An Acoustic Study of the Word-final Lateral Approximant in Korea*

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Ahn, Miyeon. (2017). An Acoustic Study of the Word-final Lateral Approximant in Korean. ***Language Research*****, 53.2, 231-245.**

The phonological representation of the Korean lateral has been widely discussed while less attention has been paid to the phonetic realizations of the sound. In the present study, we examine the static and dynamic properties of the Korean lateral from a production study and we measure the duration, the three formants and the time-normalized trajectories. Based on the results of a production study, it was found that (i) the duration of the lateral approximant in Korean is constant irrespective of the preceding vowel contexts, that (ii) the three formants of the lateral are severely influenced by the preceding contexts, and that (iii) the initial part of the lateral articulation share similar acoustic properties with the preceding vowels, but as the articulation continues, it becomes unaffected by the vowels.

Keywords: lateral approximant /l/, Korean, contexts, acoustic properties

1. Introduction

The phonological nature of lateral approximant /l/ in Korean has been widely discussed. Phonologically, it is known that Korean has one liquid sound /l/ which, phonetically, either remains as a lateral [l] or alters to a non-lateral [ɾ] (Shin 2015). This devious variety is suggested to depend on where the sounds appear within a syllable. In other words, in Korean [l] and [ɾ] phonologically alternates and this allophonic alternation is real-

* This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2015S1A5B5A07042930).

ized as [ɾ] when /l/ appears as an onset but [l] when it emerges as a coda.

It is often said that Korean has a phonotactic constraint which says a lateral is not allowed in the syllable onset (Iverson & Kim 1987; Suh 1993; Yoo 1996). The underlying representation of the allophonic variation was considered as a lateral in Kim-Renaud (1991) yet a flap in Kim (1971). A large number of previous studies have suggested that the underlying representation is /L/ in which the place is unspecified (Iverson & Sohn 1994; Iverson & Lee 2006; Kang 2003, 2011).

These two arguments — the place being unspecified and the phonotactic constraint of the lateral being against on syllable initial — may be supported by some of Sino-Korean words. For example, some of these words that have /l/ in the word initial position show a systematic against-lateral strategy either the deletion (i.e., /l/ à [Ø]) as in /lipalso/ to [ipalso] *'a barber shop'* or the replacement to another sound /n/ (i.e., /l/ à [n]) as in /lotong/ to [notong] *'labor'*. The lateral is realized as it is only when the /l/ is on the onset which is preceded by another lateral (i.e., /ll/) as in /tallita/ *'to run'* or /kullita/ *'to roll'* and when it appears as a coda /il/ *'one'* or /kal/ *'a knife'*. Intervocalically, on the other hand, the lateral becomes a flap as in /pali/ à [paɾi] *'a fly'*, /palam/ à [paɾam] *'wind'* which is another way of avoiding the lateral syllable-initially. From these examples, it can be inferred that the Korean lateral is realized as a single sound only when it is placed in the word-final position.

The phonetic realization of the Korean lateral has been largely discussed from the loanword adaptation point of view (e.g., *'online'* to [ollain]) or the assimilation process of consonant clusters including /l/ (e.g., /sʌpli/ *'providence'* to [sʌmni]). Also, in terms of articulatory study, there have been only a couple of them to examine the articulatory properties of the Korean lateral. With the ultrasound study of the Korean lateral, Oh & Gick (2002) argued that the Korean lateral involves the tongue body constricting the palatal region (Oh 2002; Gick *et al.* 2006). An MRI image also suggested the tongue body is raised in the production of the Korean lateral instead of being retracted (Lee *et al.* 2015).

To date, little discussion has been provided with regard to the acoustic properties of the Korean lateral approximant /l/. Most of the studies examining the acoustic realization were focused on stops and affricates that have three-way distinctions depending on phonation types (Lisker & Abramson 1964; Dart 1987; Shin 1997; Cho *et al.* 2002 among others). Few studies have addressed the phonetic measurements of Korean sonorants. Notably, Kim & Lotto (2004) examined the spectral properties of Korean approximants in which the spectral properties of [l], [ɾ], [w] and [j] were measured. Since the focus of the study was to compare the first two formants, the study provides the mean of F1 and F2 values and no other acoustic properties.In the study of Lee & Kang (2003), the acoustic properties of intervocalic laterals were examined. Thus, it remains unclear whether the Korean word-final lateral has any other kinds of acoustic characteristics.

In this production study, we examine the static and dynamic properties of Korean word-final lateral. By acoustically measuring the temporal duration and acoustic changes over time, we learn the detailed acoustic properties of Korean lateral. This production experiment is a preliminary study of examining the properties of Korean. At the end of this study, we compare the acoustic properties of Korean lateral to those of other languages in terms of being dark or clear.

2. Methods

The present study is aiming at providing the thorough investigation of the Korean lateral approximant. In order to achieve the goal, we designed a production study by varying the factors that are likely to affect the acoustic properties of the lateral approximant /l/. The factors include the coarticulatory effect and lexicality (Ganong 1980). While the coarticulatory effect refers to the spectral influence from neighboring sounds, lexicality is about whether a speaker or a listener perceive the speech material as a word or a non-word. Since it is commonly found that language

users plan their speech differently depending on lexicality (Krishnan *et al.* 2013; Lange-Küttner *et al.* 2013), lexicality may affect the acoustic realization of Korean word-final lateral.

In order to incorporate these two possible effects, the vowels that preceded the lateral (i.e., the pre-lateral vowels) were varied and the laterals were embedded in both words and non-words contexts.

2.1. Speakers

For the production study, six native speakers of Korean were recruited. Both genders were equally distributed and all of them were on their 20s. All participants spoke Seoul dialect and were recruited around the Seoul National University campus. They voluntarily participated in the experiment, and they were paid for their participation. No problems regarding communication were reported.

2.2. Stimulus materials

The stimuli included 60 words in total of which 30 were real Korean words while the other 30 were non-words as in Table 1. In order to explore any potential effects of lexical status, words and non-words were compared. Real words that were very high frequent or low frequent were excluded. All the words had the (C)V_1.CV_2L syllable structure. Note that the lateral is fixed on the word-final position because, as discussed in the previous section, the singleton lateral approximant appears only on the syllable final position in Korean. The immediately preceding vowels of the lateral (i.e., V_2) were varied by selecting one of the following ones /i, a, o, u, ʌ/. Various vowels were adopted for the stimuli in order to investigate whether there is any local coarticulatory effects found and whether any acoustic correlations observed between the preceding vowels and the following lateral consonant. The 60 target words were embedded in a carrier sentence, "천천히 _____ 따라하세요" (*Slowly repeat* ____) so that natural utterances were collected.

Table 1. Wordlist for the Korean Llateral Approximant /l/

	Pre-lateral vowels				
	i_	a_	o_	u_	ʌ_
Word	비닐 [pinil]	배달 [pætal]	사골 [sakol]	사물 [samul]	소설 [sosʌl]
	유실 [jusil]	이탈 [it^{h}al]	차돌 [c^{h}atol]	주술 [cusul]	구걸 [kukʌl]
	수필 [sup^{h}il]	사발 [sapal]	조촐 [coc^{h}ol]	채굴 [c^{h}ækul]	투덜 [t^{h}utʌl]
	사실 [sasil]	자갈 [cakal]	매몰 [mæmol]	보풀 [pop^{h}ul]	사절 [sacʌl]
	기질 [kicil]	서찰 [sʌc^{h}al]	포졸 [p^{h}ocol]	이불 [ipul]	개설 [kæsʌl]
	차질 [c^{h}acil]	파발 [p^{h}aal]	치졸 [c^{h}icol]	배출 [pæc^{h}ul]	재벌 [cæpʌl]
Non-word	티실 [t^{h}ʌsil]	하발 [hapal]	구볼 [kupol]	가굴 [kakul]	도걸 [tokʌl]
	다길 [takil]	고날 [konal]	다촐 [tac^{h}ol]	고풀 [kop^{h}ul]	다덜 [tatʌl]
	사닐 [sanil]	무달 [mutal]	미놀 [minol]	서줄 [sʌcul]	머걸 [mʌkʌl]
	세질 [secil]	다갈 [takal]	지돌 [citol]	소둘 [sotul]	마절 [macʌl]
	나칠 [nac^{h}il]	누말 [numal]	채볼 [c^{h}æpol]	재둘 [cætul]	바벌 [papʌl]
	투질 [t^{h}ucil]	토살 [t^{h}osal]	티골 [t^{h}ikol]	추술 [c^{h}usul]	터설 [t^{h}ʌsʌl]

2.3. Recordings

The speakers were recorded at the XX University in which recording facilities are ready in a sound-attenuated booth. A software *Praat* and the cardioid microphone (ATR3035) were used. The speakers read randomly given sentences five times and their recordings were collected in a computer with the 44.1 kHz sampling rate.

2.4. Acoustic measurements

It has been suggested that, in English, the lateral approximant [l] share similar acoustic properties with nasals (Reetz & Jongman 2009). In terms of the spectra characteristics, while nasal sounds are characterized by nasal murmur which is resulted by a complete oral airflow constriction, laterals have a steady formant portion which is a consequence of static state during the articulation of the lateral.

Concerning these acoustic consequences, we measured both the temporal and spectral cues of the lateral approximant. The properties considered in this work were the lateral duration, the three formants (F1, F2 and F3) and their normalized time trajectories, which were commonly examined acoustic propertieswhen discussing lateral characteristics (Lee & Kang

2003; Ahn 2016; Park & Jang 2016). We consider whether the formants demonstrate any changes over time by examining the trajectory of the formants. Time-normalized trajectories were calculated over 20 equidistance data point over the whole lateral articulation (Xu 2007). We also consider whether these properties vary depending on the preceding vowels and the lexical status of the words.

All measurements were made using *Praat*. We first extracted the individual words that involve the target sound laterals out of the carrier sentences by trimming off the initial and the final words. From the extracted words, lateral segmentation was made by the simultaneous observation of waveform and spectrogram (Jongman *et al.* 1998). The sound files with the segmentation labeled were then processed with a script wherein the acoustic measurements such as the duration and the three formants were automatically collected.

According to Pickett (1985; recited from Seong (2004, 2005)), the vocal tract of male speakers is about 15% longer than that of female speakers, which results in the increase of formant values; thus, female speakers' formants can be normalized by multiplying 5/6 (around 0.83) to male speakers' values. Based on the gender difference, 0.83 was multiplied to the automatically collected female formants.

3. Results

3.1. Duration

Table 2 shows mean duration of the lateral approximant in according to the preceding contexts and the lexical status. The duration of the word-final lateral in Korean was around 100 ms, which is averaged across all speakers and factors.

Table 2. Mean Duration of Korean Lateral Approximant /l/ as a Function of Lexicality and Pre-lateral Vowels (Data Represent Mean ±sd, (n=180).)

(in ms)	Pre-lateral vowels				
	i_	a_	o_	u_	ʌ_
Word	102 (±25)	101 (±35)	99 (±36)	96 (±28)	102 (±25)
Non-word	103 (±27)	100 (±28)	100 (±29)	94 (±25)	104 (±27)

A mixed repeated measure ANOVA was conducted on the lateral duration with the lexical status and the pre-lateral vowels as between-subject factors and the five repetition as a within-subject factor. The analysis showed the pre-lateral vowels [$F(4, 1796) = 0.167$, $p = 0.95$] and the lexical status [$F(1, 1796) = 2.87$, $p = 0.1$] did not affect the duration of laterals. As described in the table, the duration of the lateral was comparatively consistent throughout the phonological contexts. In other words, the duration of the lateral was moderately uniform irrespective of the preceding vowels. Lexical effect was found to be insignificant as well. Without reference to the lexical status, that is, whether the target lateral sound was embedded in a word or a non-word, the duration of the lateral approximant was regularly maintained. Thus, it could be said that Korean speakers rather regularly produce the duration of the lateral regardless of the preceding context or the status of the word.

3.2. The three formants

Table 3 describes three values of mean, minimum and maximum frequencies of the first three formants, F1, F2 and F3. The values were averaged over the preceding vowel contexts and the lexical status. Across the two factors, the frequencies were 470 Hz, 1638 Hz and 2413 Hz, respectively. A mixed repeated measure ANOVA was performed on the mean of each formant with the pre-liquid vowels and the lexicality considering as between subject variables. The statistical analysis showed that the three formants, F1, F2 and F3, were significantly affected by the preceding vowels [F1, $F(4, 1796) = 143.4$, $p < 0.05$], [F2, $F(4, 1796) = 68.268$, $p < 0.05$], [F3, $F(4, 1796) = 13.179$, $p < 0.05$] but not by lexical status [F1, $F(1, 1796) = 1.421$, $p = 0.23$], [F2, $F(1, 1796) = 0.027$, $p = 0.87$], [F3, $F(1, 1796) = 0.406$, $p = 0.52$].

Table 3. Mean, minimum and maximum F1, F2 and F3 for the Korean lateral approximant /l/ as a function of the pre-lateral vowels and lexicality (Data represent mean ±sd, (n=180).)

(in Hz)		Pre-lateral vowels				
		i_Mean (Min~Max)	a_Mean (Min~Max)	o_Mean (Min~Max)	u_Mean (Min~Max)	ʌ_ Mean (Min~Max)
F1	Word	388 (±51) (327~421)	500 (±68) (375~604)	406 (±54) (332~454)	399 (±63) (323~441)	457 (±62) (364~534)
	Non-word	391 (±48) (328~422)	500 (±67) (359~615)	400 (±51) (330~435)	385 (±55) (315~431)	444 (±68) (343~521)
F2	Word	1650 (±176) (1545~1763)	1517 (±170) (1370~1665)	1359 (±97) (1219~1513)	1471 (±101) (1360~1577)	1459 (±88) (1342~1565)
	Non-word	1619 (±192) (1516~1741)	1543 (±144) (1400~1691)	1355 (±112) (1184~1525)	1456 (±95) (1360~1558)	1472 (±95) (1350~1585)
F3	Word	2326 (±231) (2180~2517)	2181 (±228) (2018~2424)	2130 (±185) (1995~2369)	2222 (±172) (2065~2479)	2148 (±179) (2010~2354)
	Non-word	2292 (±254) (2152~2493)	2202 (±219) (2044~2410)	2136 (±179) (2018~2384)	2179 (±193) (2025~2463)	2152 (±188) (2018~2365)

Figure 1. describes mean of F1, F2 and F3 with regard to the pre-lateral vowel contexts and lexicality (W for words, N for non-words, respectively). As the statistical analysis revealed, mean values of F1, F2 and F3 varied depending on the preceding vowels but not on the lexicality.

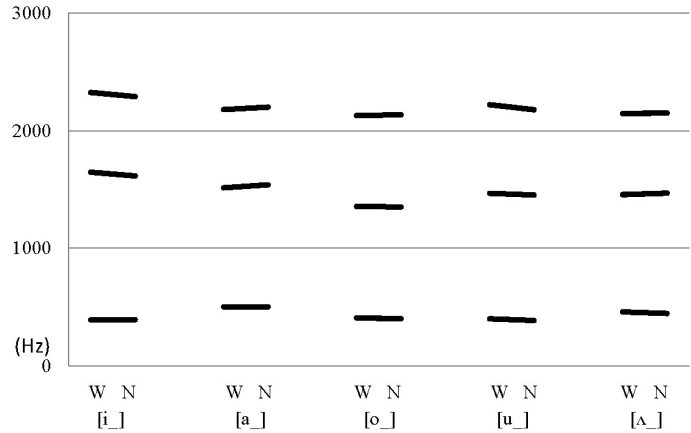

Figure 1. F1, F2 and F3 as a function of the pre-lateral vowels.

The frequencies of the first three formants, F1, F2 and F3 are determined by the articulatory gestures: F1 has to do with the height of the tongue body and F2 with the backness while F3 is relevant to the constriction location being front or back. When articulating the word-final lateral approximant /l/ in Korean, the tongue tip is toward the alveolar ridge by constricting the airflow through the center of oral cavity (Shin 2004). Since the articulatory movement of the lateral approximant differs from those of vowels, the lateral demonstrates its own formant frequencies.

As suggested above, however, the formant frequencies are considerably influenced by the preceding vowels showing the coarticulatory effect. It can be easily understood that the beginning part of the lateral approximant is affected more remarkably and, as the lateral articulation becomes away from the vowel, the effect fade away. In order to consider this dynamic change of the lateral approximant, we examined the time-normalized trajectories of the formant frequencies. The trajectory method is based on Xu (2007) in which 20 equidistance points were collected from every /l/ interval regardless of the duration. This time-normalized method allows graphical comparisons of the 20 points and visually provides the formant changes over time as in Figure 2.

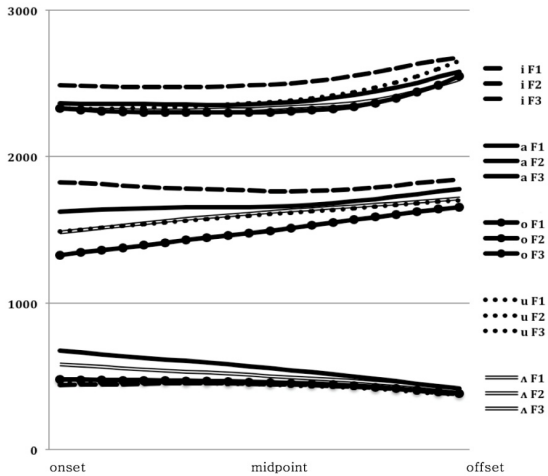

Figure 2. Trajectories of the three formants of Korean lateral /l/ after [i_], [a_], [o_], [u_] and [ʌ_] vowels.

The time-normalized trajectories of the three formants show that the formant frequencies continue changing over time from the onset to the offset of the lateral approximant. With respect to these frequency trajectories, at least two things should be noticed. On the one hand, the formant frequencies of the initial part (i.e., onset) of the lateral approximants vary and this variation is based on the formant frequencies of the preceding vowels. For instance, the broken line indicates the formant trajectories of the lateral after the [i_] vowel context. The frequencies of the first two formants of the [i] vowel are typically around 280 Hz and 2250 Hz, which display the lowest F1 and the highest F2 among the five vowels in our experiment. When the lateral approximant is articulated, the onset of the lateral is severely influenced by the preceding vowel. Because the F1 and F2 are high in the [i_] context (around 299 Hz and 2447 Hz respectively, Yang, 1996), the initial part of the lateral also displays high F1 and F2 when they appear right after the [i_] vowel. According to Yang (1996), F1 and F2values of [a_] are 857 Hz and 1560 Hz, those of [o_] are 434 Hz and 895 Hz. For the vowel [u_], F1 and F2 were 367 Hz and 888 Hz and the vowel [ʌ_] have 665 Hz and 1192 Hz, respectively.

The typical carryover effect of the preceding vowel is known as coarticulation. Because of this coarticulated gestures, the initial portion of the lateral is obviously similar to the preceding vowel [i_] and shares similar acoustic properties.As the gestures of the lateral proceed, the formants are less affected by the preceding vowels showing the inherent properties of the lateral itself.[1)]

On the other hand, the formant frequencies of the final part (i.e., offset) of the lateral show that the differences among the vowels are no longer present. That is, contrary to the initial part of the lateral which is greatly coarticulated with the preceding vowels, as the lateral articulation continues, it becomes unaffected by the vowels. Being away from the vowels, the sound is more like the plain lateral. As demonstrated in Figure 2, each frequency of the first three formants converges upon three respective data points.

4. Discussion & Conclusion

In this study, we examined the acoustic properties of Korean lateral and the coarticulatory effect of the preceding vowels. It was found that at the beginning of the lateral articulation, the coarticulatory effect was most severe and as the lateral proceeds, the effect fades away.

English word-final laterals often contain low intensity compared to the ones that appear word-initially. In the beginning of a word, laterals experience abrupt intensity change, which is one of the characteristic of laterals (Ladefoged 2005). This abrupt change, however, is not found in word-final laterals. A final lateral is articulated with low intensity, which results from little or no central airflow constriction of the tongue body. To some extent, this less contact of the tongue body toward the alveolar ridge results in reduced gestures and the lateral becomes weaken to a back

1) One of the reviewers pointed out that, the coarticulation effect at the end of the articulation of the lateral may decrease not because the lateral is away from the preceding vowel but because the following consonant is fixed as one consonant, [t] in the carrier sentence. The offset gesture of the lateral and the effect from the following consonant may be examined further by varying the carrier sentence such as 천천히 ___ 반복하세요 or 천천히 ___ 같이 말하세요.

rounded vowel (Ladefoged 2005: 196).

When the lateral /l/ is reduced, it normally shares articulatory gesture with back vowels (Sproat & Fujimura 1993). It has not been clear whether Korean word-final lateral is also weakened, however, from Figure 2, it is clear that the three formant frequencies of the Korean lateral approximant are most similar to the [u] vowel. The lateral trajectories of [i_] and [a_] indicate sharp changes from the onset to the offset of the lateral while those of [u_] show relatively constant and steady state for the same extent.

According to Sato *et al.* (2003) and Espy-Wilson (1992), the second formant of English /l/ normally ranges 980~1350 Hz (Kim & Lotto, ms.) and this value is lower than that of Korean /l/. According to the experiment result of this study, the value is in the range of 1476~1820 Hz, although it varies greatly depending on the preceding vowel context. As noted in Kim & Lotto (ms.), the F2 values of Korean lateral approximant is more similar to those of English [r] which ranges around 1900~ 2250 Hz.

It is widely known that the English lateral involves allophonic distribution of clear [l] vs. velarized (dark) [l]. This allophonic distribution depends on their appearance within syllables. English word final /l/s are mostly velarized. As for the intensity, on the other hand, this velarization of the English lateral [l] is a kind of weakening process of a sound containing low energy. When the lateral is not velarized by appearing as an onset of a syllable, it contains relatively high energy and marked as a dark color in a spectrogram. Thus, it can be said that the English laterals are asymmetric depending on where they appear.

When English lateral appears at the end of a word, its F2 values are known to be around 1000 Hz. The typically low F2 values of English represent the darkness of the lateral. The lateral from another language, French, for instance, locates its F2 values around 1500~2000 Hz, which is similar to the F2 values of Korean lateral. In this respect, the spectral properties, F2 in particular, of Korean lateral is close to French (Ahn, 2016), which represents the clearness of the lateral.

In the study of Park & Jang (2016), English learners whose native language is Korean showed their mispronunciation of English lateral. Since Korean lateral has high F2 and lower F3, the L1 interference is found in their production of English lateral.

The darkness — or, phonologically, the velarization — of the lateral is often characterized by the low F2 value. Recently, several experiment results indicate that the difference between F2 and F1 (i.e., F2-F1) should be considered to examine being dark vs. clear. According to this argument, the F2-F1 value of English laterals is around 574 Hz (Ahn 2015) and that of Korean lateral is 1052~1382 Hz from Table 3, which still shows Korean lateral is rather clear than English one. The implication of the two acoustic properties (i.e., F2-F1 vs. F2 only) should be discussed further in the future study.

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Received: February 20, 2017
Revised version received: July 22, 2017
Accepted: July 24, 2017