An Acoustic Investigation of Post-Obstruent Tensification Phenomena*

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ABSTRACT

This study investigated and compared the acoustic characteristics of the Korean stop sound [k'] in three different phonological environments: the tensified lenis stop [k'] as observed in /pæk+kaci/, the fortis stop /k'/ as in /pæ+k'aci/, and the fortis stop /k'/ following an obstruent as in /pæk+k'aci/. The specific research question was whether or not the tensified lenis stop shares all the acoustic features with the other two kinds of fortis stops. The acoustic measures adopted in this study were H1*-H2*, VOT, length of stop closure, and F_0. The major findings were that the three stops showed no significant difference in all the acoustic measures except the length of stop closure. The fortis stop /k'/ following an obstruent showed significantly longer duration of stop closure than the other two stops, both of which showed no significant difference. Based on these phonetic results, this study argued that, for the proper phonological description of post-obstruent tensification, the phonological feature [slack vocal folds] of a lenis stop should be changed into [stiff vocal folds, constricted glottis] that the fortis stops should have.

Keywords : H1*-H2* measure, post-obstruent tensification, post-release phonation, Korean obstruents

1. Aims and Organization of the Study

This paper has a single research aim: to investigate the acoustic aspects of the post-obstruent tensification phenomenon, a well-known Korean phonological process, by which a lenis obstruent becomes tensified when it follows an obstruent (for example, /cokak + tal/ → [co.gak˺.k'al] 'crescent moon,' /cik + kak/ → [ci k˺.k'ak˺] 'right angle') For this particular purpose, this study will investigate and compare the acoustic characteristics of the Korean stop sound [k'] in three different phonological environments: (i) the tensified lenis stop [k'] as observed in /pæk+kaci/;

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(ii) the fortis stop /k'/ as in /pæ+k'aci/; (iii) the fortis stop /k'/ following an obstruent as in /pæk+k'aci/. The specific research question is whether or not the tensified lenis stop shares all the acoustic features with the other two kinds of fortis stops. To answer to this question, I measure various kinds of values such as those of H1*-H2*, F_0, duration of stop closure, and VOT measures. Especially this study makes significant use of the H1*-H2* measure (a normalized amplitude difference between the first and second harmonics of vowels) to provide an acoustic correlate of vowel phonation that follows a target obstruent). To the best of my knowledge, this measure has been unexplored for this particular phonological phenomenon. Based on the phonetic findings to obtain, this study also intends to provide more appropriate phonological interpretation of the post-obstruent tensification phenomenon.

The overall organization of this study is as follows. In section 2, the measure of H1*-H2* will be briefly introduced and the need for the measure will also be briefly discussed. In section 3, the design of the phonetic experiment and the relevant statistical treatment will be described. In section 4 the experimental results will be presented. In section 5, this study will conclude with the relevant discussions and the phonological implications concerning this particular phonological process for the Korean phonology.

2. The H1*-H2* Measure

One well-known way of determining a phonation type is by numeric measurements of the observed amplitude difference in decibels between the first and second harmonics (=Obs(H1-H2), henceforth). Johnson (1997:127-130) clearly specified that the value of Obs(H1-H2) plays an important role as an index of the relative breathiness or creakiness of phonation. The assumption is that the value of Obs(H1-H2) is much larger during breathy voice than during creaky voice.

Since it is generally assumed that the spectral characteristics of the glottal waveform are directly reflected in the vowel, the value of Obs(H1-H2) can be used to determine the phonation mode of that vowel. However, the method of Obs(H1-H2) is not entirely reliable if it is measured at the voicing onset of a vowel in a /CV/ context. This is because the first and second harmonics undergo a 'boost effect,' mainly due to the amplitude of the first formant during its transition in the initial part of a vowel that follows a consonant. This F1 amplitude perturbation effect was also clearly exemplified in Fant (1960:54-55), where the F1 downward shift in frequency with the rest of the formants being fixed results in an amplitude loss in the overall spectral envelope of the vowel. The Obs(H1-H2) measure is, thus, not totally dependable, considering that the main concern of this study is to observe the difference in phonation mode at the voicing onset of the vowel following a stop. At this particular time point the laryngeal influence of the stop sound is supposedly most salient at the following vowel.

To correct this 'boost' effect at the voicing onset, Stevens and Hanson (1995) suggested a method of H1*-H2*, a normalized amplitude difference between the first and second harmonics. The value of H1*-H2* is obtained by subtracting the expected value of H1-H2 (=Exp(H1-H2), henceforth) from the value of Obs(H1-H2), as shown in formula (1) below.

(1) H1* - H2* = Obs(H1-H2) - Exp(H1-H2)

According to the acoustic theory of speech production (Fant, 1960), we can predict an expected value of Exp(H1-H2) if we know F_0 and the first few formant frequencies (Fant, 1960:49-60, 1972) (for the detailed explanation of how to calculate the value of Exp(H1-H2), see Ahn, 1999a, 2000). Since the H1*-H2* measure compares observed and expected differences, it provides an indication of how the source spectrum deviates from the reference. Therefore, the value of H1*-H2* naturally represents a corrected amplitude difference between the first and second harmonics and the H1*-H2* value is free from the variations of the formant-patterns. Conversely, a value of Exp (H1-H2) varies depending on the formant-pattern, so that the value naturally reflects the F1 amplitude perturbation effect.

For reference, I suggest a summary of what I have found so far for the Korean obstruents in terms of the H1*-H2* measure:

(2) a. Vowels following fortis stops showed significantly lower H1*-H2* values at the vowel onset position than those following lenis and aspirated stops, which showed no significant difference (Ahn, 1999a).

b. The H1*-H2* measure at the vowel onset was significantly lower when following fortis affricate than when following lenis and aspirated affricates, both of which showed no significant difference (Ahn, 2002).

c. The vowels following a fortis fricative showed significantly lower H1*-H2* values at their onset position than those following a lenis fricative (Ahn, 1999b).

3. Experimental Methods and Statistical Treatment

A total of 5 Korean male subjects speaking Seoul dialect participated in the recording. They were all students attending Seoul National University, none of whom reported any medical problems influencing their language ability. At the time of recording, the average age of the subjects was 24.2. For the data to collect, the words in (3) were used and they were embedded in the carrier sentence in (4).

(3) a. /pæk+kaci/ [pæk k'aji]
b. /pæ+k'aci/ [pæ k'aji]
c. /pæk+ k'aci/ [pæk˺ k'aji]

(4) sentence: /i + kəs + i + ____ + ta/ [igəsi ______da]
gloss: this + thing + nominative marker + _____ +be(declarative ending)
meaning: This is _______.

The subjects were required to repeat each of the items in (3), which was embedded in a carrier sentence in (4), in succession until the 5 clear tokens of each sample were obtained. A total of 15 tokens were eventually gathered from each of the subjects. The recording was made in a silent room and the subjects were asked to speak the samples at normal speed and as naturally as possible in front of the microphone (Sennheiser e815s). The microphone was connected to the hardware, CSL 4400, which was also connected to an IBM-compatible computer. The recording for each subject took approximately 15 to 20 minutes.

The on-line digitization was made at a sampling rate of 11,025 Hz with an aid of a'CSL 4400, version 2.5.1'program (a software program from Kay, Inc.) at the same time when recording was made. And than, the digitized tokens were analyzed to obtain the following raw data in (5).

(5) a. Amplitude levels of harmonics 1 and 2 at the onset position of a vowel (using FFT routine with 1,024 points)
b. Fo value at the onset position of a vowel
c. Frequency values of Format 1 through Format 4 at the vowel onset
d. VOT (voice onset time) value

e. Duration value of stop closure

In order to obtain the theoretical values of Exp(H1-H2) and H1*-H2*, the raw data in (5a, b, c) were calculated using an 'Excel' program (Microsoft Office 2000).

For the statistical analyses, the present study made use of the Repeated Measures ANOVA that was processed with an SPSS program (version 10.0). This particular method was conducted to test the significance of means obtained from the calculated data. Since each subject participated in more than one experimental condition, the repeated measures design should be employed in this experiment.

4. Results of the Experiment

The numerical values in the table 1 below represent mean values of the Obs(H1-H2), Exp(H1-H2), and H1*-H2* measures for the three [k'] cases obtained at the vowel onset position.

Table 1. Mean values of the Obs(H1-H2), Exp(H1-H2), and H1*-H2* measures at the vowel onset position for the three [k'] cases

Case	Obs(H1-H2)	Exp(H1-H2)	H1*-H2*
a. /pæk+kaci/	2.00	0.50	1.50
b. /pæ+k'aci/	1.06	0.46	0.60
c. /pæk+k'aci/	0.07	0.44	-0.37

As described above, the Exp(H1-H2) pattern reflects the predicted effects on the first two harmonics by a first formant at that particular time point. The fact that all the three cases show similar mean values on this measure reflects that the F1 formant transition patterned much alike in time interval in all cases. For reference, the table 2 below shows the average values of the VOT measure for the three cases.

Table 2. Descriptive statistics for the VOT measure

Case	Mean Value (ms)	Standard Deviation (ms)
a. /pæk+kaci/	25.28	2.186
b. /pæ+k'aci/	24.56	2.002
c. /pæk+k'aci/	22.48	2.143

As expected by the similar values shown in the table 2, the statistics for the VOT measure shows that the main effect for Case is not significant at an alpha level of 0.05 (F-value 3.145, degree of freedom (Greenhouse-Geisser) 1.333, p=0.131).

For the H1*-H2* measure, the source table for the analysis of variance with repeated measures is presented in the table 3 below:

Table 3. Source table: analysis of variance with repeated measures for the H1*-H2* measure

Sum of Squares	Degree of Freedom (Greenhouse-Geisser)	Mean of Squares	F-value	p-value
43.826	1.505	29.117	1.505	0.072

As shown in the table 3, there is no significant difference in H1*-H2* measure among the three cases, though the p-value is somewhat marginal. This result shows that the dimension of glottal width, which is indirectly reflected in the H1*-H2* value, plays no crucial role in distinguishing the tensified lenis stops from the syllable-initial fortis stops.

The Fo data is described in the table 4 below. The univariate analysis with repeated measures shows no significant Case factor effect (F=3.032, Degree of Freedom (Greenhouse-Geisser)=1.386, p=0.134).

Table 4. Descriptive statistics of the Fo measure

Case	Mean value (Hz)	Standard Deviation (Hz)
a. /pæk+kaci/	114.328	5.102
b. /pæ+k'aci/	113.892	4.162
c. /pæk+k'aci/	118.972	6.053

The duration of stop closure is the only measure that shows a statistically significant difference among the three cases. The table 5 below demonstrates the basic descriptive statistics for each of the three cases.

Table 5. Descriptive statistics for the measure of stop closure duration

Case	Mean value (ms)	Standard Deviation (ms)
a. /pæk+kaci/	106.280	2.267
b. /pæ+k'aci/	109.360	12.559
c. /pæk+k'aci/	153.360	19.380

At an alpha level of 0.05, the univariate test shows a significant main effect for the Case factor (F=9.310, Degree of Freedom(Greenhouse-Geisser)=1.197, p=0.028*). As a next step, a pair-wise LSD test was performed to determine which means statistically differ. The table 6 below shows the results.

Table 6. The LSD pair-wise comparisons of the three cases for the measure of stop closure duration

Cases Compared		
/pæk+kaci/ vs. /pæ+k'aci/	/pæ+k'aci/ vs. /pæk+k'aci/	/pæk+kaci/ vs. /pæk+k'aci/
P=0.702	P=0.044*	P=0.017*

According to the statistical results in the table 6, we find a significant difference at an alpha level of 0.05 in mean values between /pæk+kaci/ and /pæk+k'aci/ cases, and between /pæ+k'aci/ and /pæk+k'aci/ cases. This result clearly indicates that the stop closure duration is significantly longer in /pæk+k'aci/ case than in the other two cases. No statistically significant difference is found between /pæk+kaci/ and /pæ+k'aci/ cases. This result is somewhat comprehensible since we understand that the subjects tried, on their own, to distinguish between the two kinds of fortis [k'] stops in /pæ+k'aci/ and /pæk+kaci/ contexts.

To sum up, considering the phonetic results of all the acoustic measures, we come to understand that a tensified lenis stop and a fortis stop share all the acoustic characteristics except for the longer duration of stop closure in /-Vkk'V-/ context. In principle, the two stop sounds are statistically identical.

5. Discussion and Phonological Implications

Previous main phonetic studies concerning the process of post-obstruent tensification can be described like the following. First, Sawashima et al. (1979) reported in their fiberoptic studies that the glottal opening conditions for the sequence of the unreleased stop plus the lenis stop is almost the same as that of the syllable-initial fortis stop. Second, according to the EMG studies of Hirose et al. (1981, 1983), the pattern of VOC (Vocalis muscle) activity for the consonant clusters consisting of a syllable-final unreleased stop and a syllable-initial lenis stop is quite similar to that of the syllable-initial fortis stop in terms of the degree and timing of VOC suppression for the consonant segment and of the reactivation of the VOC for the post-consonantal vowel. Third, Ahn (1996) reported that no statistically significant difference appeared between the stop closure of the intervocalic fortis stop (i.e., /-Vk'V-/) and the extended stop closure made by two combined identical stops of unreleased and lenis stops (i.e., /-VkkV-/). He also reported that the VOT duration showed no significant difference in these two contexts (cf. Han, 1996).

These afore-mentioned phonetic studies suggest in common that a sequence of an unreleased stop and a lenis stop is phonetically quite similar to a syllable-initial fortis stop. This phonetic fact is also strongly confirmed by the phonetic results of the present study. Especially, the acoustic analysis performed on the H1*-H2* measure, which allows us insight into the laryngeal settings made in the articulation of the stops without the use of fiberoptic measures of glottal width, clearly confirmed the phonetic findings of the Japanese scholars above, who did not suggest any statistical generalizations. In addition, this study also finds that there is no statistically significant difference in F_0 values at the vowel onset position following the stops among the three cases. This F_0 pattern is important considering that the F_0 values are known to be significantly low in the vowel following the lenis stop than in the vowels following the fortis or aspirated stops (Ahn, 1999a). In other words, this finding strongly leads us to a conclusion that a tensified lenis stop truly becomes a corresponding fortis stop not only in terms of the phonation type (cf. the H1*-H2* measure), but in terms of vocal fold tenseness (cf. the F_0 measure).

Based on the phonetic findings in various papers (Ahn, 1999a, 1999b, 2002), I have strongly argued for the new phonological representations of the Korean obstruent sounds, as seen in (6) below:

(6) a. fortis obstruents: [stiff vocal folds, constricted glottis]
b. lenis obstruents: [slack vocal folds]
c. aspirated obstruents: [stiff vocal folds, spread glottis]

Korean fortis and aspirated obstruents are distinguished only in terms of the glottis size (constricted glottis vs. spread glottis). On the other hand, Korean lenis obstruents are characterized by their laryngeal characteristics of slackened vocal folds (cf. low F_0), while fortis and aspirated obstruents share their laryngeal feature of stiffened vocal folds (cf. high F_0).

Under the assumption of these phonological representations in (6), we can then formulate the phonological process of post-obstruent tensification as in (7) below, even though the formulation is considerably simplified.

(7) Post-Obstruent Tensification (simplified version)

lenis obstruent		tensified lenis obstruent
|	→	|
[slack vocal folds]		[stiff vocal folds, constricted glottis]

What is stressed here is that the process in (7) is grounded on the phonetic findings suggested in section 4 above. In other words, this study proved that the tensified lenis stop and the fortis stop are identical in phonetic nature. In this respect, we can argue that the phonological formulation in (7) is appropriate for the phonological description of the post-obstruent tensification in Korean. However, I will leave for the future study an issue of how to elaborate the phonological process in (7) within a certain theoretical framework in phonology, which will be beyond the scope of this paper.

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