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LT4223 Experimental Phonetics
Written Report

An acoustic analysis of the Korean plosives produced by native
speakers

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1. Introduction

Voice Onset Time (VOT) is defined as “the time interval between the burst that marks release of the stop closure and the onset of quasi-periodicity which reflects laryngeal vibration” in Lisker and Abramson (1964). The authors also claimed that VOT is an effective factor in distinction of the different phonation categories, for instance voiceless and voiced. VOT has been commonly used to describe and differentiate plosive consonant categories. In English and Cantonese, there is a two-way contrast in the word-initial plosives, with one group of plosives produced with aspiration and a long VOT and the other group of plosives produced with no aspiration and a short VOT. As for Korean, it has a three-way contrast in the phonation of the word-initial plosives, including the lax (lenis), tense (fortis), and aspirated plosives (Brown and Yeon, 2015). Each of the three types of plosives in Korean can be produced with three different places of articulation, and hence there are in total nine types of plosives in Korean. As presented in Table 1, the Korean plosives include three bilabial plosives, the lax [p], tense [p’], and aspirated [p^h]; three alveolar plosives, the lax [t], tense [t’], and aspirated [t^h]; and three velar plosives, the lax [k], tense [k’], and aspirated [k^h].

Table 1. The nine types of plosives in Korean.

Phonation \ Place	Bilabial	Alveolar	Velar
Lax	p (ㅍ)	t (ㅌ)	k (ㄱ)
Tense	p’ (ㅍㅍ)	t’ (ㅌㅌ)	k’ (ㄱㄱ)
Aspirated	p ^h (ㅍᄉ)	t ^h (ㅌᄉ)	k ^h (ㄱᄉ)

2. Purpose of study

This study aims to investigate the differences in VOT among the Korean lax, tense, and aspirated word-initial plosives in all the three place categories, including the bilabial [p p’ p^h], alveolar [t t’ t^h], and velar [k k’ k^h]. The study also examines the influence of the different types of word-initial plosives on the F₀ and intensity of the following vowel. The collected data are used to determine the distinctive acoustic features for the different types of plosives in Korean. The information can enable second language learners to have a better understanding of the pronunciation of Korean plosives.

3. Methodology

3.1 Participants

Four native speakers of Korean between the ages of 18 to 25 years participated in an individual audio recording to provide speech samples for this study. All the participants were college students. They were born and grew up in Korea, and none of them had a marked regional accent. The participants consisted of two males and two females.

3.2 Materials used for recording

Table 2 presents the 18 Korean words selected as the test materials for the study. All the test words are meaningful and commonly used by Korean speakers in daily communication. As shown in Table 2, each test word begins with one of the nine target plosive consonants [p p’ p^h, t t’ t^h, k k’ k^h] followed by a low front vowel [a] (ㅏ) or high front vowel [i] (ㅣ). The

test words are in monosyllabic or polysyllabic structure, where the initial syllable containing a target plosive is always an open type without a final consonant, in order to prevent from other factors in the level of the F_0 and intensity of the vowel after the word-initial plosive. All the test words were only presented in the written form of Korean, without the IPA transcription and gloss, on a randomized list for eliciting speech samples from the speakers.

Table 2. 18 Korean test words used for the investigation.

Test words	IPA	Gloss	Test words	IPA	Gloss
비다	[pida]	be empty	마	[pa]	method
삔다	[p'ida]	to sprain	빠르다	[p'aruɔda]	fast
피다	[p ^h ida]	to bloom	파	[p ^h a]	green onion
디자인	[tidzain]	design	다	[ta]	all
띠	[t'i]	belt	따다	[t'ada]	to pick
티	[t ^h i]	trace	타다	[t ^h ada]	to ride
기	[ki]	spirit	가방	[kabaŋ]	bag
끼	[k'i]	talent	까	[k'a]	to peel
키	[k ^h i]	height	카드	[k ^h adi]	card

3.3 Procedure

The audio recordings took place in the sound-proof booth of the Phonetics Lab at the City University of Hong Kong. During the recording, the speakers were asked to read aloud the test words on the list at a normal speech rate and at a normal level of loudness. Three repetitions of the word list were digitally recorded from each speaker. The speech samples were saved in WAV format for subsequent acoustic analysis.

3.4 Data analysis

Acoustic measurements of the speech samples were made using the speech analysis software Praat (version 6.0.31). Following the method used in Lisker and Abramson (1964), VOT of a word-initial plosive was measured as the time between the spike of the release burst and the onset of voicing. Figure 1 shows an example of VOT measurement for the word-initial aspirated plosive [k^h] in the test word [k^hi] (키). The mean VOT value of each plosive in the three tokens of each test word was calculated. The VOT values of the different types of plosives were then compared for determining the differences among the plosives (i) with the three phonation types categorized as lax, tense, and aspirated, (ii) in the three place categories as bilabial, alveolar, and velar, and (iii) in the two vowel contexts followed by [i] and [a].

Fundamental frequency (F_0) and intensity of the vowel following the word-initial plosive in the test words were also measured, based on the first regular glottal pulse of the vowel. Figure 2 shows an example of F_0 and intensity measurements for the vowel [a] in the test word [t'ada] (따다) based on the first glottal pulse of the vowel. The mean values of F_0 and intensity of each type of vowel in the three tokens of each test word were obtained and used for determining the effect of the lax, tense, and aspirated phonation types of the word-initial plosives on the following vowel.

Figure 1. Example of VOT measurement for the plosive [k^h] in the test word [k^hi] (ㄱ/) using Praat.

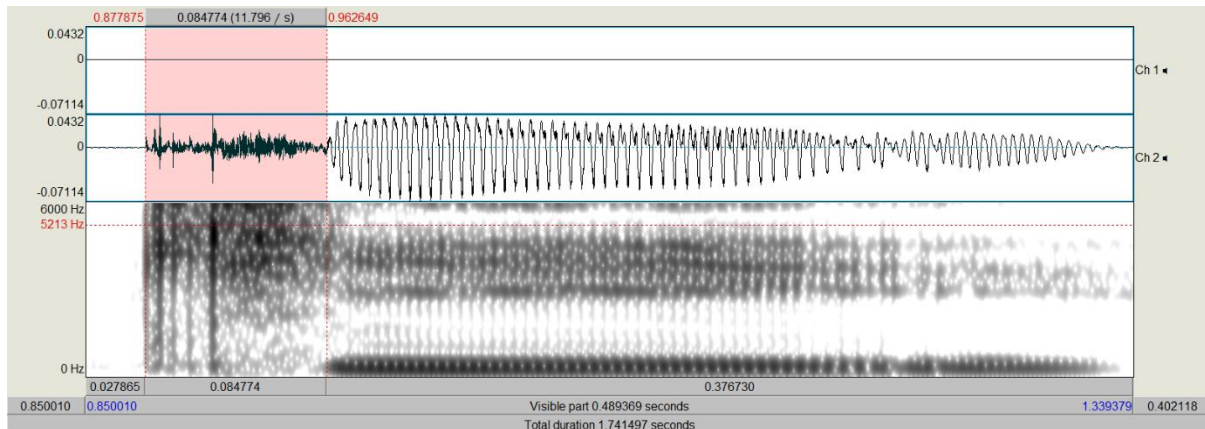
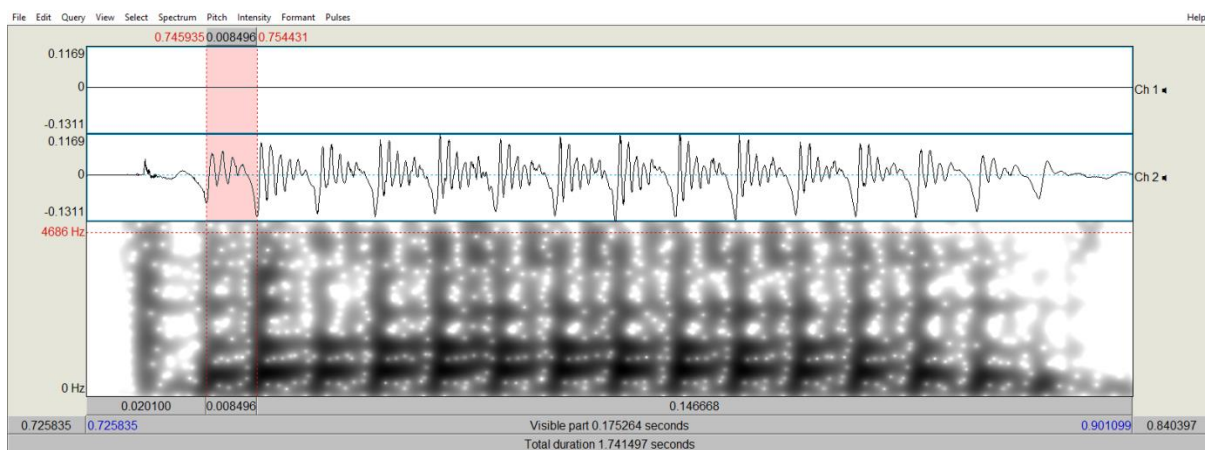


Figure 2. Example of F₀ and intensity measurements for the vowel [a] in the test word [t'ada] (ㅏ) using Praat.



4. Results

In this section, the measured acoustic data on the VOT, F₀, and intensity of the word-initial plosive and the following vowel in the test words for the four Korean speakers are presented.

4.1 VOT of the word-initial plosives

Figure 3 presents the VOT values of the nine types of Korean word-initial plosives [p p', p^h, t t', t^h, k k', k^h] followed by the vowel [i] for each of the four speakers in this study. As shown in the figure, the VOT is the shortest for the tense plosives [p' t' k'] (16-39 ms) and the longest for the aspirated plosives [p^h t^h k^h] (63-123 ms), with the lax plosives [p t k] coming in between (43-93 ms). The VOT patterns are true of the plosives in all the three place categories and for all the four speakers except for two cases. For Male 2 and Female 2, the VOT is longer for the lax [k] (79 ms and 93 ms) than the aspirated [k^h] (76 ms and 66 ms).

The VOT values of the plosives averaged across the four speakers are presented in Table 3. The data show that the VOT of the tense plosives is in the range of 16-32 ms, which is markedly shorter than the other two types of plosives. This suggests that the tense plosives in Korean can be categorized as 'unaspirated'. As for the lax and the aspirated plosives, both of

them are produced with a long VOT, in the respective ranges of 61-87 ms and 74-95 ms, while the aspirated ones tend to be slightly longer than the lax ones. Thus, in Korean the lax plosives can be categorized as ‘aspirated’ and the aspirated ones as ‘strongly aspirated’.

Figure 3. VOT values (in ms) of the Korean word-initial plosives followed by the vowel [i] for two male and two female speakers.

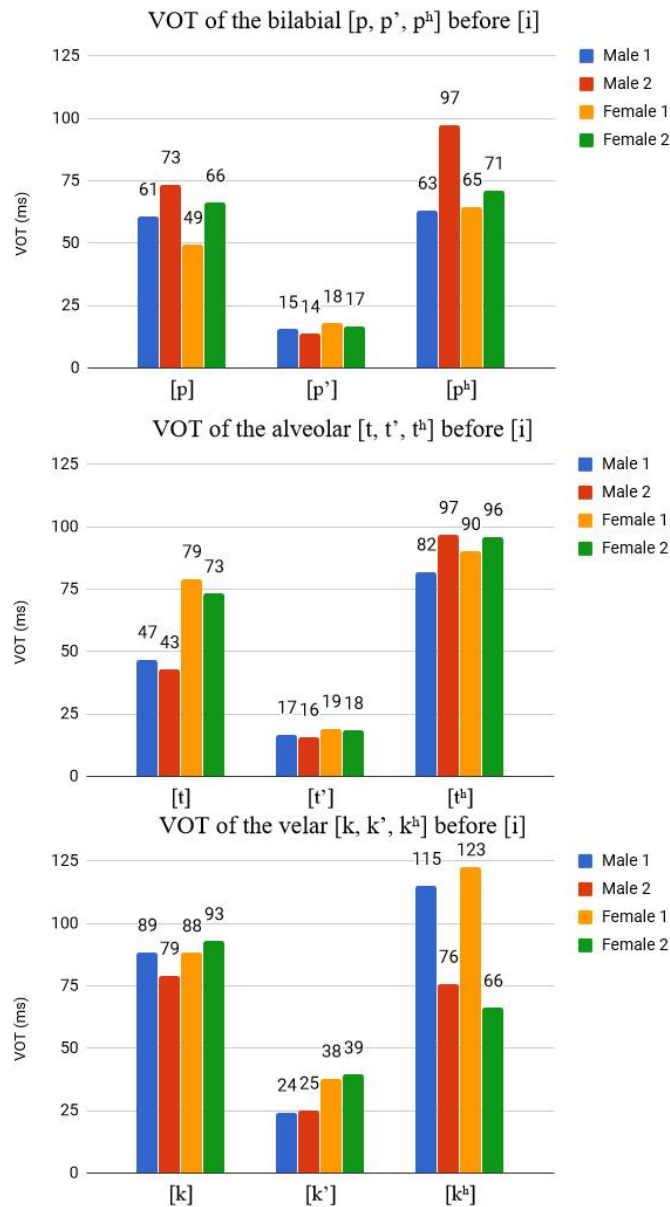


Table 3. VOT values (in ms) of the Korean word-initial plosives followed by the vowel [i] averaged across four speakers.

Phonation type	[p/pʰ/pʰ] before [i]	[t/tʰ/tʰ] before [i]	[k/kʰ/kʰ] before [i]
Lax	62.42	60.56	87.23
Tense	15.94	17.55	31.72
Aspirated	74.08	91.26	94.92

Similar VOT patterns are observed for the plosives followed by the low front vowel [a]. As shown in Figure 4, the VOT is noticeably shorter for the tense [p' t' k'] (11-33 ms) and tends to be longer for the aspirated [p^h t^h k^h] (64-94 ms) than the lax [p t k] (16-82 ms). This is true for the four speakers, except for two cases. For Male 2, the VOT of the lax plosives [p t k] (16-55 ms) is noticeably shorter than the lax plosives of the other three speakers (43-82 ms). This is especially for Male 2's bilabial lax [p], which has a short VOT (16 ms) similar to the VOT of the tense counterpart [p'] (17 ms). For Male 1, the difference in VOT between the lax velar [k] (82 ms) and the aspirated velar [k^h] (84 ms) is minimal.

Figure 4. VOT values (in ms) of the Korean word-initial plosives followed by the vowel [a] for two male and two female speakers.

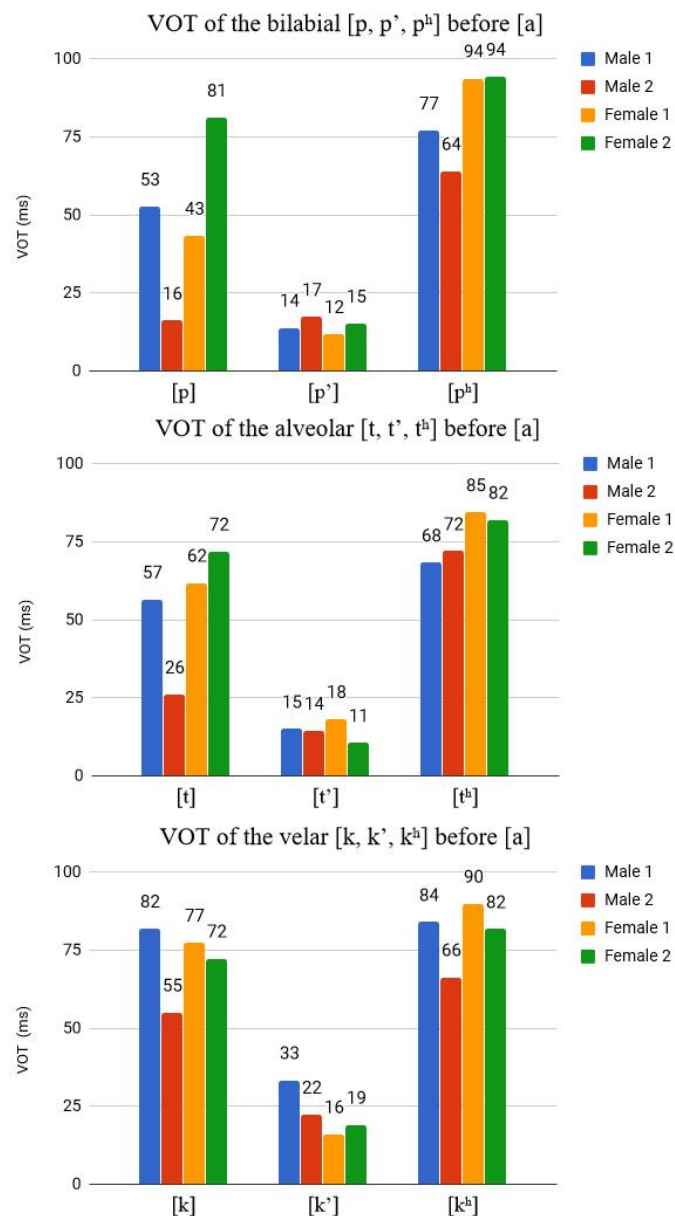


Table 4 presents the averaged VOT values across the four speakers for the lax, tense, and aspirated plosives in each of the three place categories before the vowel [a]. The data show that there is a large difference in VOT between the tense plosives and the lax or the aspirated counterparts. The VOT ranges from 15 ms to 23 ms for the tense plosives, and it is lengthened to 48-72 ms for the lax plosives and further increased to 77-82 ms for the

aspirated plosives. This again indicates that VOT is a distinctive acoustic feature for differentiation of the tense, lax, and aspirated plosives in Korean and the three types of plosives can be categorized as ‘unaspirated’, ‘aspirated’, and ‘strongly aspirated’.

Table 4. VOT values (in ms) of the Korean word-initial plosives followed by the vowel [a] averaged across four speakers.

Phonation type	[p/p’/p ^h] before [a]	[t/t’/t ^h] before [a]	[k/k’/k ^h] before [a]
Lax	48.35	54.09	71.71
Tense	14.55	14.55	22.67
Aspirated	82.29	76.74	80.55

In sum, the descending order with respect to the VOT values of the Korean plosives is aspirated > lax > tense. Among the three types of plosives, only the tense ones are categorized as ‘unaspirated’ which is defined to have a short VOT around 20 ms in Reetz and Jongman (2009). As for the aspirated and the lax plosives in Korean, they both have a long positive VOT due to the substantial delay between the release of consonantal constriction and the onset of voicing for aspiration (Reetz and Jongman, 2009). In general, the VOT difference between the aspirated and the lax plosives in Korean is not large, while the aspirated ones tend to be slightly longer than the lax counterparts. It follows that the distinction between the aspirated and the lax plosives in Korean is not relying on the VOT feature. Therefore, the other two acoustic features, F₀ and the intensity, of the vowel after the word-initial plosives in the test words are examined and presented in the coming section.

4.2 F₀ of the following vowel

Figure 5 shows the F₀ values the vowel [i] following the three types of Korean plosives, lax, tense, and aspirated, in three place categories for two male and two female speakers. The F₀ value was obtained based on the length of the first regular glottal pulse of the vowel as illustrated in Figure 2 (Section 3.4 of the Methodology part).

The F₀ data presented in Figure 5 show that the F₀ of the vowel [i] varies among the lax, tense, and aspirated plosives in any place category. For male speakers, the F₀ of [i] is higher after the aspirated plosives (120-137 Hz) than the lax plosives (96-110 Hz) and the tense plosives (97-127 Hz). Between the lax and the tense plosives, the F₀ of [i] tends to be lower after the lax ones than the tense ones. This is except for Male 2, where the F₀ of [i] is slightly higher after the lax bilabial [p] (107 Hz) than the tense counterpart [p’] (97 Hz). As for female speakers, the F₀ of [i] also tends to be the highest after the aspirated plosives (249-326 Hz), the lowest after the lax plosives (191-256 Hz), and coming in between after the tense plosives (224-319 Hz). This is in spite of the fact that for Female 1 (i) the F₀ of [i] is exceptionally increased after the tense [p] (319 Hz), while it is still slightly below the F₀ of [i] after the aspirated [p^h] (326 Hz); and (ii) the difference in the F₀ of [i] between the lax alveolar [t] (256 Hz) and the tense counterpart [t’] (254 Hz) is minimal.

Based on the F₀ data averaged across the two male or two female speakers presented in Table 5, there is a large difference in the F₀ of the following vowel [i] between the lax and the aspirated plosives, regardless of the place category of the plosives. Overall, the F₀ of [i] following the lax plosives is about 20% lowered than the F₀ of [i] following the aspirated plosives. As for the F₀ difference in the vowel [i] between the tense and the lax plosives or between the tense and the aspirated plosives, it is less pronounced, and overall the F₀

difference in each case is about 10%. In general, the F_0 value of the following vowel can be considered as a secondary acoustic feature for the distinction of the word-initial plosives, in particular for differentiation between the lax and the aspirated plosives in Korean.

Figure 5. F_0 values (in Hz) of the vowel [i] following the lax, tense, and aspirated plosives in Korean for two male and two female speakers.

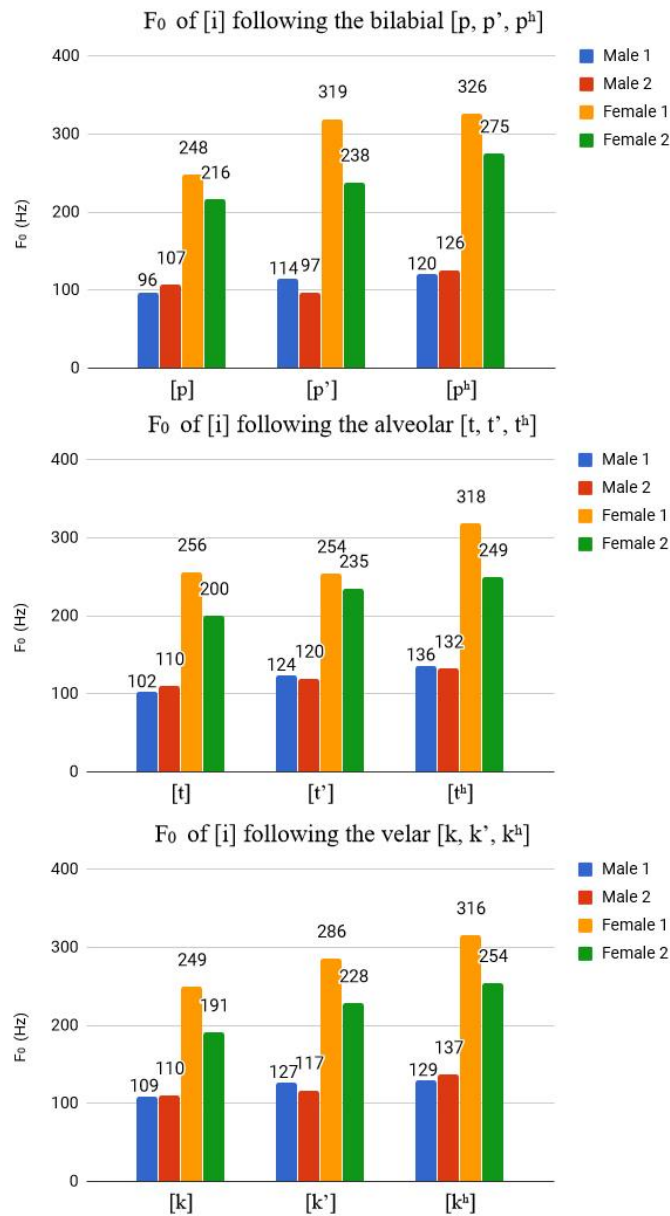
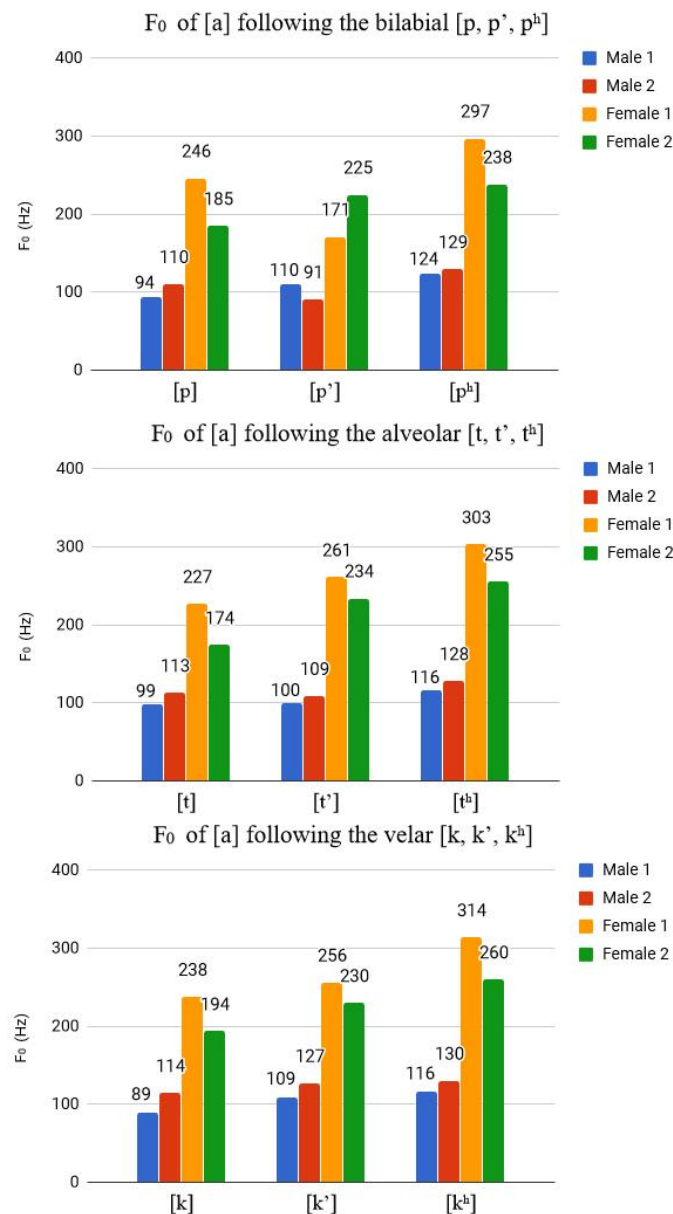


Table 5. Averaged F_0 values (in Hz) of the vowel [i] following the different types of word-initial plosives in Korean for two male and two female speakers.

Phonation type	F ₀ of [i] for Male speakers			F ₀ of [i] for Female speakers		
	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]
Lax	101.50	105.95	109.63	232.05	228.13	220.22
Tense	105.58	121.79	121.76	278.82	244.53	257.10
Aspirated	123.16	134.27	133.06	300.69	283.84	284.93

Figure 6 and Table 6 present the F_0 values of the low front vowel [a] following the different types of Korean plosives for each individual speaker and for the speakers of each gender. As shown in Figure 6, the F_0 of the vowel [a] is the lowest after the lax plosives (89-114 Hz for males and 174-246 Hz for females), the highest after the aspirated plosives (116-130 Hz for males and 238-314 Hz for females), and coming in between after the tense plosives (91-127 Hz for males and 171-261 Hz for females). The data again indicate that in general the ascending order of the F_0 of the vowel following the three types of word-initial plosives in Korean is lax < tense < aspirated. Within speakers, a few exceptional cases are observed. For instance, (i) the F_0 of [a] is higher after the lax [p] than after the tense [p'] for Male 2 (110 Hz and 91 Hz) and Female 1 (246 Hz and 171 Hz); and (ii) the difference in the F_0 of [a] between the lax [t] and the tense [t'] is small for Male 1 (99 Hz and 110 Hz) and Male 2 (113 Hz and 109 Hz).

Figure 6. F_0 values (in Hz) of the vowel [a] following the lax, tense, and aspirated plosives in Korean for two male and two female speakers.



Based on the averaged F_0 data for the two male and two female speakers presented in Table 6, the F_0 of [a] is noticeably higher after the aspirated plosives (122-127 Hz for males and 268-287 Hz for females) than after the tense plosives (100-118 Hz for males and 198-248 Hz for females) and the lax plosives (102-106 Hz for males and 201-216 Hz for females). The difference in the F_0 of [a] between the tense and the lax plosives is small, especially for the male speakers. In general, the patterns of the differences in the F_0 of the vowels [a] and [i] following the lax, tense, and aspirated plosives are similar. The data suggest that F_0 of the following vowel is a distinctive acoustic feature, which is in particular for differentiation between the aspirated and the lax plosives, though less apparent between the tense and the lax plosives.

Table 6. Averaged F_0 values (in Hz) of the vowel [a] following the different types of word-initial plosives in Korean for two male and two female speakers.

Phonation type	F_0 of [a] for Male speakers			F_0 of [a] for Female speakers		
	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]
Lax	102.14	105.75	101.70	215.42	200.54	215.73
Tense	100.47	104.25	117.92	197.99	247.55	243.16
Aspirated	126.81	121.99	122.78	267.54	279.34	286.87

4.3 Intensity of the following vowel

Aside from F_0 , intensity is also measured for the vowel following the word-initial lax, tense, and aspirated plosives in Korean. Figure 7 presents the intensity data on the vowels [i] (the left panel) and [a] (the right panel) following the three types of plosives in three place categories for each speaker. In general, there is no observable pattern of the difference in the intensity of the vowels [i] and [a] following the lax, tense, and aspirated plosives among the four speakers. For instance, for the vowel [i] following the bilabial [p p' p^h] as shown in the left panel of Figure 7, the intensity is larger for the tense [p'] than the lax [p] and the aspirated [p^h] for Male 1 ([p'] 60 dB > [p] 57 dB, [p^h] 57 dB) and Female 1 ([p'] 52 dB > [p] 50 dB, [p^h] 50 dB), but the difference in the intensity of [i] between [p'] and [p] is minimal for Male 2 ([p'] and [p] both around 66 dB) and Female 2 ([p'] and [p] both around 55 dB). As for the vowel [a] following the bilabial plosives [p p' p^h] shown in the right panel of Figure 7, the intensity is noticeably larger for the tense [p'] than the lax [p] and the aspirated [p^h] for Female 1 ([p'] 56 dB > [p] 48 dB, [p^h] 50 dB) and Female 2 ([p'] 57 dB > [p] 49 dB, [p^h] 51 dB), but the intensity value of [a] is similar between [p'] (68 dB) and [p] (70 dB) for Male 2 and similar among the three bilabial plosives [p] (60 dB), [p'] (61 dB), and [p^h] (61 dB) for Male 1.

Table 7 presents the intensity values of the vowels [i] and [a] following the lax, tense, and aspirated plosives averaged across the four speakers. The data show that generally the difference in the intensity of [i] among the lax (57-58 dB), tense (56-59 dB), and aspirated (56-59 dB) plosives is minimal. As for the vowel [a], the difference in intensity is also minimal between the lax (56-57 dB) and the aspirated (56-57 dB) plosives, while the intensity is slightly higher for the tense plosives (60-61 dB). In view of the small increase in the intensity of the vowel [a] following the tense plosives and the similarity in the intensity of the vowel [i] following the plosives with the different phonation types, it is considered that intensity is not a distinctive acoustic feature for differentiation of the lax, tense, and aspirated plosives in Korean.

Figure 7. Intensity values (in dB) of the vowels [i] (the left panel) and [a] (the right panel) following the lax, tense, and aspirated plosives in Korean for two male and two female speakers.

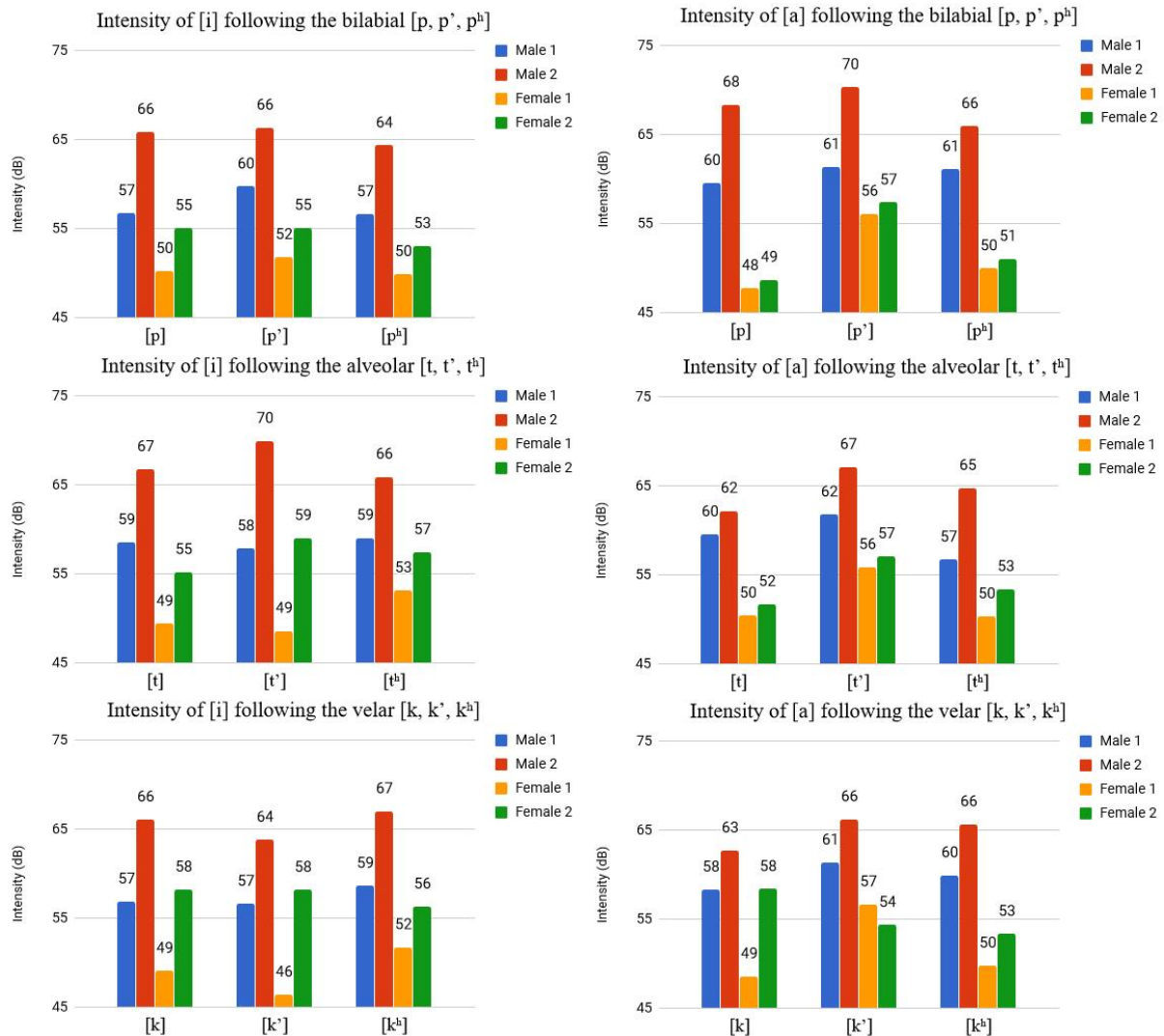


Table 7. Intensity values (in dB) of the vowels [i] and [a] following the different types of word-initial plosives in Korean averaged across four speakers.

Phonation type	Intensity of [i]			Intensity of [a]		
	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]	After [p/p'/p ^h]	After [t/t'/t ^h]	After [k/k'/k ^h]
Lax	56.97	57.48	57.56	56.10	55.98	57.00
Tense	58.25	58.86	56.26	61.30	60.47	59.66
Aspirated	55.97	58.90	58.42	57.02	56.31	57.18

5. Conclusion

To conclude, there is a significant difference in the VOT of the word-initial plosives in Korean, where the VOT is noticeably short for the tense plosives [p' t' k'] as compared with the lax plosives [p t k] and aspirated plosives [p^h t^h k^h]. The VOT difference between the lax

and the aspirated plosives is not large, while the aspirated ones tend to be longer than the lax counterparts. In general, the VOT patterns of the tense, lax, and aspirated plosives in Korean suggest them to be categorized as ‘unaspirated’, ‘aspirated’, and ‘strongly aspirated’.

Aside from the VOT, another difference among the three types of plosives in Korean is in the F_0 of the vowel following the plosives. The F_0 of the following vowel tends to be higher after the aspirated plosives than after the lax and the tense plosives. Since the VOT difference between the lax and the aspirated plosives is not large, a high F_0 of the vowel after the aspirated plosives can be considered as a secondary distinctive acoustic feature for enhancing their distinction. Between the lax and the tense plosives, the difference in the F_0 of the following vowel is not pronounced. Thus, it may be considered that the differentiation between the lax and tense plosives mainly relies on their VOT patterns.

As for the intensity of the following vowel, it is not considered as a distinctive acoustic feature for differentiation of the Korean plosives, due to lack of observable pattern for the variations in the vowel intensity after the lax, tense, and aspirated plosives.

Table 8 presents the three acoustic features which have been examined in this study for their roles in the differentiation of the lax, tense, and aspirated plosives in Korean. In the table, the plus and minus signs are used to indicate the association of the two distinctive acoustic features, a long VOT and a high F_0 of the following vowel, with the three types of plosives in Korean. The acoustic feature of a high intensity of the following vowel is also shown in the table, while it is considered to be non-applicable (n.a.) to the differentiation of the Korean plosives.

Table 8. Acoustic features involved in the differentiation of the lax, tense, and aspirated plosives in Korean (n.a. = non-applicable).

Korean Plosives	Long VOT	High F_0 of the following vowel	High intensity of the following vowel
Lax [p t k]	+	–	(n.a.)
Tense [p' t' k']	–	–	(n.a.)
Aspirated [p ^h t ^h k ^h]	+	+	(n.a.)

Based on Table 8, the distinction of the three types of plosives in Korean is described as follows. The so-called tense plosives [p' t' k'] are produced with the shortest VOT than the other two types of plosives, which can be categorized as ‘unaspirated’. The aspirated [p^h t^h k^h] and the lax [p t k] both have a long VOT, but the aspirated ones are followed by a relatively high-pitched vowel and the lax ones are followed by a relatively low-pitched vowel. The data suggest that both the lax and the aspirated plosives are ‘aspirated’, but the latter ones are ‘high-pitched’. This information is useful for the second language learning of Korean pronunciation, especially for the learners whose first language only has a two-way contrast in the VOT of the plosive consonants.

Last but not least, this project is just a small-scale study of the acoustic properties of Korean plosives based on the speech samples from four native speakers. I look forward to further studies with larger sample size to confirm the findings of the present study.

6. References

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Appendix

The VOT values (in ms) of the word-initial plosives and the F_0 (in Hz) and intensity (in dB) of the following vowel in the 18 test Korean words produced by two male and two female speakers

Male 1

Test words	VOT (ms)			F_0 (Hz)			Intensity (dB)		
	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3
비다 [pida]	51.79	69.95	60.34	101.79	91.95	95.59	56.14	57.11	56.93
빼다 [p'ida]	19.92	14.33	12.19	120.73	108.62	113.35	59.61	60.00	59.64
피다 [p ^h ida]	67.69	53.47	68.43	105.63	127.45	128.13	58.39	54.52	56.89
디자인 [tidzain]	35.57	43.51	61.54	103.22	96.49	106.87	59.77	60.18	55.71
띠 [t'i]	17.54	15.64	16.95	121.32	121.89	128.29	57.32	58.58	57.69
티 [t ^h i]	61.33	92.52	92.18	137.62	128.79	143.04	59.75	60.22	57.21
기 [ki]	105.90	82.74	76.98	109.07	107.65	110.79	57.58	56.00	57.04
끼 [k'i]	20.17	26.76	26.04	133.33	120.13	126.25	57.11	56.48	56.30
키 [k ^h i]	114.93	118.00	112.28	137.32	122.15	128.11	59.62	59.08	57.19
바 [pa]	86.43	15.76	55.90	84.75	104.74	92.36	57.53	62.88	58.34
빠르다 [p'aruɔda]	13.66	14.88	12.97	106.21	118.23	106.48	62.27	61.98	59.82
과 [p ^h a]	68.92	72.07	90.17	124.34	128.91	119.69	62.41	61.08	59.88
다 [ta]	59.77	25.66	84.10	91.58	108.17	96.12	58.18	60.73	59.79
따다 [t'ada]	19.37	15.03	10.68	102.67	99.53	97.00	62.24	62.48	60.65
타다 [t ^h ada]	70.26	63.36	71.45	109.56	119.45	119.70	55.35	57.55	57.28
가방 [kaban]	77.60	76.14	92.05	87.08	93.43	86.45	59.33	58.61	57.03
까 [k'a]	36.57	27.47	35.96	112.80	107.37	106.05	63.57	59.85	60.73
카드 [k ^h adi]	87.56	84.87	79.75	103.24	118.91	124.43	59.34	60.42	60.02

Male 2

Test words	VOT (ms)			F ₀ (Hz)			Intensity (dB)		
	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3
비다 [pida]	47.24	81.00	92.15	107.97	105.94	105.76	61.77	69.32	66.52
빼다 [p'ida]	19.83	11.92	9.41	87.86	118.05	84.88	64.30	70.42	64.32
피다 [p ^h ida]	90.99	103.03	98.09	119.81	124.53	133.41	62.87	62.86	67.35
디자인 [tidzain]	38.03	50.04	40.55	109.98	110.18	108.94	65.17	67.07	68.09
띠 [t'i]	14.78	16.29	16.38	123.48	120.82	114.93	70.68	70.76	68.45
티 [t ^h i]	97.52	95.89	96.96	123.87	139.23	133.08	66.42	66.03	65.31
기 [ki]	80.06	80.78	76.51	110.36	108.66	111.26	68.28	61.89	68.11
끼 [k'i]	24.63	34.22	16.75	117.07	103.95	129.82	59.20	66.14	66.13
키 [k ^h i]	97.46	118.21	11.92	133.46	140.86	136.43	63.76	69.66	67.63
바 [pa]	13.96	23.24	11.24	90.89	109.80	130.31	67.73	67.35	70.08
빠르다 [p'aruda]	17.90	17.76	16.41	81.14	95.40	95.35	69.47	71.01	70.53
파 [p ^h a]	45.72	73.36	72.95	125.24	121.42	141.28	67.08	64.63	66.21
다 [ta]	34.20	19.81	24.06	118.02	108.94	111.66	60.43	61.51	64.68
따다 [t'ada]	15.92	17.58	9.88	100.07	115.38	110.82	64.99	69.38	67.06
타다 [t ^h ada]	73.91	72.56	69.60	134.28	126.18	122.78	64.11	64.09	66.16
가방 [kabaŋ]	54.40	51.49	59.31	113.51	113.48	116.22	60.13	64.12	63.88
까 [k'a]	25.48	19.25	22.18	107.72	148.10	125.50	66.50	65.73	66.51
카드 [k ^h adi]	61.17	78.14	59.85	125.68	134.77	129.67	66.90	65.52	64.65

Female 1

Test words	VOT (ms)			F ₀ (Hz)			Intensity (dB)		
	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3
비다 [pida]	47.24	81.00	92.15	107.97	105.94	105.76	61.77	69.32	66.52
빼다 [p'ida]	19.83	11.92	9.41	87.86	118.05	84.88	64.30	70.42	64.32
피다 [p ^h ida]	90.99	103.03	98.09	119.81	124.53	133.41	62.87	62.86	67.35
디자인 [tidzain]	38.03	50.04	40.55	109.98	110.18	108.94	65.17	67.07	68.09
띠 [t'i]	14.78	16.29	16.38	123.48	120.82	114.93	70.68	70.76	68.45
티 [t ^h i]	97.52	95.89	96.96	123.87	139.23	133.08	66.42	66.03	65.31
기 [ki]	80.06	80.78	76.51	110.36	108.66	111.26	68.28	61.89	68.11
끼 [k'i]	24.63	34.22	16.75	117.07	103.95	129.82	59.20	66.14	66.13
키 [k ^h i]	97.46	118.21	11.92	133.46	140.86	136.43	63.76	69.66	67.63
바 [pa]	13.96	23.24	11.24	90.89	109.80	130.31	67.73	67.35	70.08
빠르다 [p'aruda]	17.90	17.76	16.41	81.14	95.40	95.35	69.47	71.01	70.53
파 [p ^h a]	45.72	73.36	72.95	125.24	121.42	141.28	67.08	64.63	66.21
다 [ta]	34.20	19.81	24.06	118.02	108.94	111.66	60.43	61.51	64.68
따다 [t'ada]	15.92	17.58	9.88	100.07	115.38	110.82	64.99	69.38	67.06
타다 [t ^h ada]	73.91	72.56	69.60	134.28	126.18	122.78	64.11	64.09	66.16
가방 [kabang]	54.40	51.49	59.31	113.51	113.48	116.22	60.13	64.12	63.88
까 [k'a]	25.48	19.25	22.18	107.72	148.10	125.50	66.50	65.73	66.51
카드 [k ^h adi]	61.17	78.14	59.85	125.68	134.77	129.67	66.90	65.52	64.65

Female 2

Test words	VOT (ms)			F ₀ (Hz)			Intensity (dB)		
	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3	Token 1	Token 2	Token 3
비다 [pida]	47.24	81.00	92.15	107.97	105.94	105.76	61.77	69.32	66.52
빼다 [p'ida]	19.83	11.92	9.41	87.86	118.05	84.88	64.30	70.42	64.32
피다 [p ^h ida]	90.99	103.03	98.09	119.81	124.53	133.41	62.87	62.86	67.35
디자인 [tidzain]	38.03	50.04	40.55	109.98	110.18	108.94	65.17	67.07	68.09
띠 [t'i]	14.78	16.29	16.38	123.48	120.82	114.93	70.68	70.76	68.45
티 [t ^h i]	97.52	95.89	96.96	123.87	139.23	133.08	66.42	66.03	65.31
기 [ki]	80.06	80.78	76.51	110.36	108.66	111.26	68.28	61.89	68.11
끼 [k'i]	24.63	34.22	16.75	117.07	103.95	129.82	59.20	66.14	66.13
키 [k ^h i]	97.46	118.21	11.92	133.46	140.86	136.43	63.76	69.66	67.63
바 [pa]	13.96	23.24	11.24	90.89	109.80	130.31	67.73	67.35	70.08
빠르다 [p'aruda]	17.90	17.76	16.41	81.14	95.40	95.35	69.47	71.01	70.53
파 [p ^h a]	45.72	73.36	72.95	125.24	121.42	141.28	67.08	64.63	66.21
다 [ta]	34.20	19.81	24.06	118.02	108.94	111.66	60.43	61.51	64.68
따다 [t'ada]	15.92	17.58	9.88	100.07	115.38	110.82	64.99	69.38	67.06
타다 [t ^h ada]	73.91	72.56	69.60	134.28	126.18	122.78	64.11	64.09	66.16
가방 [kaban]	54.40	51.49	59.31	113.51	113.48	116.22	60.13	64.12	63.88
까 [k'a]	25.48	19.25	22.18	107.72	148.10	125.50	66.50	65.73	66.51
카드 [k ^h adi]	61.17	78.14	59.85	125.68	134.77	129.67	66.90	65.52	64.65