hz higher than F2 for English /l/. It is also noticeable that F3 value for /ol/ and /ul/ is much lower than F3 in other contexts.

To summarize, we have seen that phonetic characteristics of Korean /l/ are different from English /l/ in a very interesting way, contrary to the description in many other previous studies. The research questions in this study were motivated by these phonetic differences between Korean /l/ and English /l/. Why is F2 for Korean /l/ much higher

3) Gick, Campbell and Oh[3] adopted ultrasound to observe tongue movement.

4) Note that Tsuzuki[25] only provided formant values for one time occurrence of each token, not an averaged formant value of each token.

than F2 for English /l/? Why does F3 for Korean /l/ become much lowered when the preceding vowel is a back vowel? Will the same pattern be observed in English /l/?

However, it is true that there exist certain limitations in comparing phonetic characteristics of Korean /l/ and English /l/ solely based on the experimental results from the previous studies, since these studies did not aim to compare /l/ in Korean and in English. For instance, it is difficult to directly compare formant frequencies of a lateral in the two languages without controlling the physical conditions of the participants and the environment where a lateral occurs in a word.

Thus, to provide more objective and comparable evidence for the acoustic characteristics of a lateral in the two languages, this study provides two experiments in which possible variables affecting acoustic characteristics of the laterals were carefully controlled. In Experiment 1, formant frequencies and formant structures of a lateral in English and Korean were measured and compared. Experiment 2 was designed to examine the influences of adjacent vowels on the production of Korean /l/. Based on the results from Experiment 1 and Experiment 2, this study discusses the articulatory and acoustic correlates of /l/ in Korean and English.

This paper is organized as follows. Section 2 presents an experimental design for the current study. Section 3 presents results from the two experiments. Section 4 discusses formant frequencies and formant structures of Korean /l/ and English /l/ in connection with articulatory configuration of /l/ in the two languages. In particular, Section 4.1 and 4.2 discuss articulatory and acoustic characteristics of English /l/ based on the published data on the phonetics of English /l/. Section 4.3 discusses how the acoustic findings of this study can be interpreted in connection with the articulatory characteristics of Korean /l/.

2. Method

2.1. Participants

Four native speakers of Korean (2 males and 2 females) and four native speakers of American English (2 males and 2 females) participated in the study. The four native speakers of English were students (three undergraduates and one graduate) at Michigan State University at the time of the study. The native speakers of Korean were undergraduates in a university in Korea except one female participant, who was a spouse of a visiting scholar at Michigan State University. In particular, the native speakers of Korean were chosen in a way that the participants' age, weight, and height are similar to the native English speakers in the study in order to control for any physical conditions affecting the acoustics. Detailed descriptions of the participants are provided in <Table 3>.

<Table 3> Participant profile

Measures: Height (ft), Weight (lb)

	Korean	Age	Height	Weight	English	Age	Height	Weight
Male	K1	24	5.90	198	E1	23	5.90	198
	K2	25	5.64	132	E2	20	5.80	127
Female	K1	21	5.18	117	E1	20	5.18	119
	K2	30	5.34	143	E2	27	5.38	149

2.2. Stimuli

Eighteen target items containing /l/ in intervocalic position were used as stimuli. Intervocalic position was chosen, since this is one of the positions where /l/ occurs in both of the languages. A lateral also occurs in syllable-final position both in English and Korean, but /l/ in this position is only included as a filler in the study due to the velarization of /l/ in syllable-final position in English.

Phonetic environments where /l/ occurs in English and in Korean were carefully controlled. That is, stimuli in each language were chosen based on the phonetic similarity between English and Korean. For instance, native speakers of English produced 'Billy' /bili/, while native speakers of Korean produced /pilli/ so that English and Korean stimuli match well in terms of the phonetic environment where /l/ occurs. In addition, since the Korean intervocalic lateral is always represented as two Ls in spelling, English words with two Ls were chosen as stimuli to keep consistency in terms of the spellings of the stimuli. When it comes to the stress pattern, the stress pattern in English words only was kept consistent due to the fact that Korean does not contrast lexical stress. In the English items, the preceding vowel (V1) is stressed and the following vowel (V2) is unstressed. A filler, which contains a syllable-final /l/, was inserted after every two words. <Table 4> presents the target stimuli in Experiment 1.[5]

5) All English stimuli were real words, but not all corresponding Korean words were real words. In addition, some of the Korean stimuli do not exactly match with the corresponding English stimuli (i.e., "pulley" vs. "굴리", "Nellie" vs. "넬름"). This is one of the limitations

<Table 4> Target words[6]

Vowel[7]	English		Korean	
/i/	Billy	/bɪli/	/billi/	빌리
	silly	/sɪli/	/silli/	실리
	killer	/kɪlər/	/killə/	길러
	miller	/mɪlər/	/millə/	밀러
/ɛ/	Nellie	/neli/	/nɛllɨm/	넬름
	pallet	/pælət/	/pɛlli/	벨리
	seller	/selər/	/sɛlli/	셀리
	tally	/tæli/	/tɛlli/	델리
/a/	dolly	/dɑli/	/talli/	달리
	hollow	/hɑlou/	/allo/	알로
	Molly	/mɑli/	/malli/	말리
/u/	bully	/bʊli/	/pulli/	불리
	pulley	/pʊli/	/gulli/	굴리
	puller	/pʊlər/	/pullə/	불러

2.3. Procedure

In the practice session, participants were given a chance to read over the wordlists before being recorded. Each word was presented to the participants on 4x6 index cards one at a time, and pseudo-randomized order was kept to make sure there is no order effect.

The participants first stated the carrier phrase and then read each word aloud for the recording. Each token was read one time. The carrier phrase was used to provide consistent phonological environment before each target word: a) English carrier phrase: "Please say _____ several times", b) Korean carrier phrase: "Naege _____ sebeon malhaseyo ("please say _____ three times to me"). The experiment was recorded on a Marantz PMD 201 cassette recorder, and the recorded sounds were digitized through a USBPre at the Linguistics Lab at Michigan State University.

The recordings were digitized at a sampling rate of 22050 Hz and analyzed using Praat (version 4.3.18). Formant values at /l/ midpoint were examined for data coding. The justification for measuring formant values at /l/ midpoint is found in Huffman[5], where she states that "Examination of spectrograms and LPC formant analysis

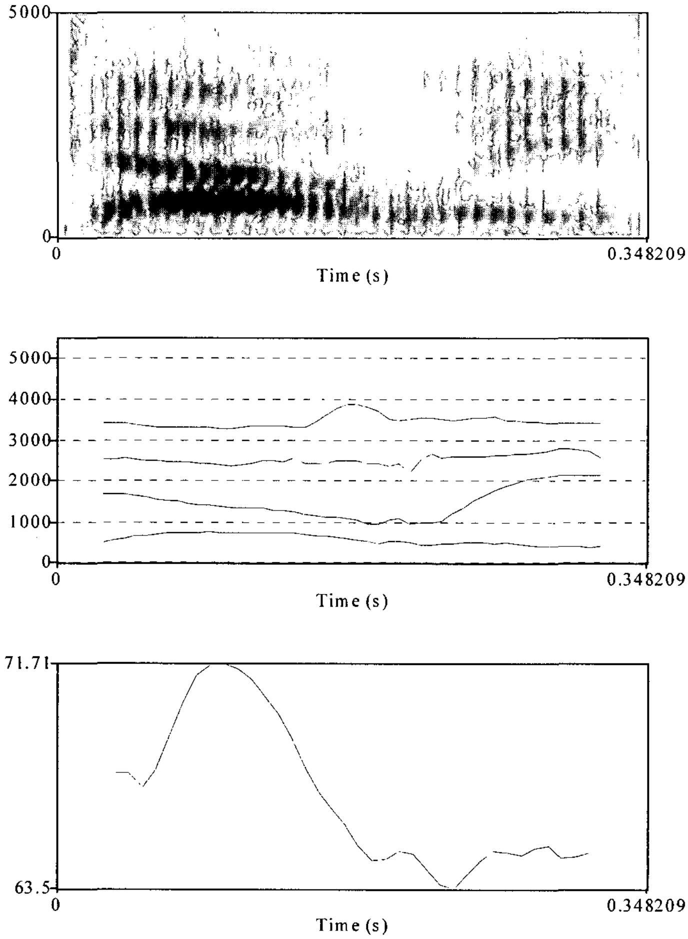
of this study, and future research will be needed to improve upon this limitation.

6) Stimuli with the preceding vowel /o/ were not analyzed for the current study because some problems with stimuli were found after the experiment. However, the exclusion of stimuli with vowel /o/ from the analysis does not affect general patterns found in the study.

7) Korean /i/, /ɛ/, /a/, and /u/ correspond to English /ɪ/, /æ/, /ɑ/, and /ʊ/ respectively.

indicated that most /l/'s had an identifiable steady state portion, so the midpoint values were representative of the formant extrema." (fn 6.)

<Figure 1> presents how /l/ midpoint value was determined in this study. The figure at the top shows the spectrogram for /dɑli/ by an English male speaker, the figure in the middle shows the formant track for the same token, and the figure at the bottom shows the intensity contour of the same token. First of all, onset and offset of /l/ were identified from wideband spectrograms in conjunction with waveform displays. In most cases, the onset and offset of English /l/ and Korean /l/ were relatively easily determined, showing a fairly rapid shift in formant structure.



<Figure 1> /dɑli/ by an English male speaker: Spectrogram, formant track, and intensity contour

After identifying the onset and offset of /l/, the formant list from the onset and offset was generated. This formant list was carefully inspected to see whether F2 and F3 value are stable across the duration of /l/. Bandwidths for each formant value were also checked to minimize a possible analysis error. Then F1-F3 formant values for /l/ midpoint were taken out from the formant list and saved in the Excel file. In some of the tokens, F3 value for /l/ was unstable. In these cases, rather than guessing the formant value from the spectrogram, the F3 values of these tokens were not coded for analysis.

2.4. Statistical analysis

A one-way between groups analysis of variance (one-way ANOVA) was conducted to evaluate the mean difference of formant values of /l/ among groups. ANOVA was designed to test variation among the means of the several groups, and the null hypothesis in ANOVA is that the several groups being compared have the same mean.

Two types of independent variables were set for data analysis: a) native language and b) vowel context. Native language of the participants was divided into two groups: American English and Korean. Vowel context was divided into five groups: /i/, /ɛ/, /o/, /a/, /u/. Statistical difference at $p < .05$ level was measured. If a significant mean difference among groups was found, post-hoc comparison (Tukey HSD) was further conducted to isolate exactly where the significant differences occurred among groups.

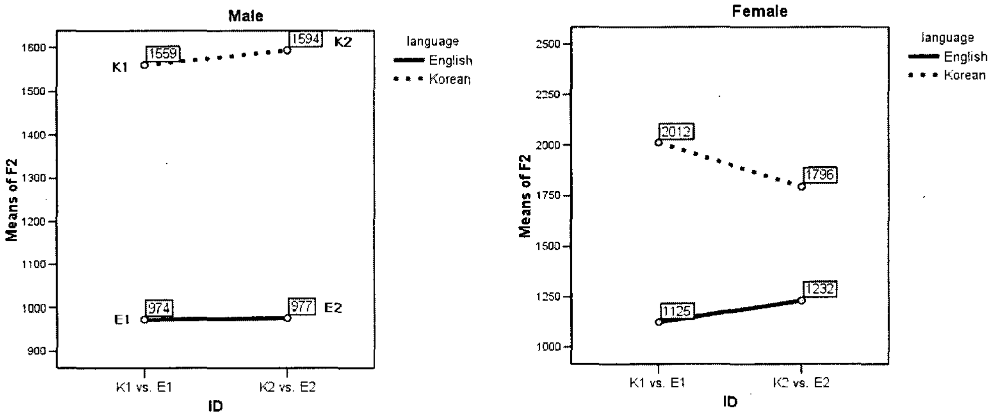
3. Results

3.1 Experiment 1

3.1.1 Means of F2

<Figure 2> presents F2 mean value by each male and female participant. An average F2 value by each participant is given in the box. Recall that the participants' age, weight, and height were approximately matched in order to control for physical conditions affecting the formant frequencies. Thus, the results from the Korean male speaker, K1 (K = Korean speaker) are compared with the results from E1 (E =

English speaker). In the same way, results from K2 are compared with E2.



<Figure 2> F2 means by individual

<Figure 2> basically shows that F2 value for Korean /l/ is much higher than F2 for English /l/ regardless of the physical conditions of the participants.

To examine whether the F2 mean values for Korean /l/ and English /l/ are statistically significant, individual results were pooled together by gender and one-way ANOVA was implemented. <Table 5> provides the descriptive statistics for F2 value by native language, and <Table 6> provides results from one-way ANOVA test. Descriptive statistics for F1-F3 values are provided in Appendix A.

<Table 5> Means of F2 by native language group

Gender	Language		Mean	Std. Deviation	N
Male	English	F2	975.6282	111.71746	28
	Korean	F2	1576.3677	121.11379	28
Female	English	F2	1178.5702	138.01688	26
	Korean	F2	1903.7756	189.98485	28

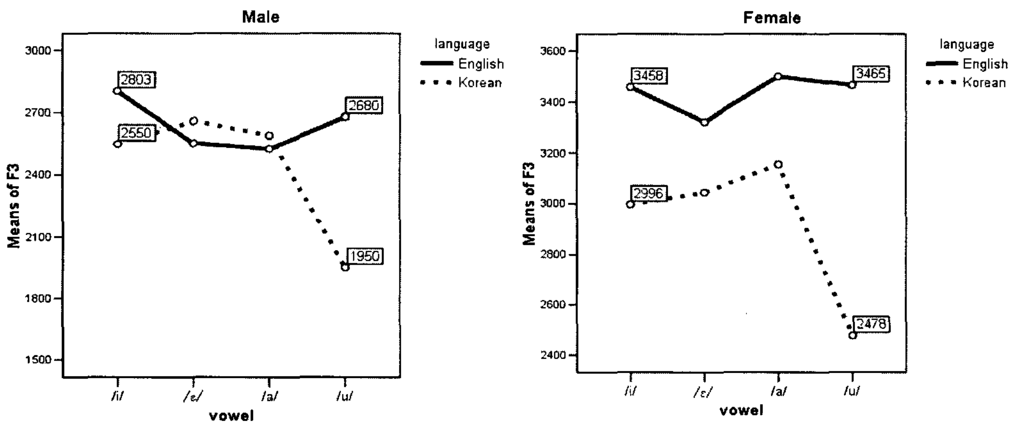
<Table 6> ANOVA: F2 by native language group

Gender			Sum of Squares	df	Mean Square	F	Sig.
Male	F2	Between Groups	5052430.849	1	5052430.849	372.195	.000
		Within Groups	733032.225	54	13574.671		
		Total	5785463.075	55			
Female	F2	Between Groups	7090219.408	1	7090219.408	254.137	.000
		Within Groups	1450761.062	52	27899.251		
		Total	8540980.470	53			

<Table 6> demonstrates that F2 mean difference between English /l/ and Korean /l/ is significant: male $F(1, 54) = 372.195$, $p < .05$, female $F(1, 52) = 254.137$, $p < .05$. In sum, F2 mean values by individual and by native language group demonstrate that F2 value for Korean /l/ is significantly different from F2 for English /l/.

3.1.2. Means of F3

One interesting pattern was observed in F3 for Korean /l/: F3 value for Korean /l/ is influenced by a preceding vowel. <Figure 3> presents F3 mean value by vowel for each language group. F3 mean values for /l/ when the preceding vowel is /i/ and /u/ are indicated in the box.



<Figure 3> F3 means by vowel

The solid line in the figure indicates F3 mean value for English /l/ by vowel, while the dotted line indicates F3 mean value for Korean /l/ (refer to Appendix B for the descriptive statistics). <Figure 3> shows that when it comes to English /l/, F3 mean does not show much variation depending on the preceding vowel. In contrast, F3 mean for Korean /l/ demonstrates very abrupt lowering when the preceding vowel is /u/. The variable F3 value for Korean /l/ depending on the preceding vowel is actually consistent with the formant value for Korean /l/ provided in Tsuzuki[25].

The remaining question is whether the F3 mean difference for Korean /l/ by vowel is statistically significant. This question could not be answered with the data at hand because the number of tokens for Korean /l/ by vowel is too small to implement ANOVA test.

To improve upon this limitation, Experiment 2 was set up. Experiment 2 incorporated both intervocalic and syllable-final /l/ (Experiment 1 only tested intervocalic /l/) and /l/ in five vowel contexts (/i/, /ɛ/, /o/, /a/, /u/). In addition, all the words are real words in Korean. <Table 7> presents stimuli in Experiment 2.

<Table 7> Stimuli

vowel	word	meaning	word	meaning	word	meaning
/i/, /ɨ/	/pillida/	'borrow'	/tɨllɨda/	'stop by'	/killɨda/	'grow'
/ɛ/	/pɛllyəko/	'to cut'	/tɛllyəko/	'to provide'	/kɛllyəko/	'to fold'
/o/	/pollok/	'swollen'	/tollida/	'rotate'	/kollida/	'tease'
/a/	/pallaneda/	'hull'	/tallida/	'run'	/kallaneda/	'sort out'
/u/	/pullida/	'make it swollen'	/tullida/	'surrounded'	/kullida/	'roll over'
/i/, /ɨ/	/pil/	'a roll of cloth'	/tɨl/	'field'	/kil/	'road'
/ɛ/	/pɛlsuit'a/	'can cut'	/tɛlsuit'a/	'provide'	/kɛlsuit'a/	'fold'
/o/	/pol/	'cheek'	/tol/	'stone'	/kol/	'brain'
/a/	/pal/	'foot'	/tal/	'moon'	/kal/	'a study of'
/u/	/pul/	'fire'	/tul/	'two'	/kul/	'tunnel'

Twelve Korean speakers (6 males and 6 females) participated in the study. At the time of the study, eleven participants were students (graduate students, exchange students) at Michigan State University, and one participant was a spouse of a graduate student. The participant read each word aloud two times, and the second run was analyzed for data coding. The experiment was recorded on a Marantz PMD 201 cassette recorder, and the recorded sounds were digitized through an Mbox at the Linguistics Lab at Michigan State University. The following section discusses results from Experiment 2.

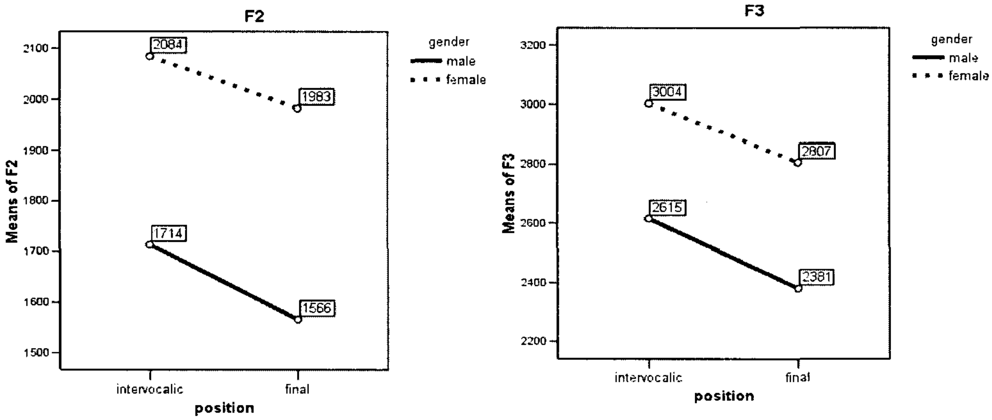
3.2. Experiment 2

3.2.1. F2 and F3 pattern

One reviewer of this paper pointed out that F2 value for Korean /l/ in Experiment 1 may have been influenced by the palatalization of Korean /l/ which has been assumed to occur when the following vowel is /i/ or /j/ (e.g., /bulli/). That is, the results from Experiment 1, which contains many stimuli where the following vowel is /i/, should be taken cautiously since it may be possible that F2 for Korean /l/ is relatively high compared to English /l/ simply due to the influence of the palatalized /l/ (palatalization of /l/ raises F2 value for /l/)[2].

To deal with this issue, F2 and F3 values for Korean /l/ in Experiment 2 are divided into two groups according to the position where /l/ occurs (intervocalic and syllable-final). In this way, we can see whether the higher F2 value for Korean /l/ is simply because of the palatalization of Korean /l/ when the following vowel is /i/ or /j/ or a general pattern for Korean /l/. Stated another way, if a relatively higher F2 value for Korean /l/ is general acoustic characteristics of Korean /l/, then the higher F2 pattern should be observed in syllable-final /l/ as well as in intervocalic /l/.

<Figure 4> presents F2 and F3 mean values for Korean /l/ in Experiment 2. The solid line indicates F2 and F3 values by male speakers and the dotted line indicates F2 and F3 values by female speakers. Descriptive statistics are provided in Appendix C.



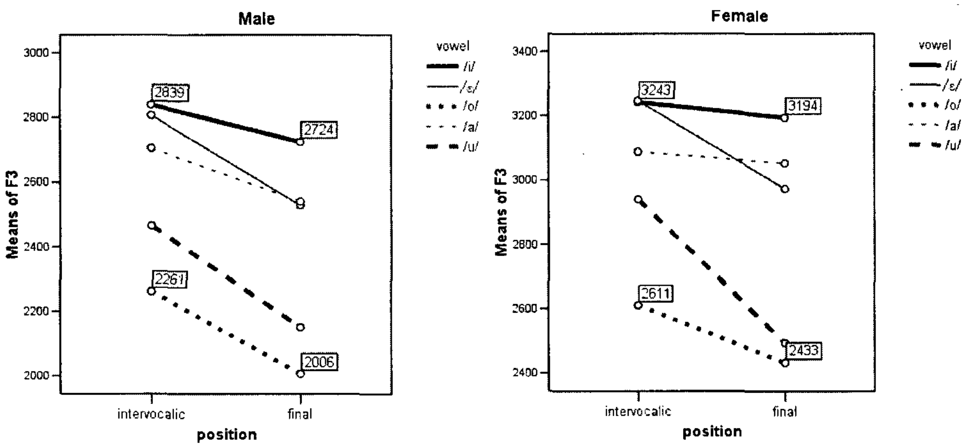
<Figure 4> Means of F2 and F3

<Figure 4> shows that both F2 and F3 for Korean /l/ are higher in intervocalic position than F2 and F3 in syllable-final position. When it comes to F2 mean value, the relatively higher F2 for intervocalic /l/ may result from the influence of the following vowel /i/ as was pointed out by one reviewer of this paper. However, it should be also noted that F2 value for syllable-final /l/ is still higher than F2 for English /l/ (1566 Hz for Korean male speakers and 1983 Hz for Korean female speakers). Given that F2 for English /l/ is around 900-1000 Hz for male speakers and 1100-1200 Hz for female speakers, we can safely say that F2 value for Korean /l/ is higher than F2 value for English /l/ regardless of the position where it occurs.

3.2.2. F3 pattern by vowel

This section discusses how the preceding vowel affects F3 value for Korean /l/. We have seen in Section 3.1.2 that F3 for Korean /l/ becomes lower when the preceding vowel is a back vowel. However, statistical significance of F3 mean difference by vowel could not be examined due to the small number of tokens tested in Experiment 1. In addition, tokens with preceding vowel /o/ could not be analyzed in Experiment 1. Experiment 2 improved upon these limitations by incorporating tokens with vowel /o/ and more tokens in each vowel context.

<Figure 5> presents F3 for Korean /l/ depending on vowel context. F3 values for /l/ when the preceding vowel is /i/ and /u/ are presented in the box. Refer to Appendix C for the descriptive statistics.



<Figure 5> Means of F3 by vowel

One clear pattern is attested in <Figure 5>: F3 becomes much lower when the preceding vowel is a back vowel (/o, u/) than when the preceding vowel is a front vowel (/i, ɛ/). To examine whether the F3 mean difference by vowel is statistically significant, one-way ANOVA test was implemented. <Table 8> demonstrates that F3 mean difference depending on the vowel is significant in both males and females.

<Table 8> ANOVA: F3 by vowel

Gender			Sum of Squares	df	Mean Square	F	Sig.
Male	F3	Between Groups	9565501.972	4	2391375.493	19.112	.000
		Within Groups	20395178.712	163	125123.796		
		Total	29960680.685	167			
Female	F3	Between Groups	10741520.158	4	2685380.040	22.704	.000
		Within Groups	18096545.445	153	118278.075		
		Total	28838065.603	157			

In addition, post-hoc test (Tukey HSD) was conducted to determine exactly which means are significantly different from which other ones in the five vowel contexts. Post-hoc test results in <Table 9-1> and <Table 9-2> demonstrate that F3 in a front vowel context is always significantly different from F3 in a back vowel context.

What follows is the summary of the experimental results in this study. First of all, Experiment 1 showed that F2 value for Korean /l/ is significantly different from F2 for English /l/. The F2 mean difference between Korean /l/ and English /l/ was around 600-700 Hz. In particular, the results from Experiment 1 merit attention in that acoustic characteristics of Korean /l/ and English /l/ were directly compared by controlling possible factors which may affect acoustics of /l/ in the two languages.

Experiment 2 was set up to improve upon the limitations of the Experiment 1. The results from Experiment 2 showed that F2 value for Korean /l/ is higher than F2 for English /l/ regardless of the position that it occurs (intervocalic and syllable-final). In addition, F3 for Korean /l/ is significantly lower when the preceding vowel is a back vowel than when the preceding vowel is a front vowel. This kind of vowel-context dependent F3 value (front vowel vs. back vowel) was not observed in English /l/.

<Table 9-1> Multiple Comparisons: F3 by vowel (male speakers)

Dependent Variable	(I) vowel	(J) vowel	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
F3	/i/	/ε/	114.34635	93.21562	.736	-142.7939	371.4866
		/o/	647.91109(*)	93.21562	.000	390.7708	905.0514
		/a/	159.22619	93.21562	.432	-97.9141	416.3665
		/u/	474.31436(*)	93.21562	.000	217.1741	731.4546
	/ε/	/i/	-114.34635	93.21562	.736	-371.4866	142.7939
		/o/	533.56475(*)	83.37459	.000	303.5715	763.5580
		/a/	44.87984	83.37459	.983	-185.1134	274.8731
		/u/	359.96802(*)	83.37459	.000	129.9748	589.9613
	/o/	/i/	-647.91109(*)	93.21562	.000	-905.0514	-390.7708
		/ε/	-533.56475(*)	83.37459	.000	-763.5580	-303.5715
		/a/	-488.68491(*)	83.37459	.000	-718.6782	-258.6917
		/u/	-173.59673	83.37459	.233	-403.5900	56.3965
	/a/	/i/	-159.22619	93.21562	.432	-416.3665	97.9141
		/ε/	-44.87984	83.37459	.983	-274.8731	185.1134
		/o/	488.68491(*)	83.37459	.000	258.6917	718.6782
		/u/	315.08818(*)	83.37459	.002	85.0949	545.0814
	/u/	/i/	-474.31436(*)	93.21562	.000	-731.4546	-217.1741
		/ε/	-359.96802(*)	83.37459	.000	-589.9613	-129.9748
		/o/	173.59673	83.37459	.233	-56.3965	403.5900
		/a/	-315.08818(*)	83.37459	.002	-545.0814	-85.0949

* The mean difference is significant at the .05 level.

<Table 9-2> Multiple Comparisons: F3 by vowel (female speakers)

Dependent Variable	(I) vowel	(J) vowel	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
F3	/i/	/ε/	112.01271	97.45813	.780	-157.0283	381.0538
		/o/	696.87538(*)	95.91353	.000	432.0983	961.6524
		/a/	147.89187	97.45813	.553	-121.1492	416.9329
		/u/	501.32389(*)	95.91353	.000	236.5468	766.1010
	/ε/	/i/	-112.01271	97.45813	.780	-381.0538	157.0283

		/o/	584.86267(*)	82.88357	.000	356.0559	813.6695
		/a/	35.87916	84.66622	.993	-197.8488	269.6071
		/u/	389.31118(*)	82.88357	.000	160.5044	618.1180
	/o/	/i/	-696.87538(*)	95.91353	.000	-961.6524	-432.0983
		/ɛ/	-584.86267(*)	82.88357	.000	-813.6695	-356.0559
		/a/	-548.98351(*)	82.88357	.000	-777.7903	-320.1767
		/u/	-195.55149	81.06173	.118	-419.3289	28.2260
	/a/	/i/	-147.89187	97.45813	.553	-416.9329	121.1492
		/ɛ/	-35.87916	84.66622	.993	-269.6071	197.8488
		/o/	548.98351(*)	82.88357	.000	320.1767	777.7903
		/u/	353.43202(*)	82.88357	.000	124.6252	582.2388
	/u/	/i/	-501.32389(*)	95.91353	.000	-766.1010	-236.5468
		/ɛ/	-389.31118(*)	82.88357	.000	-618.1180	-160.5044
		/o/	195.55149	81.06173	.118	-28.2260	419.3289
		/a/	-353.43202(*)	82.88357	.000	-582.2388	-124.6252

* The mean difference is significant at the .05 level

4. Discussion

This section discusses formant frequencies and formant structures of Korean /l/ and English /l/ in connection with articulatory configuration of /l/ in the two languages. To provide background information on the acoustic correlates of /l/ configuration, Section 4.1 and 4.2 present the articulatory and acoustic relation of the English lateral. Section 4.3 discusses how the acoustic findings of this study can be interpreted in connection with the articulatory characteristics of Korean /l/.

4.1. Articulation of English /l/

Lateral articulation in American English is formed with the tongue having lingual-alveolar contact along the mid-sagittal line. The tongue is laterally compressed with a raised, convex posterior segment. This lateral compression along the mid-sagittal plane enables the creation of lateral cavities on one or both sides of the constriction, which in turn allows air to flow past the constriction[12][20][22][23].

Johnson[7] notes that the opening around one side of lateral cavity is more open than the other, citing Stone's[21] finding that the tongue shape during /l/ configuration in American English shows a side to-side rocking motion of the tongue. In addition, a pocket of air remains on top of the tongue during /l/ configuration, and this serves as an anti-formant-producing side branch. Stevens[18] attributes the characteristics of the lateral in English to a backed and somewhat lowered tongue body position.

The characteristics of two allophones of the English lateral, i.e., light /l/ and dark /l/ are also well established in the literature. A light variant of /l/ has been assumed to occur in syllable-initial position, while a dark variant occurs in syllable-final position.

The typical characteristics of dark /l/ are narrow upper pharyngeal areas (due to high position of the posterior tongue body raising) and retraction of the tongue root[12]. Similarly, Giles and Moll[4] observed that tongue dorsum positions are different in the two variants: dark /l/ shows more posterior positions than clear /l/. In addition, contact with the maxilla is not achieved in some post-vocalic contexts depending on the phonetic context and the rate of speech. Giles and Moll[4] also note that the dynamic control of the tongue tip is different in the two variants of /l/. The dark /l/ shows relatively slow movement of the tongue due to the tongue back articulation, while the clear /l/ shows relatively high rate of articulatory movement. Based on this observation, Giles and Moll[4] suggest that clear /l/ is consonantal in nature whereas dark /l/ is vocalic, forming the second element of a diphthong.

Further developing the proposal that dark /l/ is predominantly vocalic[4], Sproat and Fujimura[17] proposed that the lateral articulation is divided into two gestures: a consonantal apical gesture and a vocalic dorsal gesture. It was also found in the study that timing relation between two gestures is different depending on the syllable position. Tongue tip and tongue dorsal gestures occur almost simultaneously in syllable-initial position, whereas tongue dorsal gesture occurs before tongue tip gesture in syllable-final position[17].

4.2. Acoustics of English /l/

It has been well documented that English lateral has both consonantal and vocalic characteristics. When it comes to the consonantal aspect, liquids are known to have properties similar to stops: the articulatory movements for /r/ and /l/ are quite rapid in some phonetic contexts. In particular, the acoustic change for /l/ tends to be faster than for /r/, especially with regard to F1[8]. Stevens[18] models F1 in American English laterals at around 360 Hz.

On the other hand, /l/ and /r/ have vocalic properties similar to the glides in that “both liquids and glides have a well-defined formant structure associated with a degree of vocal tract constriction that is less severe than that for other obstruents”[8] (p.138). In particular, the lesser degree of constriction for the lateral is reflected in the transitions in and out of the /l/ sound: /l/ has a low target of F2 similar to the bilabial /w/[15].

When it comes to the formant value, the F1 and F2 values for /l/ are similar to F1 and F2 values for /r/. On the contrary, F3 value for /l/ is considerably higher (by approximately 1 kHz) than F3 for /r/[8]. Similarly, Stevens[18] characterizes the lateral as being produced “with an F3 that is as high as possible, and well separated from F2”(p.543). For Stevens[18], the second formant for the lateral is the resonance of the back cavity, and the effect of tongue body backing lower this frequency to about 1100 Hz.

One of the important acoustic correlates of the lateral is that the side branch in lateral configuration results in a zero within the range 2200-4400 Hz[18]. Spectral discontinuity resulting from this zero in the formant structure of /l/ is a typical characteristic of a clear lateral, while a dark variant of /l/ usually does not show such abrupt spectral discontinuity[15]. Stevens and Blumstein[19] attribute the existence of spectral discontinuity in the structure of /l/ to an abrupt change in F2 amplitude of about 10 dB at consonant release. Olive, Greenwood, and Coleman[15] observed a dark vertical line at the juncture of clear /l/ to a vowel and state that this line shows up due to the tongue contact with the alveolar ridge. They assumed that there is a greater extent of closure for light /l/ than for dark /l/ based on the fact that there is no line visible in the transition to the dark /l/.

Regarding the coarticulation of /l/ with the neighboring vowels, Olive, Greenwood, and Coleman[15] note that the lateral sound is resistant to coarticulatory variations, since “the tongue configuration during the /l/ inhibits its movement during the production of the lateral” (p.215). They found justification for this statement in the observation that the formant value is similar regardless of the identity of the preceding or following vowel, and /l/ spectra is in general consistent regardless of vowel contexts. Somewhat contrary to Olive, Greenwood, and Coleman’s[15] statement about the coarticulatory variation of /l/, Stevens and Blumstein[19] reported that F1 and F2 frequencies in prestressed laterals vary depending on the formant frequencies in the following vowel. For instance, F2 for /l/ is higher before a front vowel (cited in [1]).

Secondary articulations involved in the lateral configuration also influence the formant structure of a lateral. A dark variant of /l/, which involves greater tongue back articulation, has a particularly low F2 and acoustically resembles vowels much more than the clear counterpart.

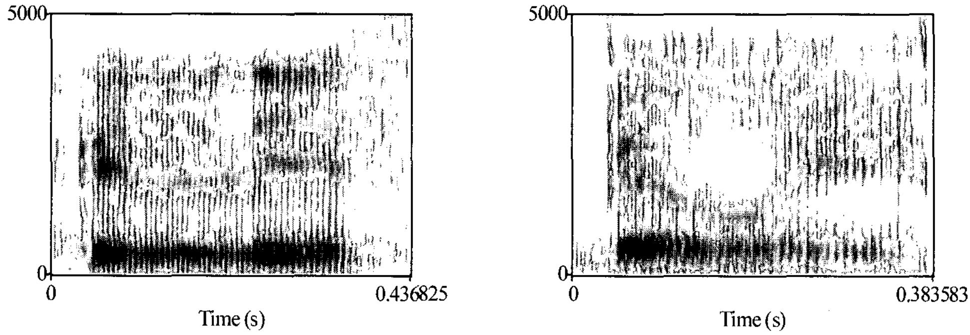
In this section, I have discussed articulatory-acoustic relation of the English lateral based on the published data on the given issue. The acoustic characteristics of English /l/ are summarized as follows. First, a lateral has both consonantal and vocalic characteristics. Second, English /l/ involves high F3 (compared to /r/) with a fairly low F2. Third, spectral discontinuity is an important acoustic correlate of clear /l/ articulation. Fourth, dark /l/ is characterized by a gradual movement of the formants and lower F2 due to greater tongue back articulation.

4.3. Articulatory and acoustic correlates of Korean /l/

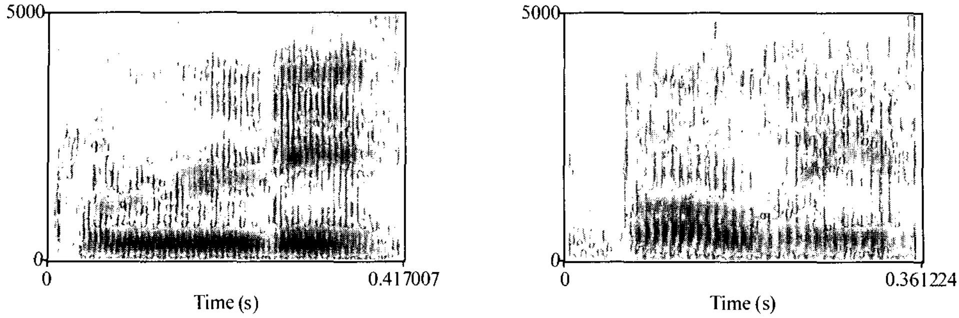
In this section, I will discuss acoustic correlates of Korean /l/ in comparison with English /l/ based on the formant structures and formant frequencies of /l/ in the two languages. In particular, I will try to answer the following two questions, which were raised based on the results from the experiments in the current study.

a) Why is F2 for Korean /l/ higher than F2 for English /l/?
b) Why does F3 become lower when the preceding vowel is a back vowel?

<Figure 6> and <Figure 7> present spectrograms of Korean /l/ (left) and English /l/ (right) produced in two different vowel contexts.



<Figure 6> /pilli/ by a Korean speaker and /bɪli/ by an English speaker



<Figure 7> /pulli/ by a Korean speaker and /bʊli/ by an English speaker

What is most noticeable in <Figure 6> and <Figure 7> in terms of formant movement is that F2 for English /l/ starts to move down at the juncture of the preceding vowel to /l/, reaches its bottom, and moves up again when /l/ is released to a following vowel. On the other hand, this downward movement of F2, which is typical in English intervocalic /l/, is not observed in Korean /l/. F2 for Korean /l/ is in general steadily high and sometimes moves a little upward in <Figure 7>. Actually, the lack of F2 downward movement in Korean /l/ is consistent with the formant frequencies of Korean /l/ discussed in section 3.1.1 and 3.2.1: F2 for Korean /l/ is much higher than F2 for English /l/. Then the question is what factors contribute to the higher F2 value for Korean /l/ (or lack of F2 downward movement). In this paper, I propose that the overall high F2 value for Korean /l/ can be attributed to the following two factors: a) tongue body gesture involved in Korean /l/ and b) the lack of tongue backing articulation.

Carter's[1] dissertation on the liquids in the varieties of British English provided important clues for the proposal in this study. Carter[1] notes that "initial [l] in American English is not as clear as in many varieties of British English" (p.84). Carter's statement that clear /l/ in American English is not as clear as the British English can find its justification in the difference of F2 value between British English /l/ and American English /l/: F2 value for /l/ in British English is around 1350 Hz[13], while it is 980 Hz in Lehiste[11] and Stevens[18] which investigated /l/ in American English. Given this variation in American English and British English, we can surmise that Korean /l/ may be even clearer than British English /l/, especially in the sense that Korean /l/ does not involve tongue backing articulation, which has been assumed to lower F2 value in /l/ configuration.

Actually, this assumption can find supporting evidence in the recent articulatory study of Korean /l/. Gick, Campbell and Oh[3] found that Korean /l/ involves two gestures, tongue tip raising and tongue body raising (palatalization), while tongue tip raising pairs with tongue dorsal gesture for English /l/[3].

That Korean /l/ is sometimes realized as a palatalized lateral is also discussed in Tsuzuki[25], but he identifies a palatalized /l/ only when /l/ occurs in intervocalic position and when the following vowel is /i/ or /j/. However, according to Gick, Campbell and Oh[3], palatalization of Korean /l/, which involves tongue body raising, is a typical characteristic of /l/ in Korean. The issue of palatalization in Korean /l/ seems controversial, but I will adopt the results from Gick, Campbell and Oh[3] for the purpose of the current analysis.

Given the difference in the articulation of Korean /l/ and English /l/ discussed in Gick, Campbell, and Oh[3], it is reasonable to assume that there is an acoustic consequence resulting from these articulatory differences. More specifically, if the observation that Korean /l/ involves tongue body raising along with tongue tip raising is correct, we can find a possible relation between the tongue body raising and F2 value: Palatalization of Korean /l/ may have contributed to high F2 for Korean /l/. Actually, there is empirical evidence for this statement. Fant[2] identifies a higher F2 in a palatalized /l/ in Russian than non-palatalized /l/ due to a pharyngeal constriction.

Moreover, the lack of dorsal gesture in Korean /l/ may have affected F2 value. Recall that the lateral in English is characterized by a backed and somewhat lowered tongue body position, and the second formant for a lateral is primarily a resonance of the cavity posterior to the main constriction in the oral cavity[18]. Accordingly, the lack of dorsal gesture in Korean may have acoustic consequences, which is high F2.

In what follows, I will discuss the question regarding F3 value in Korean: Why does F3 become lower when the preceding vowel is a back vowel?

In this paper, I propose that the lowered F3 value results from the retroflexion of the Korean lateral which occurs when the preceding vowel is a back vowel. The remaining question is then how the retroflexion of /l/ affects F3 values for Korean /l/.

We can find some clues about this question in the work of Stevens[18]. In this study, Stevens[18] correlates the volume of the back cavity with F3 value in a lateral. That is, the bigger the volume of the back cavity, the higher the F3 value. Given the correlation between the volume of the back cavity and the F3 value, we can say that F3 lowering in a back vowel context indicates that the volume of back cavity becomes smaller in the context of back vowels than in other contexts. This matches exactly with what articulatory studies on Korean /l/ have found[25][26]. That is, /l/

articulation occurs after alveolars when the preceding vowel is a back vowel, and as a result, the volume of the back cavity becomes smaller. The acoustic consequence of this retroflexed /l/ is a lower F3.

The line of reasoning such that F3 value for Korean /l/ is correlated with the retroflextion of Korean /l/ finds additional support from the F3 mean difference when the preceding vowel is /o/ and /u/. That is, the lowest F3 mean value for Korean /l/ was observed when the preceding vowel is /o/ (refer to <Figure 5>). If the assumption that F3 value for Korean /l/ is correlated with the retroflexion of /l/, we can surmise that F3 value for Korean /l/ is not only influenced by front vs. back vowel contrast, but also influenced by the degree that /l/ is retroflexed depending on the preceding vowel. This reasoning leads to the prediction that there may occur more retroflexion when the preceding vowel is /o/ than when the preceding vowel is /u/, given the lower F3 value in the context of /o/. This prediction is confirmed by the work of Umeda[26], where he states that "the point of articulation is further back in the utterance of *ol* occurring around postalveolar to palatal"(p.873).

Furthermore, we can also account for why F3 value when the preceding vowel is /a/ is not as low as F3 value when the preceding vowel is /o, u/ even though some previous studies observed that Korean /l/ is realized as a retroflex lateral when the preceding vowel is /o, a, u/[25]. The reasoning is as follows. F3 value for Korean /l/ in the context of /a/ is not as low as F3 value for /o, u/ because /a/ is a low mid vowel in Korean while /o, u/ are back vowels[27]. Accordingly, there may be less retroflexion in the context of /a/ than in the context of /o, u/.

5. Conclusion

This study investigated articulatory and acoustic relation of Korean /l/ in comparison with English /l/. The acoustic experimental findings in this study indicate that Korean /l/ is different from English /l/ in several properties. First, F2 value for Korean /l/ is much higher than F2 for English /l/. This overall higher F2 value for Korean /l/ is attributed to the fact that Korean /l/ involves tongue body raising while it lacks a dorsal gesture. Second, abrupt F3 lowering in the back vowel context indicates that Korean /l/ undergoes retroflexion. This result is consistent with the findings of the previous articulatory study on Korean /l/ such that Korean /l/ is realized as a retroflex lateral when the preceding vowel is a back vowel[25][26].

There have been several studies examining articulatory characteristics of Korean

/l/[3][10][14][25][26], but few studies, to my knowledge, examined articulatory-acoustic relation of Korean /l/. Given this, this study provided important data on the acoustic characteristics of Korean /l/ and provided accounts for these characteristics in relation to the articulatory configuration of Korean /l/.

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Appendix A

<Table A-1> Descriptive Statistics: F1-F3 (Experiment 1)

Gender	Language		Mean	Std. Deviation	N
Male	English	F1	470.8175	61.52468	28
		F2	975.6282	111.71746	28
		F3	2646.3493	308.66609	28
	Korean	F1	347.3444	39.45289	28
		F2	1576.3677	121.11379	28
		F3	2462.0558	353.94465	28
Female	English	F1	581.2281	90.34065	26
		F2	1178.5702	138.01688	26
		F3	3432.7494	244.83703	26
	Korean	F1	455.6776	70.34764	28
		F2	1903.7756	189.98485	28
		F3	2933.0963	340.35191	28

Appendix B

<Table B-1> Dependent Variable: F3 by vowel (Experiment 1)

Language	Gender	vowel	Mean	Std. Deviation	N
English	Male	/i/	2803.3751	427.62788	8
		/ε/	2553.9978	342.50412	8
		/a/	2526.3844	117.87811	6
		/u/	2680.0819	92.79599	6
		Total	2646.3493	308.66609	28
	Female	/i/	3457.6163	91.50962	7
		/ε/	3322.4782	379.02788	7
		/a/	3500.0113	193.72987	6
		/u/	3465.1258	234.89362	6
		Total	3432.7494	244.83703	26
Korean	Male	/i/	2549.9939	217.66418	8
		/ε/	2660.9717	225.07138	8
		/a/	2591.5149	238.37207	6
		/u/	1950.1246	268.59608	6
		Total	2462.0558	353.94465	28
	Female	/i/	2996.4839	265.10995	8
		/ε/	3044.4953	229.75708	8
		/a/	3155.0959	251.74612	6
		/u/	2478.0481	236.53526	6
		Total	2933.0963	340.35191	28

Appendix C

<Table C-1> Descriptive Statistics for F2 (Experiment 2)

Gender	Position	Mean	Std. Deviation	N
Male	Intervocalic	1713.5771	201.30525	90
	Final	1566.0027	197.72111	90
	Total	1639.7899	212.27645	180
Female	Intervocalic	2084.3273	247.85355	90
	Final	1983.0092	269.68345	90
	Total	2033.6683	263.22272	180
Total	Intervocalic	1898.9522	291.97384	180
	Final	1774.5059	315.14365	180
	Total	1836.7291	309.68947	360

<Table C-2> Descriptive Statistics for F3 (Experiment 2)

Gender	Position	Mean	Std. Deviation	N
Male	Intervocalic	2615.1141	414.69804	90
	Final	2380.8502	391.10914	90
	Total	2497.9822	418.75924	180
Female	Intervocalic	3003.6696	410.61552	84
	Final	2806.6498	421.34147	86
	Total	2904.0007	426.44563	170
Total	Intervocalic	2802.6926	455.28095	174
	Final	2588.9114	457.80378	176
	Total	2695.1912	468.29463	350

<Table C-3> Descriptive Statistics: F3 by vowel (Experiment 2)

Gender			Mean	Std. Deviation	N
Male	F3	/i/	2781.4367	277.03494	24
		/ε/	2667.0904	300.98622	36
		/o/	2133.5256	417.47630	36
		/a/	2622.2105	267.02923	36
		/u/	2307.1224	442.83290	36
		Total	2482.3372	423.56260	168
Female	F3	/i/	3218.5979	275.54358	20
		/ε/	3106.5851	315.41991	33
		/o/	2521.7225	392.64689	36
		/a/	3070.7060	325.66381	33
		/u/	2717.2740	365.68866	36
		Total	2891.3066	428.58132	158

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