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Phonetic Implementation of the Darkness of English Word-final /l/ across Prosodic Positions: Comparison of Native English Speakers and EFL Korean Speakers*

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Sohn, Hyang-Sook and Shinyoung Lim. 2020. Phonetic implementation of the darkness of English word-final /l/ across prosodic positions: Comparison of native English speakers and EFL Korean speakers. *Korean Journal of English Language and Linguistics* 20, 450-474. This study investigates the way in which darkness of the word-final /l/ is implemented in two speaker groups of the native English speakers and EFL Korean speakers across three prosodic contexts, by measuring the acoustic parameters of pre-lateral vowel duration and formant frequencies at the time of onset and offset of post-peak duration. The rates of the F1 increase and those of the F2 decrease, and values of (F2-F1) indicate implementation of darker /l/ for the native English speakers compared with the Korean speakers despite shorter vowel duration. Acoustic parameters derived from the measures suggest that the two speaker groups are more dependent on tongue dorsum retraction than tongue body lowering to implement velarization. This asymmetry is particularly characteristic of the Korean speakers and is attributed to interference of the articulatory property of the Korean lateral. Prosodic strengthening was partially observed between PP and the foot level for both speaker groups, with no foot-internal distinction. Within each speaker group post-peak duration and the F2 decrease rate cumulatively increased in PP compared with the foot level, which lends supporting evidence to the undershoot effect on velarization. Prosodic effects on acoustic measures suggest that darkness of /l/ is not categorical but gradient on a phonetic continuum.

Keywords: coarticulatory gesture, darkness of /l/, F1 raising, F2 lowering, lateral /l/, prosodic strengthening, undershoot, velarization, vowel duration

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1. Introduction

It is well known that the English lateral /l/ has two allophonic variants, light [l] and dark [ɬ], with their complementary distribution based on positions in the syllable: the light [l] surfaces in the onset of the syllable, while the dark [ɬ] in the rime of the syllable.

In the articulatory accounts (Ladefoged and Johnson 2015, Sproat and Fujimura 1993, Stevens 1998 among others), the lateral is produced by the constriction primarily made by the tongue blade in contact with the alveolar ridge. In the case of the dark [ɬ], an additional articulation is imposed by the tongue body movement. The tongue body is pulled down and the tongue back is retracted as in a back unrounded vowel, whereby a secondary articulation of velarization is superimposed. Velarization of the English lateral is an attribute to the coda position, while absence of this secondary articulation is characteristic of the lateral in the onset position, hence making the allophonic variants of the English lateral categorical (Chomsky and Halle 1968).

Recent findings in experimental research, however, indicate that the darkness of the English lateral is phonetically on a continuum with respect to the various prosodic positions (Sproat and Fujimura 1993), to morphological boundaries (Lee-Kim et al. 2013), or to the nature of pre-lateral vowels in conjunction with the lexicality effect (Ahn 2015). Sproat and Fujimura (1993) claimed that the darkness of /l/ is not categorical but is phonetically implemented as a function of the strength of word-internal morpheme boundaries and prosodic positions. Based on the articulatory X-ray microbeam data and the acoustic measures, they showed that the articulatory measures and formant frequency measures correlate with duration of the rime containing /l/. That is, the lateral is darker as duration of the rime gets longer, which in turn is a reflection of its position in the prosodic hierarchy.

The correlation between the darkness of the English lateral and the boundary strength is further attested in Lee-Kim et al. (2013). Based on both articulatory imaging and acoustic measurements, they investigated the morphological effects on the darkness of intervocalic /l/ in the pre-boundary (stem-final) and post-boundary (suffix-initial) positions, in comparison with word-final /l/. Five different vowels were employed in the pre-lateral position so that valid generalization might be drawn from the experiment. Assuming the hypothesis in Hayes (2000) on the morphological effects on the darkness of /l/, they made a prediction that the intervocalic /l/ in the stem-final position (*tall-est*) is darker in comparison with the one in the

suffix-initial position (*flaw-less*) even though the lateral is syllabified as onset in both cases. According to Hayes (2000), the difference lies in their morphological affiliation, namely that the former, unlike the latter, is under the morphological pressure to keep the paradigmatic relationship with its output correspondent, the stem form (*tall*).

Their experiment of ultrasound imaging showed a greater degree of tongue body lowering and tongue dorsum retraction in /l/ in the pre-boundary position (*tall-est*) than the one in the post-boundary position (*flaw-less*). Word-final /l/ showed the greatest degree of movements in both gestures of lowering and retraction. This shows that /l/ is the darkest in the word-final position, while it is the lightest in the post-boundary position. This leaves the darkness of /l/ in the pre-boundary position inbetween the other two contexts, accounting for its misalignment between morphological and phonological affiliation.

Acoustic measurements indicated similar results parallel to the articulatory implementation. F1 values are expected to increase as tongue body is lowered, and /l/ in the word-final or pre-boundary position turned out to have higher F1 values, compared with the post-boundary /l/. On the other hand, F2 values are expected to decrease as tongue dorsum retracts, and hence inversely to F1, /l/ in the word-final or pre-boundary position showed lower F2 values, compared with the post-boundary /l/. As predicted, /l/ in the word-final position showed higher F1 and lower F2 values than intervocalic /l/ in the pre- or post-boundary position. The acoustic asymmetry between the pre- and post-boundary positions on the one hand, and the one between the word-internal and word-final positions on the other suggest the gradient nature of phonetic implementation of the /l/ darkness.

Given substantial evidence in the recent studies supporting the correlation between the darkness of /l/ and the boundary strength in the word-internal structure, this study investigates if darkness of the word-final /l/ is gradiently implemented in the wake of different prosodic environments and corroborates the findings in experimental research on prosodic enhancement of acoustic features related to /l/ darkness. Since the darkness is the greatest in word-final position in terms of gestural movements and acoustic parameters, it will be intriguing to see if the effect of boundary strength on the /l/ darkness works in a similar way in different prosodic contexts as well.

Provided the volume of research on the effect of prosodic strengthening in the boundary positions, it is predicted that the higher the prosodic position is, the darker the word-final /l/ is. Thus, word-final /l/ in phonological phrase (PP), is darker than

the one in the lower prosodic hierarchy such as phonological word (Pwd), an equivalent to foot (Ft). For the sake of prosodic comparison, foot-internal /l/ is also examined. In this study the word-final /l/ is examined in three prosodic boundaries of phonological phrase (PP), foot-final (Ft-f) and foot-medial (Ft-m) positions.

Following the hypothesis in Sproat and Fujimura (1993), namely that /l/ darkness is affected by duration of the rime containing /l/, we measure duration of the pre-lateral vowel. It is assumed here that the darkness of the word-final /l/ is reflected in duration of the preceding vowel. This is because velarization of /l/ requires transitional time in the period of the vowel duration to implement coarticulatory gesture for the subsequent /l/. Also measured in this study are formant frequencies of F1 and F2 as acoustic equivalents of the articulatory movements of tongue body lowering and tongue dorsum retraction. The rates of the F1 increase and F2 decrease as well as values of (F2-F1) are derived from these formant frequencies so that the degree of the /l/ darkness can be accounted for.

Assuming the effect of boundary strength on the darkness of /l/, it is predicted that for three acoustic measures of vowel duration, F1 and F2, word-final /l/ is the darkest in PP, while it is the lightest in Ft-m position. Ft-f position will be intermediate between the other two prosodic boundaries. We examine if the predictions are borne out in these prosodic contexts. In addition to the prosodic effect on the /l/ darkness, this study also accounts for the way in which darkness of the word-final /l/ is produced by English learning (EFL) Korean speakers, since the lateral is not velarized word-finally in their native language Korean (Ahn 2017, Iverson and Sohn 1994, Lee et al. 2015, Park and Jang 2016). Acoustic features of the English /l/ produced by EFL Korean speakers are compared with those produced by native speakers of American English.

2. Methods

2.1 Participants

Participants were composed of two groups of speakers. One group consisted of native speakers of American English (henceforth, native speakers). This group was made up of five American undergraduate students, two male and three female. At the time of this experiment, they were visiting a university in Daegu as exchange

students. The other group consisted of thirteen Korean undergraduate students, of which one was male and twelve were female. All of the members of this second group were native speakers of North Kyeongsang Korean born in the Daegu area and were English language learners with their proficiency in the high-intermediate level or above. All the participants, both American and Korean, attended the same university in Daegu, and ranged in age from 20 to 25. None of them reported any speech or hearing disorders.

2.2 Materials

The stimuli included nine English target words ending with the lateral /l/ preceded by high front vowel /i/ ('deal', [i-l#]). High front vowel was chosen as a pre-lateral context because tongue body is raised and fronted in production of the vowel [i] and hence the transitional movement will be clearer to observe when tongue body is lowered and retracted to produce the velarized [ɬ] word-finally. Compared with high or front vowels, non-high or back vowels will be less evident in the gestural transition because tongue is already lowered or retracted for these vowels and hence it takes a smaller transition to reach the following target /l/.

The experiment was designed to investigate the acoustic characteristics of the English word-final /l/ in three prosodic environments of phonological phrase (PP), foot-final (Ft-f), and foot-medial (Ft-m) positions. Each prosodic environment was tested by three target words, which were embedded in natural sentences. Given in the following are the sentences carrying the target words:

(1) Stimuli in three prosodic contexts

a. Phonological phrase (PP)

This book has [a broader appeal]$_{PP}$ than the previous one.
He made [a big deal]$_{PP}$ today and he is feeling good
[This wonderful meal]$_{PP}$ is home-made.

b. Foot-final (Ft-f)

What do you do when you [feel]$_{Ft}$ irritated?
She was about to [peel]$_{Ft}$ oranges.
We [feel]$_{Ft}$ young when we work out.

c. Foot-medial (Ft-m)
Don't [steal a]$_{Ft}$ book from the shelf.
The man would [steal a]$_{Ft}$way across the lawn.
Don't [reveal it]$_{Ft}$.

2.3 Recordings

The list of nine sentences plus six filler sentences were presented two times in random order. In order to control the speech rate, these sentences were presented in the format of Powerpoint slides with each slide being shown for seven seconds before flipping to the next. The subjects were instructed to read the sentences as naturally as possible after taking some time to be familiar with the material. The recording was conducted on a digital audio tape (DAT) in a sound-treated room. The speech signal was digitized at 16kHz. The recordings were saved by the Praat program and the target words were segmented by the first author from wave forms and spectrogram displays using Praat version 6.0.52 (Boersma and Weenink 2019).

2.4 Measurements

Acoustic measurements were manually done for duration of the pre-lateral vowel and formant frequencies of F1 and F2 at two points of the vowel duration using Praat. Acoustic duration of the pre-lateral vowel was measured from the interval between the onset of vowel to its offset which coincides with the time of the onset of the following /l/. Total duration of the pre-lateral vowel is called Dur0. When the precise boundary between the vowel and its following /l/ was difficult to determine, formant frequencies of vowel were taken into consideration. The boundary between the vowel and /l/ was located when two conditions were met: one was the beginning of the lowest point of F2, and the other was maintenance of F3 with stable acoustic energy at the time of minimum F2.

Total duration of the vowel Dur0 was divided by two sub-components of Dur1 followed by Dur2: one was from the onset of the vowel to the maximum F2, and the other was from F2 peak to the offset of the vowel. F2 served the basis for the criterion of the dividing point in duration because the peak of F1, compared with F2, was not easy to set since it is continually on the rise. Pre-peak duration as the first part of the vowel duration is called Dur1 in this study and reflects the acoustic

character of the high front vowel /i/. The subsequent post-peak duration is called Dur2 and reflects the transitional movement of tongue body lowering and tongue dorsum retraction from the vowel [i] to the following /l/ to implement velarization.

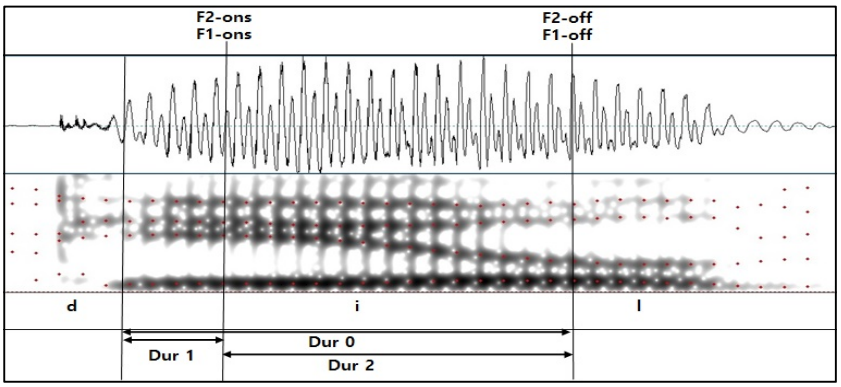


Figure 1. Measurement Example of *deal* [dił]

Formant frequencies of F1 and F2 were measured at two points during the full target of the high front vowel [i]. Maximum F2 values were measured at the peak of F2 after the onset of vowel, and at this point F1 was measured as minimum F1 values. Subsequently minimum F2 values were measured at the end of the vowel duration, i.e., when the target reached the onset of the velarized word-final /l/, and then at the same point F1 was measured to represent maximum F1 values. This is the endpoint of the high front vowel where F1 is inversely the highest and F2 the lowest. Formant frequencies measured right after the onset of vowel are called F1 and F2 at the onset, while those measured at the end of vowel duration are called F1 and F2 at the offset.

3. Results

3.1 Vowel Duration

In Table 1 we see the average vowel duration of the native and Korean speakers across the prosodic positions. Dur1 refers to the gestural time for the high front vowel [i] starting from the onset of the vowel voicing until the F2 peak is reached, while Dur2 refers to the interval between maximum and minimum F2. The difference

between Dur2 and Dur1 is represented by ΔDur (ms) and the increase rate (%) of Dur2 over Dur1 is given in parentheses.

Table 1. Average Duration of Native and Korean Speakers (ms)

	Native				Korean			
	Dur0	Dur1	Dur2	ΔDur	Dur0	Dur1	Dur2	ΔDur
PP	151	69	82	13(19)	187	74	113	39(53)
Ft-f	119	56	63	7(13)	155	70	85	15(21)
Ft-m	140	65	75	10(15)	152	70	82	12(17)
Avg	137	63	73	10(16)	165	71	93	22(30)

* Numbers in parentheses represent the increase rate (%) of Dur2 over Dur1.

Average total duration Dur0 as well as its two sub-components Dur1 and Dur2 was longer for the Korean speakers in comparison with the native speakers, and the difference was statistically significant: Dur0: p = .000; Dur1: p = .030; Dur2: p = .000.

For both of the speaker groups, Dur2 was longer than Dur1. This shows that more time was allowed in implementing the articulatory movement of tongue body lowering and tongue dorsum retraction to reach the target for the dark /l/. However, the two speaker groups differed in the way in which the sub-components of the pre- and post-peak were sequenced. For the native speakers the average difference ΔDur was 10ms, while it was as long as 22ms for the Korean speakers. In terms of the increase rate, Dur2 was 16% longer than Dur1 for the native speakers, while it was 30% longer for the Korean speakers.

Under the duration-based hypothesis in Sproat and Fujimura (1993), more time for the coarticulatory gesture allows room for greater degree of tongue body lowering and retraction for the dark /l/. Following this hypothesis, it might be inferred that a greater degree of darkness is expected in the word-final /l/ for the Korean speakers in comparison with the native speakers. This is to be seen in discussion of formants in the following section.

We now turn to vowel duration in the prosodic contexts. For the native speakers, Dur0 was longer in the PP and Ft-m positions than Ft-f: PP = Ft-m > Ft-f (PP-Ft-f: p = .000; Ft-m-Ft-f: p = .013; PP-Ft_m: p = .329) As for Dur2, PP was also longer than Ft-f, but Ft-m was significantly different neither from PP nor from Ft-f: PP > Ft-f, PP = Ft-m, Ft-f = Ft-m (PP-Ft-f: p = .017; Ft-m-Ft-f: p = .170; PP-Ft-m: p = .571). There was no significant difference among prosodic positions in Dur1. Put together, prosodic strengthening based on pre-lateral vowel duration was observed in the PP against Ft-f position.

For the Korean speakers, Dur0 was also by far longer in the PP in comparison with the Ft-f or Ft-m contexts: PP > Ft-f =Ft-m (PP-Ft-f: p = .010; PP-Ft-m: p = .004; Ft-f-Ft-m: p = .950). The prosodic effect of Dur2 was the same as Dur0: PP >Ft-f = Ft-m (PP-Ft-f: p = .001; PP-Ft-m: p = .000; Ft-f-Ft-m: p = .912). As in the native speakers, there was no significant difference among prosodic contexts in Dur1.

The effect of prosodic strengthening with respect to Dur0 and Dur2 is summarized as follows:

Table 2. The Effect of Prosodic Strengthening in Duration

	Native	Korean
Dur0	PP = Ft-m > Ft-f	PP > Ft-f = Ft-m
Dur2	PP > Ft-f, PP = Ft-m, Ft-f = Ft-m	PP > Ft-f = Ft-m

For both speaker groups, duration of Dur0 as well as Dur2 was cumulatively longer in PP in comparison with the foot domain. However, Ft-m behaved like Ft-f for the Korean speakers, while it behaved like PP for the native speakers.

3.2 Formant Frequencies

Darkness of the word-final /l/ is implemented essentially during the post-peak duration Dur2, where tongue body lowering and tongue dorsum retraction take place. As their acoustic correlates, formant frequencies are examined with respect to the onset vs. offset points of Dur2. In the table below, minimum F1 at the time of maximum F2 is given as the onset value, while maximum F1 at the time of minimum F2 is given as the offset value.

Table 3. F1 and F2 Values at the Onset and Offset of Dur2 (Hz)

		F1-ons	F1-off	F2-ons	F2-off
Native	PP	374	527	2334	1128
	Ft-f	370	506	2172	1149
	Ft-m	386	525	2241	1126
	Avg	377	519	2249	1134
Korean	PP	450	551	2345	1302
	Ft-f	465	541	2169	1339
	Ft-m	449	532	2303	1401
	Avg	455	541	2272	1349

It is noteworthy that the average value of F2 at the offset was 1134Hz for the native English speakers, similar to 1100Hz for the F2 value of the English dark /l/ (Stevens 1998). In comparison, the F2 value was more than 200Hz higher for the Korean speakers, suggesting that the lateral was less velarized. The higher F2 value for the Korean speakers appears to be a consequence of L1 interference as the F2 value of the Korean /l/ is reported to range from 1476Hz to 1820Hz (Ahn 2017)[1].

For the native speakers, the average F1 value increased from 377Hz at the onset to 519Hz at the offset. This indicates that tongue body was first raised for production of the high front vowel [i] and that subsequently it was relatively lowered to implement darkness of the post-vocalic /l/. For the Korean speakers, both the onset and offset values of F1 were higher compared with the native speakers. The two groups were significantly different in onset values (p = .000), but not in offset values (p = .072). Higher onset value of F1 for the Korean speakers indicates that tongue body was not sufficiently raised in production of the high front vowel [i].

As for F2, both the native and Korean speakers had similar onset values, but their average offset values were 215Hz apart. The two groups were significantly different in offset values (p = .000), but not in onset values (p = .659). Similar onset values of F2 indicate that the Korean speakers as well as the native speakers had the tongue dorsum fronted to produce the high front vowel [i]. On the other hand, offset values suggest that the degree of tongue dorsum retraction was greater for the native speakers, hence resulting in implementation of heavily velarized /l/, compared with the Korean speakers.

In the figure below, maximum and minimum values of formant frequencies are compared across the prosodic positions for the native and the Korean speakers.

[1] Park and Jang (2016) cites the F2 values of /l/ in English and Korean respectively from Espy-Wilson (1992) and Kim and Lotto (2004): the F2 value of the English /l/ represents 1074Hz, while that of the Korean /l/ 1868Hz.

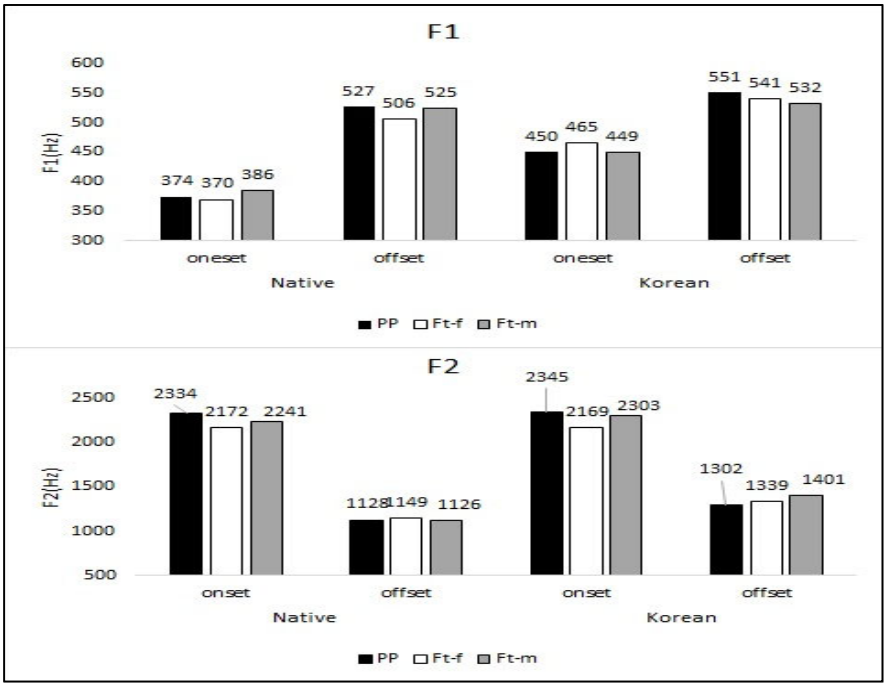


Figure 2. F1 and F2 Values at the Onset and Offset of Dur2

In prosodic contexts, there was significant difference in F2 between PP and Ft-f at the time of onset for the Korean speakers (p = .039). Otherwise, no other significant difference was observed for any other parameters related to formant frequencies for any speaker group.

It is noteworthy here that the average F1 values at the onset and offset were higher for the Korean speakers than the native speakers (cf. Table 3). This seems to suggest that the Korean speakers had larger movement of tongue body lowering, hence implementing greater degree of /l/ darkness. In assessment of darkness of the word-final /l/, not only is it crucial to compare the raw values of formant frequencies at the onset and offset points, relative interval between these two points also needs to be taken into consideration.

The following table shows the differences between the onset and offset values of F1 and F2, namely ΔF1 (off-ons) and ΔF2 (ons-off)). The rates of F1 increase and F2 decrease are also derived from offset values over their corresponding onset values.

Table 4. Difference between the Onset and Offset Values of F1 and F2 (Hz) and Rates (%) of F1 Increase and F2 Decrease during Dur2

	ΔF1(off-ons)		ΔF2(ons-off)	
	Native	Korean	Native	Korean
PP	153(41)	101(22)	1206(52)	1043(44)
Ft-f	136(37)	76(16)	1023(47)	830(38)
Ft-m	139(36)	83(18)	1115(50)	902(39)
Avg	142(38)	86(19)	1115(50)	923(41)

* Numbers in the parentheses refer to the F1 increase and F2 decrease rates (%).

The F1 difference between the onset and offset values was 86Hz for the Korean speakers, a much smaller difference compared with 142Hz for the native speakers. In addition to the raw difference ΔF1, when the F1 increase rate between the onset and offset values was taken into consideration, it turns out that for the native speakers the increase rate was as high as 38% based on 142Hz difference, while it was only 19% based on 86Hz difference for the Korean speakers. It is for the Korean speakers that the word-final /l/ proved to be implemented with lesser degree of tongue body lowering. This leads to the claim that darkness of /l/ is greater for the native speakers than the Korean speakers.

As for F2, the native speakers showed a drastic decline between the onset and offset values (ΔF2 = 1115Hz). This indicates that there was a substantial transitional gesture of tongue dorsum retraction from the high front vowel [i] to the post-vocalic /l/, hence implementing the darkness of the word-final /l/. The Korean speakers also showed a sharp F2 decrease from the onset to the offset values (ΔF2 = 923Hz), but by lesser difference compared with the native speakers. Smaller difference is primarily attributed to the higher offset values. Note again that the Korean /l/ is represented with high F2 value (Ahn 2017, Kim et al. 2000, Park and Jang 2016). Consideration of the F2 decrease rate also points to the same result: for the native speakers the decrease rate was as high as 50%, while it was 41% for the Korean speakers. This shows that the tongue dorsum was fronted for the vowel [i] in a similar way but there was less retraction for the Korean speakers compared with the native speakers.

The F1 increase and F2 decrease rates are plotted in the following figure to compare phonetic implementation of velarization in the two speaker groups:

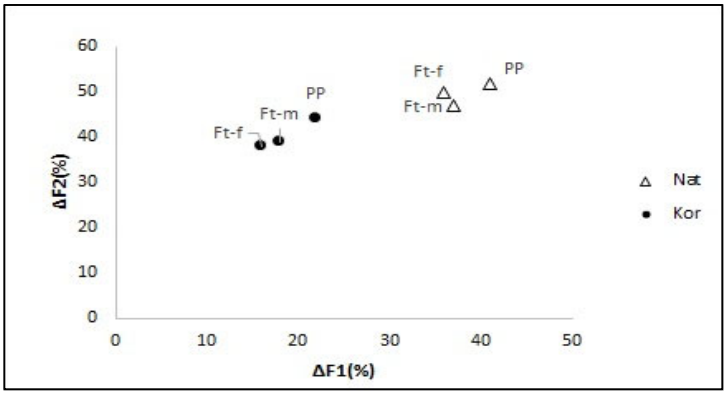


Figure 3. Rates of F1 Increase (ΔF1) and F2 Decrease (ΔF2)

The greater the rates of the F1 increase and F2 decrease, the darker the word-final /l/ is, since tongue body lowering and tongue dorsum retraction are reflected in the increase of F1 and decrease of F2 respectively. The native speakers are relatively higher in both the ΔF1 and ΔF2 rates, and therefore the word-final /l/ proves to be darker for the native speakers in comparison with the Korean speakers. Rates of the F1 increase and F2 decrease also suggest that compared with the native speakers, the Korean speakers are more dependent on tongue dorsum retraction than on tongue body lowering in implementing the effect of velarization.

3.3 Relation between Vowel Duration and Formant Frequencies

Articulatory gestures for velarization are carried out by tongue body lowering and tongue dorsum retraction. As their acoustic correlates, the F1 increase and the F2 decrease are implemented in the wake of the coarticulatory gesture of the vowel and its following target /l/. As a consequence, the spectral interval between F2 and F1 will decrease at the time of offset as the lateral target becomes more velarized. Therefore, values of (F2-F1) can be represented as a function of /l/ darkness (Ladefoged and Johnson 2015, Lee-Kim et al. 2013).

On the other hand, post-peak duration Dur2, as the second sub-component of the total duration of the pre-lateral vowel, refers to the temporal interval for coarticulation in which transition from the vowel [i] into its following /l/ takes place. Dur2 is expected to increase as /l/ becomes darker since more time is needed for coarticulatory gesture of velarization (Sproat and Fujimura 1993).

Under the inverse condition of these two parameters, we now turn to examination of the relationship between vowel duration and formant frequencies. Consider the following table, in which the values of (F2-F1) at the time of offset are given, in conjunction with Dur2.

Table 5. Post-peak Duration and Values of (F2-F1) at the Offset

		Dur2 (ms)	(F2-F1) (Hz)
Native	PP	82	601
	Ft-f	63	643
	Ft-m	75	601
	Avg	73	615
Korean	PP	113	751
	Ft-f	85	798
	Ft-m	82	869
	Avg	93	806

Dur2 was 20ms longer and (F2-F1) was 191Hz greater for the Korean speakers than the native speakers. Smaller values of (F2-F1) at the time of offset for the native speakers suggest that the word-final /l/ is darker by way of tongue body lowering and tongue dorsum retraction. Although the post-peak duration Dur2 is longer for the Korean speakers, their word-final /l/ is not as dark as the native speakers in terms of the values of (F2-F1). That is, for the Korean speakers neither is F1 raised nor is F2 lowered enough despite sufficient time allowed for velarization.

It is noteworthy that the value of (F2-F1) was 615Hz for the native speakers, while it was much higher for the Korean speakers. This is comparable to the results reported in Ahn (2015), where the value of (F2-F1) was 574Hz for the English /l/, while it ranged 1052Hz to 1387Hz for the Korean /l/. Relatively high (F2-F1) value of the English /l/ produced by the Korean speakers in this experiment appears to reflect the L1 interference of the high F2 values of the Korean /l/ (Park and Jang 2016).

Shown below is the scatter plot of (F2-F1) in relation to Dur2. Three target words are plotted for each prosodic context.

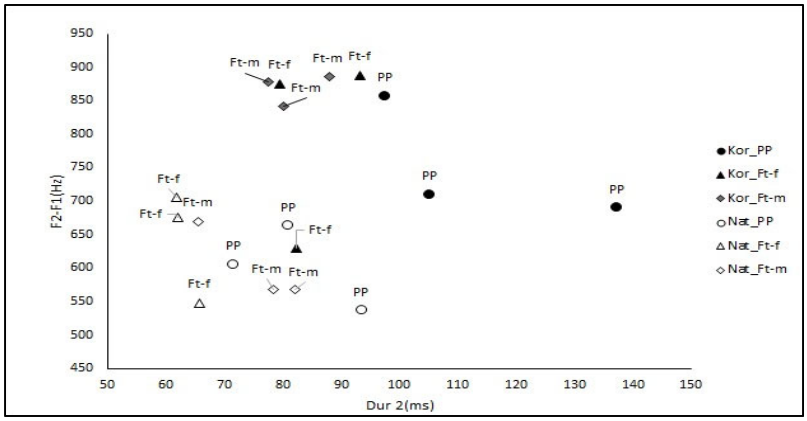


Figure 4. Dur2 and Values of (F2−F1) at the Offset

Values of (F2−F1) are smaller for the native speakers despite the relatively shorter Dur2. This indicates that word-final /l/ is more velarized for the native speakers than the Korean speakers. By contrast, the Korean speakers show greater values of (F2−F1), which are detrimental to implementation of darkness of /l/. Smaller values of (F2−F1) for the native speakers suggest that they had greater gestural movements of both tongue body lowering and tongue dorsum retraction. In order to implement darkness of /l/, the two parameters of Dur2 and values of (F2−F1) are expected to hold the inverse relation, namely that the longer the Dur2, the smaller the values of (F2−F1). This relation does not appear to be upheld across the two speaker groups. Within the group of Korean speakers, however, Dur2 is longer and values of (F2−F1) are smaller in PP compared with other prosodic contexts.

4. Discussion

4.1 Comparison of the Speaker Groups

The results in the present study show that a number of acoustic parameters are significantly different between the native and Korean speakers, hence representing different ways and degrees of velarization. In the table below, the acoustic measures are specified in terms of whether or not there is significant difference between the native and Korean speakers at the 0.05 level[2].

Table 6. Comparison of the Two Speaker Groups

Dur0, Dur1, Dur2	Nat<Kor
F1-ons, F2-off	Nat<Kor
F1-off, F2-ons	Nat=Kor
ΔF1, ΔF2	Nat>Kor
(F2-F1)	Nat<Kor

As for vowel duration, there was a significant difference between the native and Korean speakers in Dur1, the span for the primary articulation of the pre-lateral vowel /i/. Difference was also significant in Dur2, the interval in which gestural coarticulation is carried out to implement /l/ darkness. This naturally leads to a significant difference between the two speaker groups in total duration Dur0 as well.

Dur2 turned out to be longer for the Korean speakers than the native speakers. Following the duration-based hypothesis in Sproat and Fujimura (1993), this parameter alone makes the prediction that darkness of the word-final /l/ will be heavier for the Korean speakers since more time is allowed for greater gestural movement of tongue body lowering and tongue dorsum retraction. When the acoustic measures of formant frequencies are taken into consideration, however, the prediction proves to be no longer borne out as will be presently discussed.

There were significant differences between the two speaker groups in the acoustic measures of F1 at the time of onset and F2 at the time of offset; on the other hand, difference was not significant between the two speaker groups for F1 at the time of offset and F2 at the time of onset. Significant difference of F1 and non-significant difference of F2 values at the time of onset indicate that the two speaker groups had diverging points to which the tongue body was raised but similar target points to which it was fronted for the pre-lateral vowel /i/. On the other hand, non-significant difference of F1 and significant difference of F2 values at the time of offset indicate that in the wake of transitional gesture the target points to which the tongue body was lowered was similar, while the target points to which the tongue dorsum was retracted was not.

These results are also informative when the relation among acoustic parameters is derived. Lower F1-ons values or F2-off values as in the native speakers contribute to increasing the difference between the onset and offset values, namely ΔF1(off-ons)

[2] Dur0: p = .000 (N < K); Dur1: p = .030 (N < K); Dur2: p = .000 (N < K); F1 (ons): p = .000 (N < K); F1 (off): p = .072; F2 (ons): p = .659; F2 (off): p = .000 (N < K); ΔF1 (off-ons): p = .000 (N > K); ΔF2 (ons-off): p = .002 (N > K); (F2-F1): p = .000 (N < K)

and ΔF2(ons-off). Likewise, lower F2-off values also cause (F2-F1) values to decrease. Greater differences between the onset and offset values of formant frequencies and smaller values of (F2-F1) at the offset, as in the acoustic measures of the native speakers, conspire for implementation of heavier velarization of the word-final /l/.

Comparison of formant frequencies indicates that the native speakers make sufficient use of tongue body lowering and tongue dorsum retraction, while for the Korean speakers the degree of tongue body lowering is constrained due to insufficient raising at the onset, and the tongue dorsum is less retracted presumably due to limited use of the oral cavity[3]. For the native speakers, maximum raising and fronting of the tongue body at the onset leaves room for lowering and retraction in the wake of coarticulatory gesture for velarization. Note that darkness of the word-final /l/ was implemented by lowering the tongue body by 38% and retracting the tongue dorsum by 50% during the interval of post-peak duration Dur2. Values of ΔF1, ΔF2, and (F2-F1) indicate that despite shorter duration, the word-final /l/ is darker for the native speakers than the Korean speakers.

For the Korean speakers, by contrast, these acoustic parameters indicate that the word-final /l/ is not as dark as the native speakers. The extent of coarticulatory gesture turned out to be limited despite sufficient amount of time allowed for it. Values of F1 at the onset also suggest that sufficient room is not available for tongue body lowering since pre-lateral target [i] was reached with less raised gesture. Note that the tongue body was only lowered by 19%, while the tongue dorsum was retracted by 41%.

Comparison of the rates of ΔF1 and ΔF2 also reveals that the F2 decrease rate is higher than the F1 increase rate for both speaker groups. This suggests that tongue dorsum retraction plays a more crucial role than tongue body lowering in implementing the effect of velarization. This result, however, is not consistent with the previous studies, which reported that the primary determinant of the phonetic scale of darkness was the duration of the rime containing the /l/ (Sproat and Fujimura 1993), that the

[3] According to the formant analysis of English vowels produced by the Korean speakers (Sohn and Ahn 2009), high vowels are relatively lower and back vowels are pushed towards the center of the vowel space with respect to the F1 or F2 values. That is, high vowels are produced with relatively higher F1 values, while back vowels with relatively higher F2 values. As a result, English vowel space produced by the Korean speakers turned out to be skewed ranging from the bottom left corner to the central region. Similar tendency in production is also reported in Jang and Shin (2006).

strongest articulatory correlate of darkness was tongue body lowering (Hayes 2000), or that the continuum of darkness of /l/ was most consistently implemented articulatorily by tongue body lowering and acoustically by the F1 raising instead of the F2 lowering (Lee-Kim et al. 2013).

Unlike these findings, vowel duration did not function as a determinant of /l/ darkness for the Korean speakers, when compared with the native speakers. In addition, tongue body lowering did not emerge as a primary correlate of darkness in the native as well as the Korean speakers. The inconsistency seems to call for a more elaborate experiment, but it might be attributed to the high front vowel employed as a pre-lateral context: various contexts using low or back vowels were not tested in this study. It is speculated here that back vowels as pre-lateral contexts may cause tongue dorsum retraction to be more constrained and that as a consequence, tongue body lowering might have functioned as an alternative strategy to that effect.

The fact that darkness of the word-final /l/ is even less dependent on tongue body lowering for the Korean speakers has bearings on the articulatory characteristics of the Korean /l/. Unlike the English lateral where constriction is produced with the tongue blade in contact with the alveolar ridge (Stevens 1998), the Korean lateral is reported to be produced by constricting the palatal region (Oh and Gick 2002). This takes the tongue body to be raised and as a consequence, the tongue body is more resistant to retraction, as documented by MRI image of articulatory gesture (Lee et al. 2015, Lee-Kim et al. 2013). Since the tongue body is raised to constrict the palatal region for production of the Korean /l/, however, the Korean speakers might run into difficulty in lowering the tongue body as well. In this respect, the alternative strategy of over-reliance on tongue dorsum retraction to implement velarization of the word-final /l/ in English is motivated to be compensatory. Nevertheless, the F2 values of the English word-final /l/ produced by the Korean speakers are consistently reported to be higher than those produced by the native speakers (Ahn 2015, Kim et al. 2000, Park and Jang 2016), which is interpreted as a reflection of L1 interference on L2 production. In fact, it is reported in Kim and Rhee (2019) and Lee and Kim (2019) that the word-final lateral is even harder to produce than the central approximant [ɻ] in the onset for EFL Korean speakers. Given the acoustic results in the present study, this difficulty in L2 production is due to the higher F2 values of the word-final /l/ in L1 Korean, where velarized variant [ɬ] is absent[4].

[4] It is speculated here that the allophonic variant [ɬ] in English is produced by the Korean speakers with intrusive mid central vowel [ə] in the gestural transition between /i/ and the

4.2 The Prosodic Effect

In this study three prosodic contexts were postulated to examine the effect of prosodic strengthening in darkness of the word-final /l/. Following the previous studies, darkness of /l/ is expected to be heavier in PP than in Ft-final position (Ft-f), which in turn is expected to be heavier than Ft-medial position (Ft-m). Based on the acoustic measures in this study, we examine if darkness of the word-final /l/ is implemented in a gradient fashion by lengthening post-peak vowel duration or by F1 raising and F2 lowering depending on the prosodic contexts.

Shown in the following table is the effect of prosodic strengthening of a number of acoustic parameters in PP, Ft-f, and Ft-m contexts. In the table below, significant differences between the prosodic positions are represented at the 0.05 level.

Table 7. Prosodic Effects

	Native	Korean
Dur0	PP = Ft-m > Ft-f	PP > Ft-m = Ft-f
Dur1	none	none
Dur2	PP > Ft-f, PP = Ft-m, Ft-f = Ft-m	PP > Ft-m = Ft-f
F1-ons	none	none
F1-off	none	none
F2-ons	none	PP > Ft-f, PP = Ft-m, Ft-f = Ft-m
F2-off	none	none
ΔF1 (off-ons)	none	PP > Ft-f, PP = Ft-m, Ft-f = Ft-m
ΔF2 (ons-off)	PP > Ft-m, PP = Ft-f, Ft-f = Ft-m	PP > Ft-m = Ft-f
(F2-F1)	none	none

* "none" represents no significant differences among three prosodic positions.

The prosodic effect based on duration was partially observed. Pre-peak duration Dur1 showed no significant differences among the three prosodic positions. This seems to make sense since Dur1 is the interval designated primarily for the high front vowel /i/, while the coarticulatory gesture for velarization of /l/ is reflected in the post-peak duration Dur2. It showed significant difference between the PP and Ft-f positions, and so did total duration Dur0, in which Dur2 is contained. PP was significantly longer than Ft-f for both of the speaker groups. Ft-m banded together with PP for the native speakers, while it did with Ft-f for the Korean speakers. The prosodic effect based on

subsequent /l/ (e.g., *feel* [fiəɬ]). In this transition, dark /l/ is articulatorily implemented by the intrusive target of the mid central vowel, rather than by the dark variant [ɬ] per se, hence resulting in lesser degree of tongue body lowering and tongue dorsum retraction.

duration was observed between PP and the foot level. That is, more temporal span was allowed in PP compared with the foot level for coarticulatory gesture of velarization.

We now turn to formant frequencies. The native speakers showed no significant differences across the prosodic positions with respect to the measures of F1 and F2 at the time of the onset as well as the offset. Nor was there any prosodic effect with respect to the derivatives such as ΔF1 (off-ons) and (F2-F1) at the offset. The effect was limited to ΔF2 (ons-off) between the PP and Ft-m positions. For the Korean speakers, the prosodic effect was observed between PP and Ft-f with respect to the derivatives such as ΔF1 (off-ons) and ΔF2 (ons-off), in addition to the measure of F2 at the time of onset. These results suggest that darkness of the word-final /l/ was implemented by way of greater tongue dorsum retraction in PP for the Korean speakers as well as the native speakers. In addition, for the Korean speakers tongue body lowering also played an important role for the prosodic strengthening in PP relative to Ft-f.

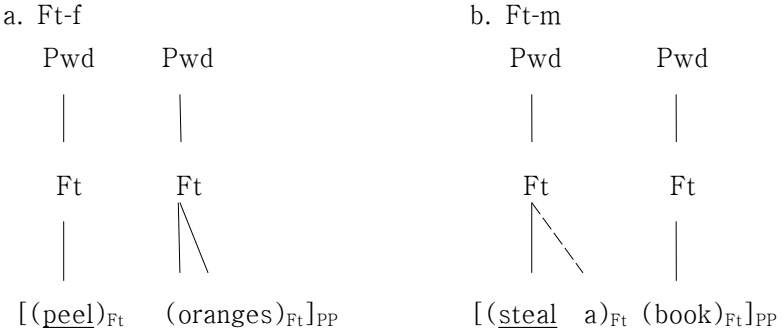
It is noteworthy here that despite lack of strong prosodic effects in formant frequencies across the prosodic positions, incremental steps were observed between PP and the foot level. Specifically, both values of ΔF1 (off-ons) or ΔF2 (ons-off) on the one hand and values of ΔDur on the other ratchet up as the prosodic position gets higher, with peak values in PP (cf. Table 1 and 4). This suggests that higher rates of F1 increase and F2 decrease are made possible by sufficient time allowed for the articulatory gesture. This account then lends supporting evidence to the claim that articulatory undershoot is motivated by insufficient time allotted for the gesture (Sproat and Fujimura 1993).

With respect to cumulative strengthening as one of essential properties of prosodic phonology, there is a residual problem to be addressed. Unlike the general prediction in prosodic phonology, no case was observed where values of duration or formant frequency were more cumulative in Ft-f than Ft-m. For reasons that are not clear for now, the foot-final context did not play a stronger position than the foot-medial one. In most of the acoustic parameters, Ft-m was reported to be stronger than Ft-f in terms of the raw values: post-peak duration, formant frequencies, and other parameters derived from the acoustic measures turned out to be greater in Ft-m than Ft-f, if not statistically different.

The effect of prosodic strengthening is primarily observed in the edges of the prosodic hierarchy with cumulative increments in phonetic implementation. In this

respect, two levels of foot may not be distinct with each other. However, the motivation for postulating two levels of Ft-f and Ft-m in this experiment lied in the possibility of foot-internal resyllabification in English, as represented in (2). In (2) the verb as well as the object projects its own foot and subsequently Pwd. The stranded indefinite article in (2b) is adjoined to the left, hence forming a single foot with the preceding verb:

(2) Foot-internal resyllabification



The word-final /l/ in (2a) is crisply aligned with the right edge of foot, while in (2b) it is a weak vowel to the left of the right edge of foot. Despite the one-vowel distance away from the edge, the word-final /l/ is velarized into [ɬ] foot-internally, because of the paradigmatic relation with its stem form *steal* (Hayes 2000)[5].

At the same time, it can also be resyllabified as the onset of the following syllable within the same foot (Nespor and Vogel 1986), and as a consequence, the dark [ɬ] becomes ambisyllabic within the foot. This puts the pre-lateral vowel in open syllable, which in turn contributes to lengthening it. For this reason, vowel duration is expected to be longer or more cumulative in Ft-m than in Ft-f, and as a consequence, so are other acoustic parameters motivated by vowel duration. Similar accounts might be extended to explain why foot-medial /l/ is no less dark than its foot-final counterpart. The rest of the issues on the anomaly of cumulative values for the Ft-m position we leave behind for future research.

To summarize, prosodic strengthening was partially observed between PP and the foot level for both speaker groups, with no foot-internal distinction. Within each

[5] Hayes claims that [l] in *feeling* is resyllabified as onset and yet it is realized as a dark [ɬ]. This is also due to the output-to-output correspondence between the stem and its affixed form (Benua 1995).

speaker group post-peak duration and the F2 decrease rate cumulatively increased in PP compared with the foot level. For the Korean speakers the F1 increase rate also participated in prosodic strengthening in PP. These results indicate that darkness of /l/ is primarily determined by post-peak duration and tongue dorsum retraction. For the Korean speakers, tongue body lowering is also an important factor in the prosodic effect. Prosodic effects on acoustic measures further lend supporting evidence to the claim that darkness of /l/ is not categorical but gradient on a phonetic continuum (Lee-Kim et al. 2015, Sproat and Fujimura 1993, Turton 2017). Within each speaker group, gradient implementation of /l/ darkness is based on post-peak duration, and in this respect, the lesser degree of tongue dorsum retraction or tongue body lowering in the foot level is attributed to the articulatory undershoot effect.

5. Conclusion

This study investigated the way in which darkness of the word-final /l/ is implemented in two speaker groups across three prosodic contexts, by measuring the acoustic parameters of pre-lateral vowel duration and formant frequencies at the time of onset and offset of post-peak duration.

Total duration Dur0 and its sub-components Dur1 and Dur2 were longer for the Korean speakers than the native speakers. The increase rate of Dur2 over Dur1 was also higher for the Korean speakers than the native speakers. The fact that Dur2 was longer than Dur1 for both speaker groups indicates that more time was allowed to implement the coarticulatory gesture for velarization.

Despite more time allotted for the coarticulatory gesture, the Korean speakers failed to show higher rates of the F1 increase and F2 decrease, which function as acoustic correlates of tongue body lowering and tongue dorsum retraction. In addition, values of (F2-F1) also as an acoustic correlate of /l/ darkness were smaller for the native speakers despite relatively shorter vowel duration. These results on formant frequencies uniformly point to implementation of darker /l/ for the native speakers compared with the Korean speakers.

Comparison of the rates of the F1 increase and F2 decrease reveals that both speaker groups were more dependent on tongue dorsum retraction than tongue body lowering to implement /l/ darkness. This asymmetry is particularly characteristic of the Korean speakers as indicated by their distinctly lower rate of the F1 increase. The

skewed representation of the F1 increase rate is interpreted as L1 interference of the articulatory property of the Korean lateral, namely that tongue body is raised to the palatal region for constriction of the Korean lateral, which in turn makes tongue body to be more resistant to lowering.

As acoustic correlates of /l/ darkness, vowel duration and formant frequencies did not prove to be consistent with each other across the two speaker groups: the native speakers implemented darker /l/ despite shorter vowel duration compared with the Korean speakers. Within each speaker group, however, post-peak duration and the F2 decrease rate cumulatively increased in PP compared with the foot positions. For the Korean speakers the F1 increase rate also participated in prosodic strengthening in PP.

The prosodic effect between PP and the foot level with respect to post-peak vowel duration and derivatives such as ΔF1 (off-ons) and ΔF2 (ons-off) suggests that higher rates of F1 increase and F2 decrease are based on sufficient time allowed for the coarticulatory gesture. In other words, less dark implementation of word-final /l/ in lower prosodic hierarchy is accounted for by the articulatory undershoot effect. Unlike the relation between duration and formant frequencies across the speaker groups, each of these two acoustic parameters turned out to be cumulative and consistent with each other within the speaker group. Prosodic strengthening in PP relative to the foot level in each speaker group further leads to the claim that darkness of word-final /l/ in English is gradient on a phonetic continuum.

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Examples in: English
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