Post-Affricate Phonatory Processes in Korean and English: Acoustic Correlates and Implications for Phonological Analysis*

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ABSTRACT

This study investigates phonation modes of vowels following the affricate consonants in Korean and English--tense affricate /c'/, lenis affricate /c/, and aspirated affricate /c^h/ for Korean; voiced affricate /ǰ/ and aspirated affricate /č/ for English. The investigation makes significant use of the H1*-H2* measure (a normalized amplitude difference between the first and second harmonics) to provide acoustic correlates of the phonation types. The major findings for English are that the H1*-H2* measure at the vowel onset was significantly larger in post-aspirated position than in post-voiced position. The Korean data showed the H1*-H2* measure at the vowel onset to be significantly higher in the post-aspirated class than in the post-tense class. On the other hand, the Fo values for the post-lenis vowels were significantly lower than those of the other two classes during the first half of the vowel. Based on the phonetic results, this study argues for the need to incorporate the [stiff vocal folds] and [slack vocal folds] features into the phonological treatments of Korean affricates, while maintaining the two features [constricted glottis] and [spread glottis].

Keywords: H1*-H2* Measure, Phonation, Korean Affricates, English Affricates

1. Aims and Organization of the Study

This paper has two specific aims. First, it investigates phonation modes of vowels following the three phonemically different affricate consonants in Korean (the tense affricate /c'/, the lenis affricate /c/, and the aspirated affricate /c^h/) and the two affricate consonants in English (the voiced affricate /ǰ/ and the voiceless

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affricate /č/). This study focuses on the acoustic differences of the vowels following the consonants in question, specifically in /_a/ sequences. The major acoustic measure employed in this study is the measurement of H1*–H2*, a normalized amplitude difference between the first and second harmonics. In addition, other measures such as Fo and VOT are employed as supplementary means. Secondly, based on the phonetic findings, this study intends to provide more appropriate phonological representations of affricate consonants for both languages.

The overall organization of this study is as follows. In section 2, the measure of H1*–H2* will be introduced and the need for the measure will be discussed. In section 3, the design of the phonetic experiment will be described. In addition, the relevant statistical treatment will be outlined. Section 4 will present the experimental results for the Korean data, and section 5, those for the English data. Finally, section 6 will conclude with discussions relevant to the phonetic results and phonological implications for the appropriate laryngeal features of the affricate series in both languages.

2. The H1*–H2* Measure

One way of determining a phonation type is obtained 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 difference in Obs(H1–H2) is mainly due to the difference in the shape of the glottal waveform. The general assumption is that the value of Obs(H1–H2) is much larger during breathy voice than during creaky voice. The amplitude of the first harmonic in the breathy phonation is more dominant over the other harmonics because the glottal waveform of breathy phonation is most like a sine wave. The creaky phonation does not show a difference in amplitude between the first few harmonics because the closing phase of the glottal waveform falls off abruptly. The creaky waveform is least like a sine wave.

On the assumption 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. This F1 amplitude perturbation effect is 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. Thus the Obs(H1–H2) measure is 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 an affricate. At this particular time point the laryngeal influence of the preceding affricate is supposedly most salient, especially for the post–tense vowel in Korean and the post–voiced vowel in English.

To correct this 'boost' effect at the voicing onset, Stevens and Hanson (1995) suggested a new 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) (cf. for the detailed explanation of how to calculate the value of Exp(H1–H2), see Ahn, 1999). This calculated value is based on the assumption that the glottal waveform is characteristic of modal phonation—i.e., the spectral tilt of the glottal source is fixed at –12 dB/*octave*. Since H1*–H2* compares observed and expected differences, it provides an indication of how the source spectrum deviates from the modal phonation. In this respect, the value of H1*–H2* naturally represents a corrected amplitude difference between the first and second harmonics and this 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 reflects the F1 amplitude perturbation effect. The H1*–H2* measure shows the characteristics of pure glottal phonation, which are computed relative to modal phonation. Thus, this measure will indirectly allow us insight into the laryngeal settings made in the articulation of the affricate series without the use of fiberoptic measures of glottal width.

3. Experimental Methods and Statistical Treatment

A total of 10 male subjects (five Korean speakers and five American English speakers) participated in the recording. At the time of the recording, all subjects with the exception of one Korean visiting scholar were graduate students attending the University of Texas at Austin. None reported any medical problems influencing their language ability. The average age of the Korean subjects was 36.8 and that of the English speakers was 29.8. All of the Koreans speak Seoul dialect. Among the American speakers, two were reared in Texas, one in New York State, one in Colorado and one in New Mexico. Given these facts, it is true that dialectal variance within the English data was not controlled in the experiment. Controlling this variance, however, was considered secondary in this study, because the vowel quality [a] needed to be consistently used. Since all of the American subjects were graduate students of linguistics with phonetic training, they were able to pronounce [a] presented in speech samples.

For the Korean data, the words in (2) were used. They were embedded in the carrier sentence in (3).

(2) a. tense affricate: /c'a/
b. lenis affricate: /ca/
c. aspirated affricate: /cʰa/

(3) sentence: /i+kəs+i ___+ita/ [igəʃi ___ida]
gloss: this+thing+nominative marker+ _____ +be(declarative ending)
meaning: This is _______.

For the English data, the words in (4) were used, embedded in the carrier sentence in (5):

(4) a. voiced affricate: /ǰă/
b. voiceless affricate: /čă/

(5) Say _____again

The subjects were required to repeat each of the items in (2) and (4) in succession until 5 clear tokens of each sample were obtained. Eventually, a total of 15 tokens were obtained from each of the Korean subjects, and a total of 10 tokens, from each of the English subjects. Subjects were recorded in a soundproofed room in the phonetics laboratory of the University of Texas at Austin. They were asked to speak the samples at normal speed and as naturally as possible in front of the microphone (Electro-Voice® 671A, Dynamic Cardioid, Electro-Voice, Inc.), which was connected to a stereo cassette recorder (Marantz PMD 430). The recording for each subject took approximately 15 to 20 minutes.

The digitization was made at a sampling rate of 22,050 Hz with the aid of 'PCquirer 6.0' (PC software program from Scicon R&D, Inc.). The digitized tokens were analyzed using PCquirer to obtain the following raw data in (6).

(6) a. Amplitude levels of harmonics 1 and 2 at the vowel onset (using FFT routine with 1,024 points)
b. Fo values at the vowel onset and 1/2 point of the vowel (using pitch option)
c. Frequency values of F1 through F4 at the vowel onset (using LPC option)
d. VOT (voice onset time) value

The raw data gathered were processed using 'Excel' (Microsoft Office 2000) in order to calculate the theoretical values of Exp(H1−H2) and H1*−H2*.

For the statistical analyses, the present study used Repeated Measures ANOVA. This method was conducted to test the significance of means of H1*−H2* and Fo on the three manner classes of affricates across Korean subjects and on the two classes of affricates across English subjects.

4. Results of the Korean Data

4.1 Working Hypotheses for the Korean data

Ahn (1999) performed the identical phonetic experiments as suggested in this study to investigate post-release phonation modes of vowels following Korean stop consonants--the tense stops /p', t', k'/, the lenis stops /p, t, k/, and the aspirated stops /p^h, t^h, k^h/. The major phonetic findings of that study showed that the H1*−H2* measure was significantly lower (more creaky in phonation) at the vowel onset in the post-tense class than in the post-lenis and post-aspirated classes, both of which showed no significant difference. On the other hand, the Fo values for the post-lenis vowels were significantly lower than those of the other two classes during the first half of the vowel. Since the Korean affricates are in the same line with stop series in terms of the manner of articulation, we can posit the following working hypotheses:

(7) a. The value of H1*−H2* at the vowel onset is larger in a vowel following an aspirated affricate than in a vowel following a tense affricate.

b. The value of Fo is lower in a vowel following a lenis affricate than in a vowel following a tense or aspirated affricate along the first half of the vowel.

4.2 Experimental Results of the Korean data

The numerical values in table 1 represents mean values of the Obs(H1−H2), Exp(H1−H2), and H1*−H2* measures for the three affricate categories obtained at the vowel onset. A line graph in figure 1 represents the mean values.

Table 1. Mean values of the Obs(H1−H2), Exp(H1−H2), and H1*−H2* measures

Manner Classes	Obs(H1−H2)	Exp(H1−H2)	H1*−H2*
Tense affricate	−6.36	−1.47	−4.89
Lenis affricate	−2.64	1.48	−4.12
Aspirated affricate	4.04	1.71	2.33

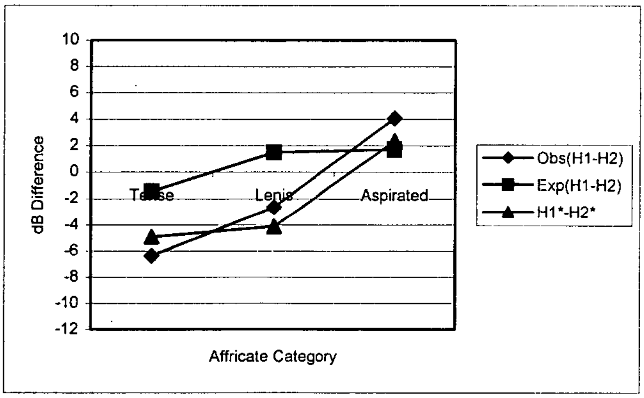

Figure 1. Line graph with average data points for Obs(H1−H2), Exp(H1−H2), and H1*−H2* for the three affricate categories. The observations were obtained at the vowel onset and were averaged over all 5 Korean subjects.

The Exp(H1−H2) pattern reflects the predicted effects on the first two harmonics of the first formant. As expected, the post-lenis and post-aspirated classes are higher on this measure than the post−tense class. For these two classes, the formant transition took place during the long aspiration interval. Because of the short aspiration (VOT), the Exp(H1−H2) value is smallest for the post−tense class. For reference, table 2 shows the average values of VOT for the lenis and aspirated classes. For the tense class, the VOT measure was not performed due to the difficulty in clear separation between frication and aspiration parts.

Table 2. Descriptive statistics for the VOT measure based on the Korean data

Manner Class	Mean Value (ms)	Standard Deviation (ms)
Lenis Affricate	47.66	5.73
Aspirated Affricate	96.84	4.88

Table 1 and graph 1 appear to confirm the working hypothesis in (7a). The average value of H1*−H2* is much higher in the vowel following the aspirated affricates than following the tense affricates. But, this observation must be statistically confirmed. See tables 3 and 4 below.

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

Sum of Squares	Degree of Freedom	Mean of Squares	F−value	p−value
787.512	2	393.756	12.269	<.01*

Table 4. The pair−wise comparisons (the Bonferroni test with an alpha level of .05) of the estimated mean values of the three manner classes obtained by the H1*−H2* measure.

Manner Classes Compared		
Tense vs. Lenis	Lenis vs. Aspirated	Tense vs. Aspirated
1.000	0.085	<.05*

As shown in table 4, the estimated value of H1*−H2* in the aspirated class is found to be significantly higher than the mean values of the post−tense class. Consequently, the working hypothesis in (7a) is statistically supported. Also notice that there is no significant difference in the H1*−H2* measure between post−tense and post−lenis classes, or between post−aspirated and post−lenis classes. These results clearly show that the dimension of glottal width plays no significant role in distinguishing the lenis affricate class from the other two classes.

The Fo data is described in table 5 below. The results of the temporal course of the Fo contours appear to suggest that the average Fo value is high for the post-aspirated class, intermediate for the post-tense class, and low for the post-lenis class. These conditions are consistently maintained along the time scale.

Table 5. Descriptive statistics of the Fo measure for the Korean data (cf. 'S.D.' below means 'standard deviation')

	Mean (S.D.) at vowel onset	Mean (S.D.) at 1/2 point
post-tense class	154.88 (10.59)	147.04 (10.14)
post-lenis class	120.52 (9.69)	125.56 (9.38)
post-aspirated class	164.92 (7.85)	152.60 (9.21)

The univariate analysis with repeated measures shows significant manner factor effect ($F=23.956$, $p<0.01*$ at the vowel onset; $F=31.226$, $p<0.01*$ at the 1/2 time point of the vowel). The Bonferroni test of the estimated Fo mean values is displayed in table 6 below:

Table 6. The Bonferroni test of the average Fo values

	Manner Classes Compared		
	Tense vs. Lenis	Lenis vs. Aspirated	Tense vs. Aspirated
vowel onset	<0.1*	<0.5*	0.713
1/2 time point	<0.1*	<0.1*	0.400

According to the statistical results, at an alpha level of 0.05 there is no significant difference in mean values between the post-tense and post-aspirated classes along the two time points. On the other hand, the lenis Fo values are significantly lower than those of the other two classes at the two time points. Therefore, the working hypothesis in (7b) is also supported.

5. Results of the English Data

5.1 Working Hypotheses for the English data

Based on the similar acoustic study of the English stop consonants in Ahn (1999), we can posit the following working hypotheses for the English affricate series:

(8) a. The value of H1*−H2* is larger in a vowel following a voiceless affricate than in a vowel following a voiced affricate.

b. The value of Fo is lower in a vowel following a voiced affricate than in a vowel following a voiceless affricate at the vowel onset, but this difference disappears at the 1/2 point of the vowel.

5.2 Experimental Results of the English data

The numerical values are given in table 7 and the statistical analysis for H1*−H2* measure is given in table 8.

Table 7. Mean values of the Obs(H1−H2), Exp(H1−H2), and H1*−H2* measures at the vowel onset

Manner Classes	Obs(H1−H2)	Exp(H1−H2)	H1*−H2*
Post−voiced	−10.88	−0.72	−10.16
Post−voiceless	−2.16	0.66	−2.82

Table 8. Analysis of variance with repeated measures for the H1*−H2* measure obtained at the vowel onset

Sum of Squares	Degree of Freedom	Mean of Squares	F−value	p−value
673.445	1	673.445	11.091	<.05*

For an alpha level of 0.05, a highly significant main effect is found for the H1*−H2* measure. It indicates that the mean value of the voiceless class is significantly higher than the voiced class. Consequently, the working hypothesis in (8a) is strongly supported.

The descriptive statistics of the Fo data is described in table 9 below:

Table 9. Descriptive statistics of the Fo measure for the English data

	Mean (S.D.) at vowel onset	Mean (S.D.) at 1/2 point
post−voiced class	115.28 (11.27)	116.60 (12.59)
post−voiceless class	131.72 (14.32)	125.84 (13.66)

Now the question is whether the differences of average Fo values between the two classes shown in table 9 are also significant in view of the inferential statistics. At an alpha level 0.05, the statistical results show that the difference in Fo between the two classes is significant at the vowel onset ($p<0.05*$), while the difference at the 1/2 time point turns out to be non−significant. This statistical result indicates that American English speakers do not implement distinct laryngeal settings at the mid point of the vowel and just return to the normal default voicing. Therefore, the working hypothesis in (8b) is also strongly confirmed. Then the next interesting question is why the significant Fo difference between the two classes shows up at the vowel onset only. As an answer to this question, previous studies (Ohde, 1984, among others) suggested that, for aerodynamic reasons, Fo naturally tends to be high at the voice onset following voiceless obstruents, whereas it is low when following voiced obstruents.

6. Discussions and Phonological Implications

It has been generally pointed out that there are four phonetic factors that distinguish English voiced and voiceless affricates in word−initial position: glottal width, VOT, frication duration, and Fo at the voice onset of the following vowel. The present study has confirmed two of those observations. First, the H1*−H2* values (indirect indication of glottal width) are significantly higher in the post−voiceless class than in the post−voiced class. Second, Fo of the post−voiceless class is significantly higher than that of its voiced counterpart. Considering these phonetic findings, this study found no evidence for replacing the laryngeal features of [+/−voice] currently used in phonological studies for the phonological description of the English affricates.

In actuality, the phonetic findings of the present study for the Korean affricate series are totally parallel with Ahn's (1999) descriptions for the phonetic properties of the Korean stop series. Specifically, the fact that the tense affricate is, like the tense stop series, characterized by the smallest glottal opening at the vowel onset was confirmed by the lowest H1*−H2* values. On the other hand, the fact that the aspirated affricate shows the largest glottis at the vowel onset was strongly implied by the largest H1*−H2* values, which were also true for the Korean aspirated stop series. Considering these facts, we can argue that the main difference in laryngeal function between tense and aspirated stop and affricate categories is controlled by the dimension of glottal width—i.e., the creaky phonation for tense stops and the breathy phonation for aspirated stops. As for the lenis affricate, its laryngeal activity appeared to share the same aim with the lenis stop series—that is, keeping Fo low during the first half of the neighboring vowel, not controlling the glottal width to a certain direction. Remember that the Fo values are significantly lower in the vowel following the lenis affricate than in the vowels following the other two series, and that this Fo pattern is maintained at least up to the 1/2 point of the vowel. Without an intentional maneuver to control laryngeal actions for this purpose, it is not easy to explain how the significantly low Fo is maintained along the vowel. In this respect the Fo pattern of the Korean affricates is different from that of the English affricates for which the significantly different Fo's at the vowel onset are all merged into a single default Fo at the 1/2 point of the vowel. In addition, the H1*−H2* measure of the Korean data did not play any role in distinguishing the lenis affricates from the other two affricate classes.

According to Stevens (1980), the stiffening of vocal folds has the consequence of increasing Fo for vowels, while the slackening of vocal folds decrease Fo for vowels Incorporating this suggestion, Halle and Stevens (1971) suggested the two-dimensional phonological features for laryngeal activities−−that is, a dimension of glottal width consists of [constricted glottis] and [spread glottis] features; another dimension of Fo is made up of [stiff vocal folds] and [slack vocal folds] features. Based on the phonetic findings, this study strongly supports their model as an appropriate system for the phonological representations of the Korean affricate sounds as well as those of the Korean stop sounds. Specifically, this paper suggests the features of [constricted glottis, stiff vocal folds] for the phonological description of the tense affricate, and the features of [spread glottis, stiff vocal folds] for that of the aspirated affricate, and a single feature of [slack vocal folds] for that of the lenis affricate.

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