On the Typology of Laryngeal Contrasts: The Case of Korean Fricatives

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0. Introduction

In an extensive crosslinguistic review of laryngeal contrasts, Jansen (2004) states that plosives seem to divide into four basic phonetic categories: prevoiced lenis, passively voiced lenis, unaspirated voiceless fortis, and aspirated voiceless fortis. Languages make use of these laryngeal categories in two main ways, giving rise on the one hand to a group of 'voicing' languages in which fortis and lenis plosives are differentiated more by the presence of periodicity during closure than by voice onset time (VOT), and on the other hand to a group of 'aspirating' languages in which they are differentiated more by VOT than by periodicity.

On the basis of less abundant work on laryngeal contrasts in fricatives and affricates, Jansen comes to the secondary conclusion that fricatives, unlike plosives, seem to divide into only two basic phonetic categories: prevoiced lenis and unaspirated voiceless fortis. In addition, he claims that this seems to be the nature of languages' laryngeal contrasts in fricatives regardless of the nature of their laryngeal contrasts in plosives (i.e. whether they are 'voicing' languages or 'aspirating' languages). However, the two fricatives of Korean present a counterexample to this generalization, since one has often been analyzed as aspirated as opposed to lenis and, moreover, both are voiceless.

The purpose of this study is thus twofold: to arrive at an analysis of laryngeal contrast in Korean fricatives on the basis of acoustic and perceptual data, and to investigate the extent to which this analysis supports or contradicts Jansen's characterization of laryngeal contrasts in fricatives. What are the cues that are most important in signaling the contrast in Korean fricatives? What does this cue hierarchy suggest about the correspondence between Korean fricatives and the four aforementioned phonetic categories? Finally, how does the Korean contrast fit into Jansen's typology?

1. Previous Research

1.1. Plosives

A great deal of past research has investigated the articulatory, aerodynamic, and acoustic characteristics of the three-way laryngeal contrast in Korean plosives.

From the results of these studies, it is generally known that the three laryngeal series (lenis, fortis, and aspirated[1]) are differentiated from each other along a number of dimensions word- and phrase-initially: linguopalatal contact, glottal configuration, subglottal and intraoral pressure, laryngeal and supralaryngeal articulatory tension, VOT, fundamental frequency (F0) of vowel onset, intensity of vowel onset, and voice quality of vowel onset.[2]

1.1.1. Articulatory and Aerodynamic Differences among the Plosives

Articulatorily the lenis, fortis, and aspirated plosives differ from each other in several ways. One notion often employed to capture the distinction is "strength" or "tension", with the fortis and aspirated plosives thought to be stronger and to involve greater articulatory tension than the lenis ones. This tension is realized in the form of greater amplitude, duration, and buildup of high pressure; faster glottal vibration upon the onset of periodicity; and a greater degree of articulatory muscle activity (cf. C.-W. Kim 1965, Hardcastle 1973). Linguopalatal contact has also been shown via electropalatographic techniques to be much more robust for fortis and aspirated plosives than for lenis ones (Cho and Keating 2001).

In addition, glottal configuration has been found to differ significantly across these three series, with the aperture being widest for aspirated plosives, intermediate for lenis plosives, and narrowest for fortis plosives (cf. C.-W. Kim 1970, Kagaya 1974). Kagaya in particular argued that the fortis and aspirated plosives are associated with "positive inherent laryngeal gestures"—the fortis series being associated with glottal adduction and stiffening, abrupt glottal relaxation near the onset of voicing, increasing subglottal pressure, and glottal lowering before release; and the aspirated series being associated with glottal abduction and increased subglottal pressure. The lenis plosives, however, constitute the unmarked member of the trio, not being associated with any of these gestures.

In an electromyographic study, Hirose et al. (1974) made more concrete the notion of "tension" by demonstrating a spike in thyroarytenoid muscle activity prior to the release of fortis plosives (resulting in increased inner glottal tension

[1] These laryngeal series have acquired a variety of names in the literature. The lenis series is also called 'lax', 'weak', 'plain', 'slightly aspirated', and 'breathy'; the fortis series is also called 'tense', 'strong', 'glottalized', 'long', 'unaspirated', and 'forced'; and the aspirated series is also called 'heavily aspirated', 'strongly aspirated', and 'super aspirated'. In this paper they will be referred to as lenis, fortis, and aspirated, respectively.

[2] The somewhat complementary dimensions of closure duration and vowel length also appear to be important cues to the laryngeal distinction, but primarily in postvocalic and intervocalic environments. The duration of fortis and aspirated plosives is much longer than that of lenis plosives; conversely, vowels are longer before lenis plosives than before aspirated or fortis plosives. While the closure duration characteristics also appear to hold in word-initial position (cf. Cho and Keating 2001), they are unlikely to serve as a cue here, since it would be difficult for a listener to separate the silence of (voiceless) closure from normal pre-utterance silence. As this paper focuses on the laryngeal contrast in prevocalic position, these factors are not discussed further here. For more details, see Silva (1992), M.-R. Kim (1994), J.-I. Han (1996), Cho and Keating (2001), and references cited therein.

and constriction at the time of oral closure) as compared to aspirated and lenis plosives. Aspirated plosives were instead associated with total suppression of the adductor muscles before release (followed by a sharp increase in adductor muscle activity with the onset of periodicity), while lenis plosives were associated with less marked suppression of the adductor muscles and no sharp increase in thyroarytenoid muscle activity prior to release. In a study of lenis and fortis plosives, Dart (1987) also expanded upon the notion of "tension" by concluding that the production of fortis plosives involves greater vocal tract wall tension than lenis plosives.

Aerodynamic differences between lenis and fortis plosives constituted another one of Dart's (1987) findings. According to her results, the main difference between these two series aerodynamically appears to be a "higher intraoral pressure before release, yet a lower oral flow after release." As noted by Cho et al. (2002), this is quite unusual, since higher pressure is normally built up precisely to be released, resulting in higher instead of lower oral flow.

1.1.2. Acoustic Differences among the Plosives

Acoustic differences between lenis, fortis, and aspirated plosives are numerous as well. VOT as well as several attributes of the following vowel have been pointed to as cues to the laryngeal status of the preceding plosive. In actuality none of these cues alone differentiates all three series from each other due to a high degree of overlap between two or sometimes all three categories with respect to their range of realizations of these phonetic dimensions. Instead, the combination of two or more cues is necessary to make a full three-way division.

Among these cues, VOT and F0 have usually been considered the most salient ones (cf. M. Kim 2004). With respect to VOT, the fortis series has the shortest and the aspirated series the longest, with the lenis series in between. Han and Weitzman (1970) claim that the VOT difference between lenis and fortis is not perceptually significant and, thus, that VOT serves to distinguish aspirated from lenis and fortis. A similar conclusion is reached by Lisker and Abramson (1964). However, many others (e.g. Hardcastle 1973, Hirose et al. 1974, J.-I. Han 1996, Cho et al. 2002, Choi 2002) have noted that the VOT ranges of the aspirated series and the lenis series overlap to a large degree, and as such M. Kim (2004) has argued that VOT is actually a more reliable cue for setting apart fortis from lenis and aspirated. As for F0, the lenis series has the lowest and the aspirated series the highest, with the fortis series in the middle. Again, however, the F0 distributions of the fortis and aspirated series overlap to a large degree (cf. J.-I. Han 1996, Choi 2002, M. Kim 2004, among others).

Other qualities of the following vowel have been noted as distinguishing the three series as well. Intensity buildup is quicker following fortis plosives than lenis or aspirated plosives (Han and Weitzman 1970). In addition, vowels following lenis plosives are accompanied by breathiness (cf. N. Han 1998, Kim and Duanmu 2004), as indicated by positive differences between the first and second harmonics of the spectrum (i.e. H1-H2, cf. Ladefoged 2003). Conversely, it has been claimed that vowels following fortis plosives have characteristics of creaky voice (Abberton 1972), but this result has not been duplicated by other researchers (N. Han 1998).

1.2. Fricatives

While much of the literature has concentrated on the nature of the three-way contrast among the plosives, comparatively few studies have investigated the two-way contrast between the fricatives. The identification of the first fricative as a fortis sibilant /s*/ has been relatively uncontroversial, but there is disagreement over the proper analysis of the non-fortis fricative. In some phonological processes such as Post-Obstruent Tensing (cf. S. Kim 2003, Park 2004), it patterns with the lenis plosives (becoming fortis following an obstruent just as the lenis plosives do). However, in other processes such as Intervocalic Lenis Stop Voicing (cf. Jun 1993), it patterns with the aspirated plosives (remaining voiceless intervocalically just as the aspirated plosives do).

1.2.1. Phonetic Differences between the Fricatives

Aspects of the non-fortis fricative's phonetic realization are similarly equivocal. Some bear more similarities to the features of the aspirated plosives than the lenis plosives. For instance, the F0 onset associated with it is close to that of the fortis fricative, in keeping with the closeness in F0 onset between the fortis and aspirated plosives, and its duration word- and phrase-initially is similar to that of the aspirated plosives (cf. K.-S. Kang 2000). In addition, the glottal configuration associated with it is similar to that of the aspirated plosives (cf. Kagaya 1974), with an opening that is significantly larger than that for the fortis fricative (cf. Jun et al. 1998). The fricative is thus heavily aspirated like the aspirated plosives (cf. K.-S. Kang 2000, Cho et al. 2002). Yoon's (1999) acoustic analyses further suggest that before mid and low vowels the duration of the aspiration interval is the only consistent difference between the two fricatives, and thus he concludes that "the duration of the aspirated segment alone can act as the primary cue for the aspirated/[fortis] distinction" (1999:iv).

On the other hand, the non-fortis fricative has significantly less linguopalatal contact than the fortis fricative (cf. S. Kim 2001), a difference similar to that between lenis and fortis plosives, and its shortened intervocalic duration is similar to that of the lenis plosives (cf. K.-S. Kang 2000, Cho et al. 2002). With respect to initial duration, Cho et al. (2002) report that including aspiration the non-fortis fricative is actually longer than the fortis fricative (which makes it seem more like the aspirated plosives than the lenis plosives), but excluding aspiration it is much shorter than the fortis fricative (which makes it seem more like the lenis plosives than the aspirated plosives). Their data also showed that the non-fortis fricative's F0 onset is generally lower than that associated with the fortis fricative (which makes it seem like the lenis plosives vis-à-vis the fortis plosives), but this was not a statistically significant trend; when they compared its F0 onset to the F0 distributions of lenis and aspirated plosives, in fact they found that it was similar to neither and fell in between. Moreover, when the non-fortis fricative is flanked by voiced sounds, though it remains voiceless it undergoes vocal fold slackening similar to that seen in the lenis plosives in the same environments (cf. Iverson 1983). Cho et al. (2002) go further in claiming that it even becomes voiced in this environment as often as 46% of the time, though the voicing they found was gradient and did not appear to be phonologized in the same way it is for lenis plosives (also, this result has not been duplicated by other researchers). Finally, H1-H2 and H1-F2 values for the non-fortis fricative are significantly higher than those for the fortis fricative (Cho et al. 2002), which indicates breathy phonation similar to that seen after lenis plosives. However, it should be noted that it is not clear that breathy phonation can be said to exclusively characterize the lenis plosives. Cho et al. (2002) themselves demonstrate that while H1-H2 and H1-F2 values are highest for the lenis plosives among the three series, these values are next highest for the aspirated plosives (with those for the fortis plosives being the lowest). Consequently, this sort of evidence has also been used to argue in favor of analyzing the non-fortis fricative as aspirated (cf. Park 1999).

Not surprisingly, then, the non-fortis fricative has been analyzed in various ways in the literature—as aspirated by some (e.g. Kagaya 1974; Park 1999, 2002; Yoon 1999, 2002), as lenis by others (e.g. Iverson 1983, Cho et al. 2002, H. Kang 2004), and as both aspirated and lenis by others still (e.g. K.-S. Kang 2000, 2004).

1.2.2. Perception of the Fricatives

In addition to exploring the acoustics of these fricatives, a few studies have examined their perception in some detail. Yoon (1999) conducted an experiment in which he synthesized syllables with an aspirated fricative [s^h] as onset and the vowel [a] as nucleus. He found that when the aspiration interval was shortened or removed, perception shifted from aspirated to fortis for most speakers at around 37 ms of aspiration. In another experiment, Yoon (1999, 2002) took natural utterances of words beginning with /s^h/ and generated stimuli by incrementally reducing the aspiration noise interval by 10 ms. Here, too, he found that perception shifted from aspirated to fortis, but only for some listeners:

> It was sometimes the case that perception did not shift from aspirated to [fortis] even when the same amount of aspiration as for the [fortis] fricative was present. In cases such as this, more aspiration reduction was necessary for the expected perception shift, indicating that the aspiration noise duration was not the only parameter for the aspirated/[fortis] distinction. (2002:184)

What might the other parameters for the distinction be? The characteristics of the laryngeal distinction in the plosives have been summarized in §1.1 above. One point that becomes evident from this discussion is that many of the cues to the laryngeal contrast among the plosive consonants are actually contained in the vowels that follow them. It follows that the vowels are the next logical place to look for information signaling the laryngeal contrast between the fricatives.

1.3. The Relative Contribution of Vocalic Information

Vowels carry so much of the information about the laryngeal distinction that some studies have demonstrated that perception of the contrast is quite good on the basis of vocalic information alone. M.-R. Kim et al. (2002), for example, found in a series of perception experiments that vowels extracted from syllables with lenis onsets largely sufficed to cue lenis plosives, while vowels extracted from syllables with aspirated and fortis onsets both tended to draw fortis identifications.

Among the cues provided by the vowel as to the laryngeal state of a consonant are F0, intensity, and voice quality, as discussed above. In addition to this information, Kluender (1991) adds first formant (F1) onset. In experiments with both human listeners and Japanese quail, he found that among the various aspects of the vowel onset related to F1, F1 onset frequency was the best predictor of voiced/voiceless labeling judgments. Later work by Benkí (2001, 2005) involving English and Spanish speakers confirmed the role of F1 onset frequency in the perception of voicing and emphasized the role of the F1 transition pattern as well.

In the case of a high consonant and a low vowel, a higher F1 onset and shallower F1 transition pattern are associated with the category having the longer VOT (i.e. the voiceless consonants). Since F1 increases in frequency as the tongue lowers from the point of consonantal occlusion into the position for vocalic articulation, this correlation is the natural result of the longer delay between consonantal release and voicing onset. In other words, with a long VOT, the tongue has more time to get into position for the vowel and thus is closer to the target position by the time the vocal folds start vibrating. Conversely, when the VOT is short, the tongue has very little time to get into position for the vowel and the vocal folds may start vibrating well before the tongue ultimately reaches the target position; thus, the F1 onset is lower and the F1 transition pattern steeper.

Park (2002) investigated the time courses of F1 and F2 as realized in the three laryngeal types in some detail. Her results indicated significant differences in F1 trajectory among the three laryngeal series. Specifically, F1 peaks earlier and higher in the aspirated series than in the fortis or lenis series. Data for F2 trajectories also showed some differences among the three series, but was less conclusive.

1.4. Summary

While the two-way contrast between the fricatives bears similarities to the three-way contrast among the plosives, there are significant differences, one of which is precisely the binary nature of the distinction. The categorization of the non-fortis fricative has consequently become a puzzling question. Another key point that has arisen out of the literature is that cues to the laryngeal identity of a consonant are largely carried on the following vowel. Thus, the present study reexamines the distribution of the Korean fricatives along the acoustic dimensions discussed above as well as the relative contribution of these consonantal and vocalic cues to the percept of these fricatives.

2. Production Study

The first part of the present study investigates a number of acoustic features of fricatives in Seoul Korean—specifically, segmental duration, aspiration duration, F0 onset, F1 onset, intensity buildup, and voice quality in the following vowel, as well as vowel length.

2.1. Methods

2.1.1. Materials

A word list of Korean monosyllables was constructed such that obstruents of all places of articulation and laryngeal states occurred before the three vowels /a, i, u/. Where no common monosyllabic words were available, the first syllables of multisyllabic words were used. In this way, all stimuli that were later used in the perception experiment were recorded as open monosyllables.

2.1.2. Subjects

The subjects in the production study were five native speakers of Korean, two males and three females in their 20s and 30s. The first male speaker (S2) and first and second female speakers (S1 and S3) were born and grew up in Seoul; the second male speaker (S5) was born in Seoul and grew up in the U.S. in a Korean-speaking family; and the third female speaker (S4) was born in the U.S. and grew up in Chile in a Korean-speaking family.

2.1.3. Procedure

The sound files for speakers S1, S2, and S3 were recorded in quiet rooms as mono sound files in Praat 4.2.17 using a Sony Vaio PCG-TR5L laptop computer and a Shure C608 microphone, and the sound files for speakers S4 and S5 were recorded in a sound-attenuated booth using a digital recording device. For all subjects and target words, three tokens were collected in isolation.

All measurements were taken in Praat 4.2.17. Segmental duration of the fricative onset was measured from the onset of high frequency noise to the onset of periodicity in the vowel; aspiration duration[3] was measured from the onset of a more distributed spectrum with low frequency noise after the sibilant fricative to the onset of periodicity; F0 was measured over the first three pitch points in the vowel resulting from the default autocorrelation method used by Praat; F1 was measured at the first visible glottal cycle; intensity was measured at the beginning of each of the first ten glottal cycles as well as across the whole vowel; H1-H2 values were calculated across a spectrum of the first four glottal cycles; and vowel length was measured from the first glottal cycle to the end of visible periodicity.

With regard to other relevant settings, the spectrogram method was Fourier and the window shape was Gaussian, with a window length of 5 ms, dynamic range of 70 dB, and pre-emphasis of 6 dB/octave. All statistical analyses were done in SPSS 13.0.

Below are two spectrograms of /s^{h}a/ ‘buy’ and /s*a/ ‘wrap’. The portions of the spectrogram corresponding to the sibilant fricative, aspiration, and vowel have been demarcated to exemplify the transition points used to measure the duration of these sections.

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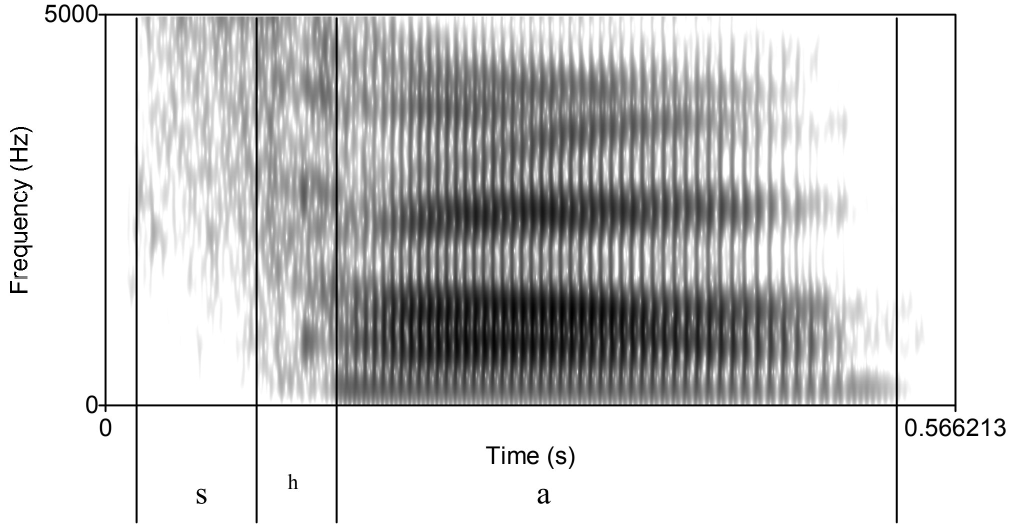
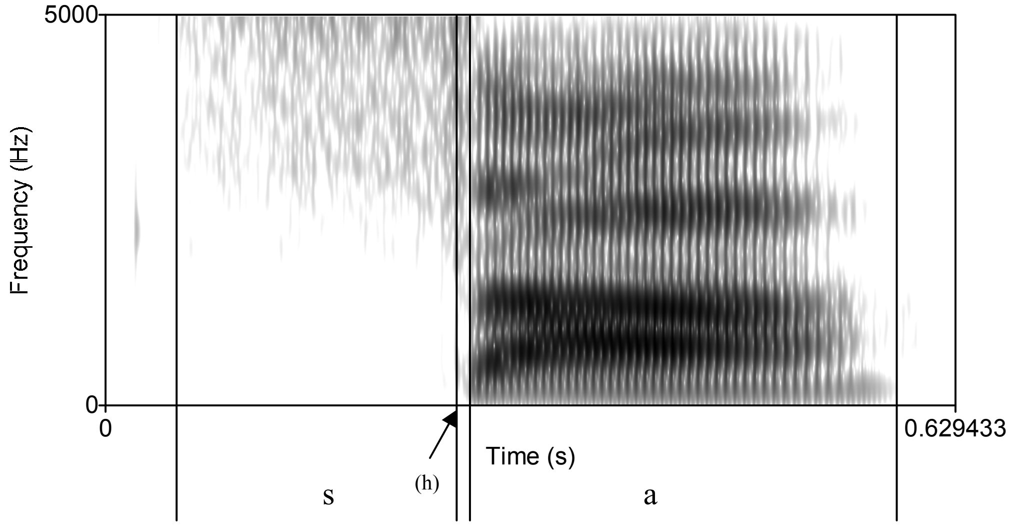
[3] Since the spectra of the fricatives do not have a clearly visible release burst that can serve as the initial measurement point of VOT, aspiration duration was measured instead as a correlate of VOT.

(1) Spectrogram of /s^{h}a/ ‘buy’ [S2, token 2]



(2) Spectrogram of /s*a/ ‘wrap’ [S2, token 2]



As acknowledged by Yoon (2002), taking measurements by hand leaves open the possibility of human error, but the dividing line between the high frequency energy of the sibilant and the low frequency energy of the aspiration is distinct enough that measurements can be taken with a high degree of consistency.

2.2. Results

2.2.1. Segmental Duration

The durational data for the five subjects’ productions of /s^{h}a/ and /s*a/ are given below.[4]

(3) Duration of [s^h] in /s^ha/ 'buy' (in ms)

	S1	S2	S3	S4	S5
Token 1	120	158	114	169	200
Token 2	105	127	110	195	187
Token 3	105	173	102	199	243
Average	**110**	**153**	**109**	**188**	**210**
StDev	9	23	6	16	29

(4) Duration of [s*] in /s*a/ 'wrap' (in ms)

	S1	S2	S3	S4	S5
Token 1	141	167	167	208	232
Token 2	199	252	198	198	222
Token 3	201	236	212	193	210
Average	**180**	**218**	**192**	**200**	**221**
StDev	34	45	23	8	11

For all subjects the fortis fricative is longer than the non-fortis fricative, and the difference is statistically significant ($t = -4.046$, $df = 14$, $p = 0.001$). Note that these data contradict the results of Cho et al. (2002), who claimed that the non-fortis fricative including aspiration was longer than the fortis fricative. On the contrary, the data above indicate that the fortis fricative can be nearly twice as long as the non-fortis fricative for some speakers.

2.2.2. Aspiration Duration

The data for aspiration duration in the five subjects' productions of /s^ha/ and /s*a/ are given below.

(5) Aspiration duration in /s^ha/ 'buy' (in ms)

	S1	S2	S3	S4	S5
Token 1	95	54	43	73	79
Token 2	62	32	15	93	69
Token 3	76	44	29	79	99
Average	**78**	**43**	**29**	**82**	**82**
StDev	17	11	14	10	15

[4] Abbreviations: StDev = standard deviation, S1 = Speaker S1, S2 = Speaker S2, etc.

(6) Aspiration duration in /s*a/ ‘wrap’ (in ms)

	S1	S2	S3	S4	S5
Token 1	15	9	20	9	13
Token 2	12	9	10	11	18
Token 3	15	10	11	10	15
Average	**14**	**9**	**14**	**10**	**15**
StDev	2	1	6	1	3

These data corroborate the results of previous studies. For all subjects the aspiration interval is much shorter in the fortis fricative than in the non-fortis fricative, and the difference is highly significant ($t = 7.775$, $df = 14$, $p < 0.0001$). The aspiration interval is often on the order of four times as long in the non-fortis fricative and sometimes over eight times as long (cf. S4).

2.2.3. F0 Onset

The fundamental frequency data for the five subjects’ productions of /s^{h}a/ and /s*a/ are given below.

(7) F0 onset in /s^{h}a/ ‘buy’ (in Hz)

	S1	S2	S3	S4	S5
Token 1	244	167	303	261	120
Token 2	249	162	301	252	124
Token 3	241	158	285	234	128
Average	**245**	**162**	**296**	**249**	**124**
StDev	4	5	10	14	4

(8) F0 onset in /s*a/ ‘wrap’ (in Hz)

	S1	S2	S3	S4	S5
Token 1	250	172	295	261	135
Token 2	235	163	296	236	125
Token 3	233	163	282	225	130
Average	**239**	**166**	**291**	**241**	**130**
StDev	9	5	8	18	5

These data again contradict the results of Cho et al. (2002), who found a general, though not statistically significant, trend for the non-fortis fricative to be associated with a lower F0 than the fortis fricative. The very slight differences seen above are also not statistically significant ($t = 0.873$, $df = 14$, $p > 0.3$) and, moreover, do not form any sort of trend, failing to fall in the same direction across speakers.

2.2.4. F1 Onset

The first formant data for the five subjects' productions of /s^{h}a/ and /s*a/ are given in the tables below.

(9) F1 onset in /s^{h}a/ 'buy' (in Hz)

	S1	S2	S3	S4	S5
Token 1	927	635	1201	1020	831
Token 2	926	473	907	958	777
Token 3	902	658	947	1000	751
Average	**918**	**589**	**1018**	**993**	**786**
StDev	14	101	159	32	41

(10) F1 onset in /s*a/ 'wrap' (in Hz)

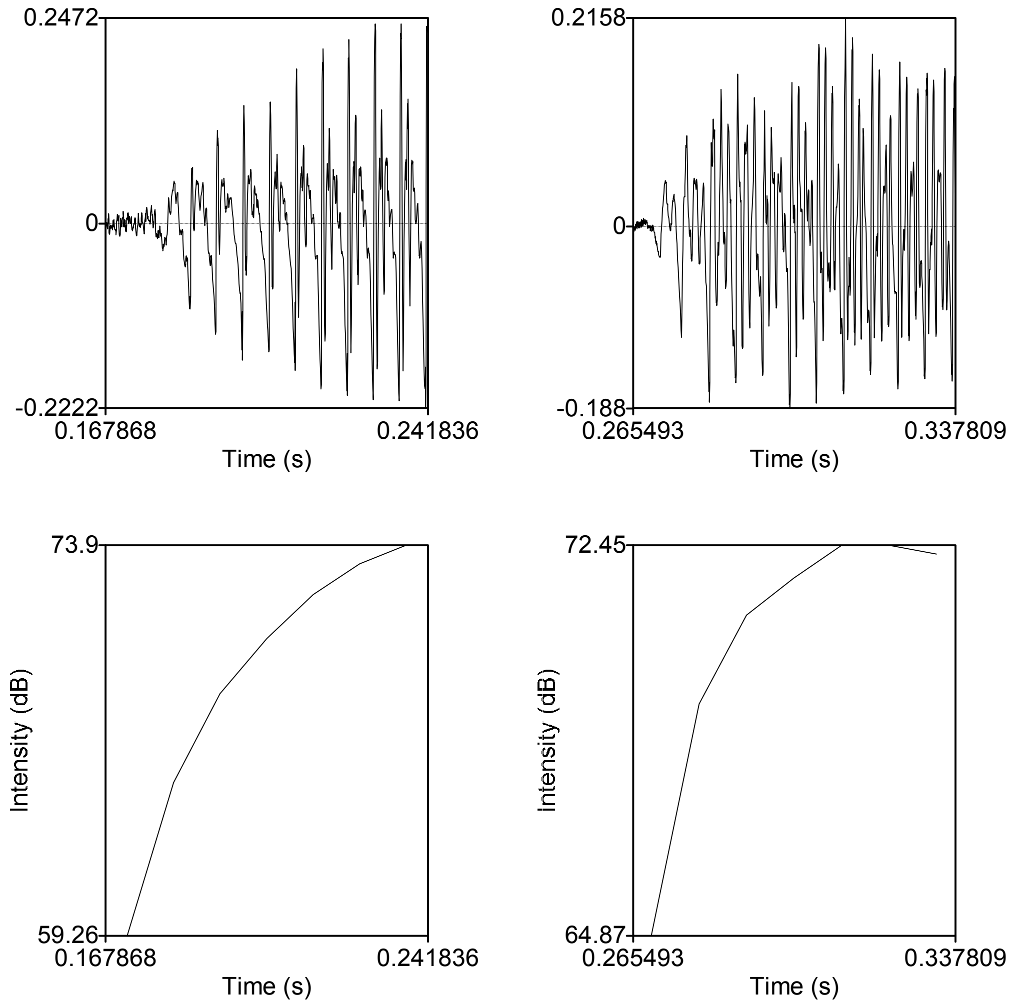
	S1	S2	S3	S4	S5
Token 1	480	436	581	656	646
Token 2	570	432	556	659	668
Token 3	566	393	588	564	678
Average	**539**	**420**	**575**	**626**	**664**
StDev	51	24	17	54	16

These data also corroborate the results of previous studies. For all subjects the first formant starts lower in the fortis fricative than in the non-fortis fricative, and the difference is strongly significant ($t = 7.393$, $df = 14$, $p < 0.0001$). The difference between the two fricatives' F1 onsets is over 100 Hz for all subjects and nearly 500 Hz for some (cf. S1, S3).

2.2.5. Intensity Buildup

The next acoustic dimension explored in the production study was intensity buildup. Han and Weitzman (1970) found that intensity buildup is quicker following fortis plosives than following lenis or aspirated plosives. This difference is indeed reflected in the intensity buildup following the two fricatives, as seen in the following comparisons of the waveforms and intensity contours of the first ten glottal cycles in /s^{h}a/ and /s*a/ (from the two tokens used in the perception experiment, cf. §3).

(11) Waveforms and intensity contours of /s^{h}a/ ‘buy’ (L) and /s*a/ ‘wrap’ (R)



As with the plosives, intensity appears to increase more sharply after a fortis fricative than after a non-fortis fricative.

In order to confirm the significance of these apparent differences, the rate of intensity buildup was measured. In the absence of a standard measure, the rate of change was measured via differences between individual intensity measurements (intensity was measured at the beginning of each of the first ten glottal periods, and the intensity difference between adjacent periods was then calculated as the intensity of one period minus the intensity of the preceding period). Thus, in the data that follows, greater (i.e. more positive) intensity differences indicate sharper intensity buildup, while less positive differences indicate more gradual intensity buildup (with negative values indicating an intensity decrease instead of an increase). These data are given below for the two tokens of /s^{h}a/ and /s*a/ used in the perception experiment.

(12) Intensity buildup in /s^{h}a/ ‘buy’ and /s*a/ ‘wrap’ (in dB)

	/s^{h}a/ [S2, token 1]	/s*a/ [S2, token 2]
Period 2 – Period 1	2.0	2.3
Period 3 – Period 2	1.8	1.4
Period 4 – Period 3	1.3	1.1
Period 5 – Period 4	1.2	0.4
Period 6 – Period 5	0.9	0.5
Period 7 – Period 6	0.8	0.4
Period 8 – Period 7	0.6	0.2
Period 9 – Period 8	0.5	0.1
Period 10 – Period 9	0.4	-0.1

There are marked differences between /s^{h}a/ and /s*a/, and these differences are significant ($t = 3.653$, $df = 8$, $p = 0.006$). In /s*a/, intensity increases sharply at first and then levels off quite rapidly, whereas in /s^{h}a/, intensity increases fairly gradually and does not begin to level off until after the tenth glottal cycle. These results confirm the findings of Han and Weitzman (1970) regarding intensity buildup: intensity increases more rapidly following a fortis consonant than following a non-fortis consonant. Thus, it appears that intensity buildup might also serve as a cue to the fricative distinction.

In addition to measuring intensity buildup, average intensity across the whole vowel was measured to see if there might also be a basic difference in average intensity between the two fricatives. Measurements for all fifteen tokens of /s^{h}a/ and /s*a/ are given below.

(13) Average vowel intensity in /s^{h}a/ ‘buy’ (in dB)

	S1	S2	S3	S4	S5
Token 1	66.6	67.3	69.4	74.3	68.0
Token 2	66.3	67.1	69.5	73.2	68.1
Token 3	66.9	68.6	69.6	71.6	64.1
Average	**66.6**	**67.7**	**69.5**	**73.0**	**66.7**
StDev	0.3	0.8	0.1	1.4	2.3

(14) Average vowel intensity in /s*a/ ‘wrap’ (in dB)

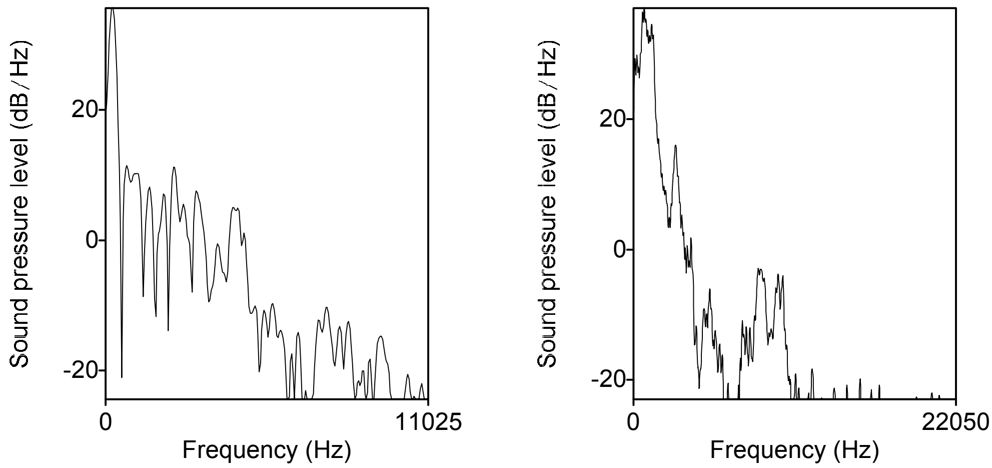
	S1	S2	S3	S4	S5
Token 1	65.9	68.0	72.1	75.0	69.5
Token 2	67.8	68.3	73.6	71.5	66.4
Token 3	65.5	65.5	71.0	70.5	68.6
Average	**66.4**	**67.3**	**72.2**	**72.3**	**68.2**
StDev	1.2	1.5	1.3	2.4	1.6

While the data for intensity differences show some significant differences, the data for average intensity do not (t = -1.012, df = 14, p > 0.3). On the other hand, intensity measures in the first five glottal periods do show significant differences, with intensity generally being higher in /s*a/ than /s^ha/ (t = -8.481, df = 74, p < 0.0001).

2.2.6. H1-H2 Difference

The voice quality of the vowel onset has also been shown to differ between the two fricatives, as indicated by more positive differences between the first and second harmonics (H1-H2) following non-fortis obstruents. This difference is illustrated in representative spectra of /s^ha/ and /s*a/ below (in both cases from S1, token 2).

(15) Representative spectra of /s^ha/ 'buy' (L) and /s*a/ 'wrap' (R)



As seen in these spectra, the first harmonic (H1) is much higher than the second harmonic (H2) in the case of /s^ha/.

The H1-H2 values for the five subjects' productions of /s^ha/ and /s*a/ were thus measured, and these data are given in the tables below.

(16) H1-H2 differences in /s^ha/ 'buy' (in dB)

	S1	S2	S3	S4	S5
Token 1	21.5	6.1	10.2	5.3	-1.2
Token 2	24.2	14	6.5	13.2	-0.6
Token 3	25.1	6	11.5	17.9	0.1
Average	23.6	8.7	9.4	12.1	-0.6
StDev	1.9	4.6	2.6	6.4	0.7

(17) H1-H2 differences in /s*a/ ‘wrap’ (in dB)

	S1	S2	S3	S4	S5
Token 1	-3.8	0.2	-10.4	-1.7	-0.9
Token 2	0.3	-1.7	-7.2	-2.5	1.4
Token 3	1.4	0.2	-11.6	-2.9	-1.7
Average	-0.7	-0.4	-9.7	-2.4	-0.4
StDev	2.7	1.1	2.3	0.6	1.6

These data agree with the results of previous studies. H1-H2 values are generally more positive in /s^ha/ than in /s*a/, and this difference is strongly significant ($t = 5.412$, $df = 14$, $p < 0.0001$).

2.2.7. Vowel Length

The final acoustic dimension explored in the production study was vowel length. Although vowel length has not usually been claimed to differ following initial obstruents in Korean, some (e.g. K.-S. Kang 2000) argue that the non-fortis fricative’s shortened duration intervocalically triggers compensatory lengthening of the following vowel. In addition, studies such as Cho and Keating (2001) have shown that closure duration differs significantly between fortis and non-fortis plosives even in word-initial position; it follows that there could be a complementary effect of “compensatory shortening” resulting in significantly shorter vowels following the longer fortis fricatives than the shorter non-fortis fricatives. Thus, vowel length in /s^ha/ and /s*a/ was also measured, and the durational data are given below.

(18) Vowel length in /s^ha/ ‘buy’ (in ms)

	S1	S2	S3	S4	S5
Token 1	455	401	394	117	86
Token 2	428	382	413	117	95
Token 3	391	287	353	122	87
Average	**425**	**357**	**387**	**119**	**89**
StDev	32	61	31	3	5

(19) Vowel length in /s*a/ ‘wrap’ (in ms)

	S1	S2	S3	S4	S5
Token 1	433	393	379	147	167
Token 2	442	322	374	146	171
Token 3	393	331	446	163	168
Average	**423**	**349**	**400**	**152**	**169**
StDev	26	39	40	10	2

Similar to the data for F0 onset, there does not seem to be a trend present here.

For some subjects (cf. S1, S2), the vowel following the fortis fricative is slightly shorter than following the non-fortis fricative, but for more subjects (cf. S3, S4, S5), the vowel following the fortis fricative is actually longer. However, these differences are not statistically significant ($t = -1.905$, $df = 14$, $p > 0.05$; for S2, the subject whose sound files were used in the perception experiment, $t = 0.266$, $df = 2$, $p > 0.8$).

2.3. Summary

In comparing the acoustic features of /s^h/ and /s*/, it is apparent that these segments are produced with (i) significantly different durations (the fortis fricative being longer than the non-fortis fricative), (ii) significantly different aspiration intervals (the fortis fricative's being shorter than the non-fortis fricative's), (iii) significantly different F1 trajectories (F1 after the fortis fricative starting lower than after the non-fortis fricative), (iv) significantly different patterns of intensity buildup (intensity increasing more rapidly after the fortis fricative than after the non-fortis fricative), and (v) significantly different voice onset qualities (a more breathy quality after the non-fortis fricative than after the non-fortis fricative, as indicated by positive H1-H2 values). On the other hand, F0 onset, average vowel intensity, and vowel length do not appear to be distinguishing factors. With these acoustic facts in mind, the contributions of segmental duration, aspiration duration, F1 onset, intensity buildup, and voice quality to the percepts of the two fricatives were investigated in a perception experiment.

3. Perception Study

The goal of this experiment was to examine how the cues of segmental duration, aspiration duration, F1 onset, intensity buildup, voice quality, and F0 onset are merged in the percept of Korean fricatives. The first five cues were seen above to show significant differences across the two fricatives; the sixth cue, F0 onset, did not show significant differences across the two fricatives, but was included as well since it has been shown to play a significant role in differentiating the plosives (cf. §1.1.2).

3.1. Methods

3.1.1. Experimental Design

There were four within-groups factors in this experiment: (i) segmental duration, (ii) aspiration duration, (iii) F0 onset, and (iv) F1 onset/intensity buildup/H1-H2. The details of the experimental design are summarized below.

(20) Design of perception experiment

Factor	*Range*	*Levels*	*Values of Levels*
SEGMENTAL DURATION	125 ms ~ 250 ms	4	125 ms
			165 ms
			205 ms
			250 ms
ASPIRATION DURATION	10 ms ~ 60 ms	3	10 ms
			35 ms
			60 ms
F0 ONSET	145 Hz ~ 185 Hz	5	145 Hz
			155 Hz
			165 Hz
			175 Hz
			185 Hz
F1 ONSET / INTENSITY BUILDUP / H1-H2 (≈ original affiliation of V)	/s^ha/ V ~ /s*a/ V	2	high F1, gradual intensity buildup, large/positive H1-H2
			low F1, sharp intensity buildup, small/negative H1-H2

Note that F1 onset, intensity buildup, and H1-H2 were combined into one factor due to the fact that none of these acoustic dimensions can be easily manipulated in a program like Praat.

Since it was ultimately S2's recordings that were used for the production experiment (due to having the least background noise and most consistent amplitude levels), the range for the first three factors was based on the range present in S2's production data (cf. §2.2.1-2.2.3 above) and, when possible, expanded within reasonable limits. Thus, his 127-252 ms range in segmental duration translated to a 125-250 ms range in the segmental duration factor; his 9-54 ms range in aspiration duration translated to a 10-60 ms range in the aspiration duration factor; and his 158-172 Hz range in F0 onset was expanded to a 145-185 Hz range in the F0 onset factor.

The whole experiment contained 120 fricative stimuli (4 levels of segmental duration x 3 levels of aspiration duration x 5 levels of F0 onset x 2 levels of F1 onset/intensity buildup/H1-H2) as well as 120 filler stimuli (cf. §3.1.2 below) for a total of 240 stimuli.

3.1.2. Stimuli

Six words were used for all the stimuli in the experiment. These are listed with glosses in the table below.

(21) Stimuli for perception experiment and pretest

Orthography	*IPA*[5]	*Gloss*
	FRICATIVE STIMULI	
사(다)	/sʰa/	'(to) buy', 'four'
싸(다)	/s*a/	'(to) wrap', '(to) be cheap'
	FILLER STIMULI	
다	/da/	'all'
따(다)	/t*a/	'(to) pluck'
타(다)	/tʰa/	'(to) ride', '(to) burn'
아	/a/	'Ah!'
	PRETEST STIMULI	
자	/d͡ʒa/	'ruler, measure'
짜(다)	/t͡ʃ*a/	'(to) wring', '(to) be salty'
차	/t͡ʃʰa/	'tea', 'car'

The first token of /sʰa/ and the second token of /s*a/ recorded by S2 in the production study provided the basic building blocks for the 120 fricative stimuli. The most difficult step in the generation of the fricative stimuli was the first step undertaken—namely, the generation of the aspiration duration continuum.[6] Aspiration was shortened by removing a central portion of the aspiration noise interval or otherwise lengthened by inserting additional aspiration noise into the center of the aspiration noise interval; in both cases, care was taken to avoid producing a sudden break in any visible formant structure (thus, in removing aspiration noise where there was formant structure, a portion with level formants was removed, and in inserting aspiration noise, the point of insertion was always before any section with formant structure). Additional (formant-less) aspiration noise was copied from the center of S2's /sʰa/ token.

Second, the stimuli in the aspiration duration continuum were manipulated to form parallel segmental duration continua, either by removing a central portion of the sibilant's high frequency noise interval (to shorten the duration) or inserting high frequency noise into the center of the sibilant's high frequency noise interval (to lengthen the duration). Additional high frequency noise was copied from the center of S2's /s*a/ token.

Third, the stimuli in the two-dimensional [segmental duration x aspiration duration] matrix were then expanded along the dimension of F0 onset via Praat's

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[5] Transcriptions follow the conventions of H. Lee (1996) and H.B. Lee (1999).

[6] M. Kim (2004) conducted a similar perception study looking at the interrelationship of VOT and F0 in the perception of the plosives and affricates, but she looked at a naturally wide range of VOT variation in a much larger corpus of recorded tokens rather than manipulating the aspiration noise, which she was careful not to alter due to the fact that it is "not a homogeneous period" and that its "spectral character changes constantly." While this circumspection is well-motivated, it seems that it is precisely the characteristically irregular, heterogeneous nature of aspiration noise that would permit it to be spliced without the inadvertent production of artifacts in the signal. Accordingly, the manipulations of aspiration noise in this study did not produce any audible artifacts.

'Shift pitch frequencies' function, with the entire pitch contour of a given stimulus either raised or lowered in 10 Hz steps.

Finally, the preceding three steps were carried out starting from both original syllables. In other words, aspiration duration was lengthened/shortened starting from the basic /s^ha/ recording and then a second time starting from the basic /s*a/ recording. In this way, the stimuli ultimately produced varied along the four dimensions schematized in (20). It should be noted that neither of the original fricative recordings used as the basis for the other stimuli happened to have exactly the right specifications for any of the first three dimensions; thus, all 120 fricative stimuli were synthesized in at least one way.

As for the filler stimuli, these were produced from fifteen of S2's recordings: three tokens of a minimal triplet containing alveolar plosive onsets and three tokens of /s^ha/ and /s*a/. The alveolar plosive tokens were simply manipulated in terms of F0 to produce ten or eleven filler stimuli from each original token, spread evenly across a range of 110-210 Hz. In the case of the fricative tokens, the frication portion was first removed, and then F0 was manipulated to produce five filler stimuli from each original token spread across a range of 145-185 Hz. The end result was 90 alveolar plosive fillers and 30 'onset-less' fillers for a total of 120 filler stimuli.

3.1.3. Subjects

Sixteen native speakers of Korean (eight females and eight males) ranging in age from 20 to 40 participated in the perception trials. Eleven of the subjects were from Seoul or the surrounding Gyeonggi Province; the other five were from Jeolla Province, Chungcheong Province, and Gangwon Province. None reported any history of hearing disorders.

3.1.4. Procedure

Subjects were asked to take a test in which they would have to listen to words and identify them by clicking buttons on a computer screen. They were told that the goal of the experiment was to see how emotional speech affected intelligibility and that they would thus be hearing many instances of one speaker saying the same words in different emotional states. They were informed that they could only listen to each stimulus once, that they would not hear the following stimulus until they made a decision about the current one, and that they could not go back to a previous stimulus.

Stimuli were presented to subjects via Praat 4.2.17's listening test function on a Sony Vaio PCG-TR5L laptop computer over Direct Sound EX-29 noise reduction headphones. The screen display contained six buttons labeled with the words corresponding to the fricative stimuli and filler stimuli, spelled in Korean orthography. Subjects made their responses via mouse by clicking the button on screen labeled with the word they thought they heard. The stimuli were arranged in a different random order for each subject and presented in four blocks of 60 stimuli, with a one-second delay between a response and subsequent stimulus and a break period after each block (the length of which was controlled by the subject via mouse click). The experiment lasted approximately 20 minutes in all, and subjects were compensated GBP5 for their time.

A short, two-minute pretest containing eighteen presentations of nine stimuli was conducted prior to the real test in order to familiarize the subject with the test procedure. The nine stimuli in the pre-test comprised three tokens each of three words recorded by S2 that were not included in the real test (see Table 21 above for a full list of pretest, filler, and fricative stimuli).

Subjects' responses were coded as integers from 1 to 6, and all statistical analyses were done in SPSS 13.0.

3.2. Results

A repeated-measures analysis of variance (ANOVA) performed on the data indicates a main effect of F1 onset/intensity buildup/H1-H2 and an interaction between F1 onset/intensity buildup/H1-H2 and aspiration duration, but no main effect of segmental duration, aspiration duration, or F0 onset and no other interactions between factors. These results are summarized in the table[7] below, where significant main effects and interactions have been placed in boldface.

(22) Results of repeated-measures ANOVA (Huynh-Feldt corrected[8])

SD	AD	F0	F1/ IB / H1-H2	Main Effects
•				$F(1.5, 22.0) = 1.900, p > 0.1$
	•			$F(1.8, 27.3) = 1.693, p > 0.2$
		•		$F(2.5, 38.2) = 0.241, p > 0.8$
			•	**$F(1, 15) = 139.439, p < 0.0001$**
SD	**AD**	**F0**	**F1/ IB / H1-H2**	**Interactions**
•	•			$F(2.2, 33.7) = 2.178, p > 0.1$
•		•		$F(6.2, 92.6) = 0.583, p > 0.7$
•			•	$F(2.0, 30.6) = 1.348, p > 0.2$
	•	•		$F(5.4, 80.8) = 1.334, p > 0.2$
	•		•	**$F(1.8, 26.7) = 7.059, p = 0.005$**
		•	•	$F(3.6, 53.4) = 0.063, p > 0.9$
•	•	•		$F(9.0, 134.2) = 1.111, p > 0.3$
•	•		•	$F(2.9, 44.1) = 2.819, p > 0.05$
•		•	•	$F(5.4, 81.5) = 1.095, p > 0.3$
	•	•	•	$F(4.6, 69.1) = 1.297, p > 0.2$
•	•	•	•	$F(8.1, 121.2) = 0.980, p > 0.4$

[7] SD = segmental duration, AD = aspiration duration, F0 = F0 onset, F1 = F1 onset, IB = intensity buildup, H1-H2 = difference between the first and second harmonics.

[8] Sphericity has not been assumed in these data, so in all cases the Huynh-Feldt corrected figures have been reported (see Max and Onghena 1999 for further details).

The ANOVA results are largely confirmed by non-parametric tests such as the Friedman test,[9] the results of which are summarized below.

(23) Results of Friedman test

<table>
<tr><th>SD</th><th>AD</th><th>F0</th><th>F1/
IB /
H1-H2</th><th colspan="3">Asymptotic Significance</th></tr>
<tr><td></td><td></td><td></td><td>•</td><td colspan="3">p < 0.0001</td></tr>
<tr><td rowspan="2">•</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">p > 0.4</td><td>p > 0.5</td><td>/s^{h}a/</td></tr>
<tr><td>p > 0.2</td><td>/s*a/</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">•</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">p = 0.001</td><td>p < 0.0001</td><td>/s^{h}a/</td></tr>
<tr><td>p = 0.009</td><td>/s*a/</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">•</td><td rowspan="2"></td><td rowspan="2">p > 0.9</td><td>p > 0.8</td><td>/s^{h}a/</td></tr>
<tr><td>p > 0.9</td><td>/s*a/</td></tr>
</table>

Similar to the ANOVA, the Friedman test indicates a significant effect of F1 onset/intensity buildup/H1-H2. The Friedman test also indicates a significant effect of aspiration duration (which again seems to interact with F1 onset/intensity buildup/H1-H2 to some degree).

To summarize, statistical analyses of the data show a significant effect of F1 onset/intensity buildup/H1-H2 on subjects' response patterns, as well as an interaction between F1 onset/intensity buildup/H1-H2 and aspiration duration. Aspiration duration appears to have a significant effect on responses as well, an effect which is stronger when the F1 onset, intensity buildup, and H1-H2 are characteristic of the non-fortis fricative (i.e. high F1 onset, gradual intensity buildup, positive H1-H2).

4. Discussion

This study has yielded several major findings. In the production domain, it was seen, contra Cho et al. (2002), that the fortis fricative is much longer in duration than the non-fortis fricative, and that there is no difference in F0 onset between the two fricatives. The first point in particular is significant because it constitutes additional evidence in favor of a lenis categorization of the non-fortis fricative (cf. the difference in closure duration between the lenis and fortis plosives vs. the lack of a difference between the aspirated and fortis plosives). The production inquiry also confirmed the results of previous studies which found that (i) aspiration duration is shorter in the fortis fricative than in the non-fortis fricative, (ii) F1 onset is lower after the fortis fricative than after the non-fortis fricative, (iii) intensity buildup is quicker after the fortis fricative than after the non-fortis

[9] One of the assumptions underlying ANOVA is that the data are continuous (cf. Smith 2006). However, in this case the judgment data are nominal scores and not interval or ordinal scores, so it is unclear whether the ANOVA results are truly valid. Thus, the Friedman test, a non-parametric test for repeated measures which does not make the same assumptions as ANOVA, was also run to check the ANOVA results.

fricative, and (iv) voice quality is breathier after the non-fortis fricative than after the fortis fricative.

Perhaps even more interesting are the results of the perceptual investigation. It was found that out of all the acoustic cues examined, the combination of F1 onset/intensity buildup/H1-H2 was the strongest cue to the laryngeal state of a preceding fricative. Aspiration duration was also a significant cue and appeared to have a stronger effect when a high F1 onset, gradual intensity buildup, and positive H1-H2 cuing the non-fortis fricative were present. Finally, F0 onset was found not to be a significant cue, lending support to an aspirated categorization of the non-fortis fricative.

Remember that Yoon (2002) found that not all listeners experienced a perception shift from aspirated to fortis in his categorical perception experiment. He states that a "comparison between the amount of aspiration in the perception test and the actual aspiration from the natural utterances leads us to suspect that other parameters or [a] synergistic effect of other parameters may exist" (184). Indeed, the F1 onset, intensity buildup, and voice quality in the following vowel would appear to be among these other parameters. In the present perception experiment, subjects' responses to any given stimulus aligned overwhelmingly with the fricative category corresponding to the F1 onset, intensity buildup, and H1-H2 of the stimulus (cf. full table of responses in the appendix), suggesting that, for the fricatives at least, F1 onset, intensity buildup, and voice quality are the most important cues to the fortis/non-fortis distinction.

In a way, these results are similar to those of M.-R. Kim et al. (2002), who found that aspirated plosives cross-spliced with vowels from syllables with fortis plosive onsets were identified as fortis a surprisingly high percentage of the time. They observe, however, that the admittedly high variability in their data is due not to random factors, but to systematic differences in how individual subjects resolved the conflicting fortis and aspirated cues from the consonant and vowel: some subjects based their judgments on the consonantal cues, while others based their judgments on the vocalic cues. In both cases, though, they were strikingly consistent, leading M.-R. Kim et al. to hypothesize that "listeners may have been aware of the conflicting cues for initial stop phonation type and consequently chose a consonant- or vowel-based strategy for responding to these stimuli" (2002:92).

While the choice of a response strategy may have had an effect on M.-R. Kim et al.'s (2002) results, if it were the case in the present study that subjects consciously chose a response strategy, then they all happened to choose the same strategy—namely, a vowel-based one. As this scenario seems rather unlikely, it appears that what is at work instead is a true hierarchy among the consonantal and vocalic cues to the laryngeal contrast in the fricatives: the F1 onset, intensity buildup, and voice quality in the vowel outrank the durational cues of the consonant.

Additional evidence for the high ranking of vocalic cues comes from subjects' judgments on the filler stimuli, the onset-less ones in particular. Remember that these were produced by removing the noise portions from the beginning of the original /s^ha/ and /s*a/ tokens, leaving behind only the vowel. Judgments on these stimuli showed a clear pattern: the bare vowels from /s^ha/ were often identified as /a/, while the bare vowels from /s*a/ were nearly always identified as /t*a/. The difference in these two patterns of judgments is highly significant ($p < 0.0001$ in the Friedman test). It appears that low F1 onset, sharp intensity buildup, and modal voice quality were alone enough to create the impression of a fortis plosive, even in the absence of an actual release burst and its cohort of cues.

4.1. Categorization of the Non-Fortis Fricative

Do the results of this study support a particular categorization of the non-fortis fricative? To review, these are the facts that have been marshaled in previous research in favor of the two possible analyses.

(24) Prior evidence for lenis vs. aspirated analyses of the non-fortis fricative

LENIS ANALYSIS	ASPIRATED ANALYSIS
subject to post-obstruent tensing	not subject to intervocalic voicing
less linguopalatal contact than fortis	not subject to phonological aspiration
vocal fold slackening intervocalically	open glottal configuration
loss of aspiration intervocalically	heavy aspiration in initial position
shorter duration than fortis fricative	duration similar to aspirated
shortened duration intervocalically	high F0 onset similar to aspirated

The findings of this study generally confirm the above facts (cf. §2.2), or otherwise do not directly contradict them (in the case of the phonological evidence). However, the production results add to the body of acoustic evidence supporting the aspirated analysis: the non-fortis fricative shows a high F1 onset, a property of the aspirated plosives.[10] As can be seen in the table above, though, there is quite a body of evidence that argues in favor of a lenis analysis. How can the major finding in this study regarding F1 onset be reconciled with these facts?

The answer to this question may lie in the generality of these facts and the interpretation of their underlying causes. First, with respect to linguopalatal contact and durational properties, it is unclear how similar the aspirated plosives are to the fortis plosives. Cho and Keating (2001) found a significant difference between the contact for lenis plosives on the one hand and that for aspirated and fortis plosives on the other, but they did not claim that the contact for aspirated and fortis plosives was in fact the same. If anything, the subordinate relation of the aspirated plosives to the fortis plosives in terms of closure duration[11] would

[10] Note that neither gradual intensity buildup nor positive H1-H2 is evidence that can be easily brought to bear here, since both lenis and aspirated plosives show more gradual intensity buildup than fortis plosives (cf. Han and Weitzman 1970), as well as more positive H1-H2 values (cf. Cho et al. 2002).

[11] Cho and Keating (2001) did not find a significant durational difference between aspirated and fortis plosive closures, but several other studies have found a difference (cf. Silva 1992, Kim 1994, J.-I. Han 1996).

suggest a similar relationship in terms of articulatory contact. Thus, neither the fact that the non-fortis fricative generally shows less linguopalatal contact than the fortis fricative nor the fact that the non-fortis fricative is generally shorter than the fortis fricative may actually constitute evidence that can adjudicate between a lenis analysis and an aspirated analysis in the first place. However, even supposing that the aspirated plosives and the fortis plosives were the same in terms of linguopalatal contact and that a similar parallelism should thus exist between an aspirated fricative and a fortis fricative, it is not unreasonable to predict the aspirated fricative would have less contact anyway due to coarticulatory assimilation with the following aspiration gesture (essentially a glottal fricative with no oral contact).

With regard to the non-fortis fricative's loss of aspiration intervocalically, again it is not clear that this is evidence that can be said to support either analysis. As Han and Weitzman (1970), Chang (2004), and others have shown, both the aspirated plosives and the lenis plosives lose a great deal of aspiration intervocalically. In addition, although it is true that in standard Seoul Korean the non-fortis fricative undergoes post-obstruent tensing like the lenis plosives, there are dialects (e.g. North Gyeongsang Korean) in which it does not and instead retains its salient aspiration. Finally, it should be noted that Vaux (1998) has argued convincingly that voiceless fricatives in their unmarked state should be specified as [+spread glottis] instead of [-spread glottis]. Since the non-fortis fricative is clearly [+spread glottis], from a featural point of view as well it seems to be closely identified with the aspirated plosives.

Nonetheless, Iverson (1983) provides some convincing arguments for the lenis analysis of the non-fortis fricative. He observes that the vocal fold slackening, or glottal width reduction, in intervocalic environments is similar in magnitude ("a reduction by 10 or 15 on the glottal width scale [of 30]") to that seen in intervocalic lenis plosives. It is debatable whether a narrowing of a partly open glottis to a fully adducted glottis (in intervocalic lenis plosives) and a narrowing of a fully open glottis to a partly open glottis (in intervocalic non-fortis fricatives) amount to parallel gestures, but in any case the narrowing is indicative of some assimilation to the glottal requirements of the adjacent voiced vowels (i.e. a "weakened" articulation). Both this fact and the fact that intervocalic non-fortis fricatives are significantly reduced in duration (cf. K.-S. Kang 2000) provide the strongest evidence in favor of the lenis analysis.

In conclusion, then, the results of this study generally support analyzing the fricative distinction as an aspirated/fortis contrast, but do not refute much of the independent evidence offered in favor of a lenis/fortis contrast. It may be that the non-committal position of K.-S. Kang (2000, 2004) is ultimately the most justified: with both lenis and aspirated features, the non-fortis fricative may simply be both lenis and aspirated.

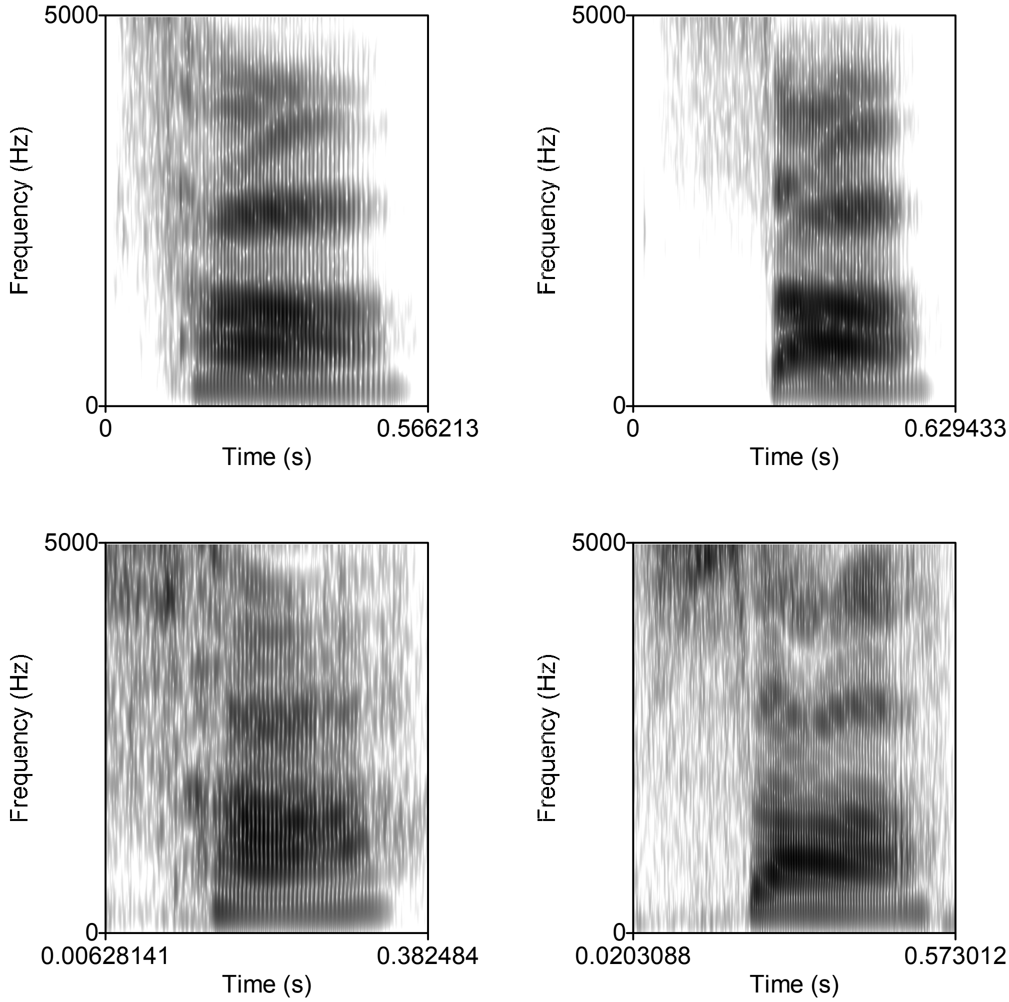
4.2. The Place of Korean in a Laryngeal Typology of Fricatives

To reiterate the points made in Jansen (2004), plosives across a wide variety of languages seem to divide into four types—prevoiced lenis, passively voiced lenis, unaspirated voiceless fortis, and aspirated voiceless fortis—while fricatives generally come in two types—prevoiced lenis and unaspirated voiceless fortis. Korean, then, is a language with a typologically unusual contrast in its fricatives (cf. Ladefoged and Maddieson 1996:176-179). One fricative can indeed be labeled unaspirated voiceless fortis, but the non-fortis fricative, as we have seen, is neither prevoiced nor passively voiced. Moreover, as summarized above, there is evidence suggesting that it is lenis. Therefore, it would appear that either (i) this fricative is aspirated voiceless fortis, or (ii) this fricative does not fit into any of Jansen's four basic laryngeal categories and is in fact aspirated voiceless lenis. As suggested above, the latter seems like the superior analysis.

At this point it might be instructive to make some comparisons to the only other language that has been claimed to have aspirated fricatives, namely Burmese (Ladefoged and Maddieson 1996 cite only Burmese in mentioning aspirated fricatives, while Silverman 2004 notes that "Korean and Burmese are two of the few languages which possess [contrastively aspirated fricatives]", which are "quite rare cross-linguistically"). In having a three-way laryngeal contrast in its fricatives (voiced, voiceless unaspirated, and voiceless aspirated), Burmese already constitutes a counterexample to the two-way generalization in Jansen (2004). What is of interest here, however, is how similar these Burmese fricatives are to the fricatives of Korean. Though an in-depth acoustic analysis of these fricatives lies outside the scope of this study, a brief inspection of the F1 onset and intensity characteristics follows in the interest of making crosslinguistic comparisons (all Burmese data comes from Chang 2003).

Spectrograms are given below of two Burmese syllables similar to the Korean syllables used in the perception experiment described in §3. These are presented alongside the Korean spectrograms from (1) and (2) for ease of comparison.

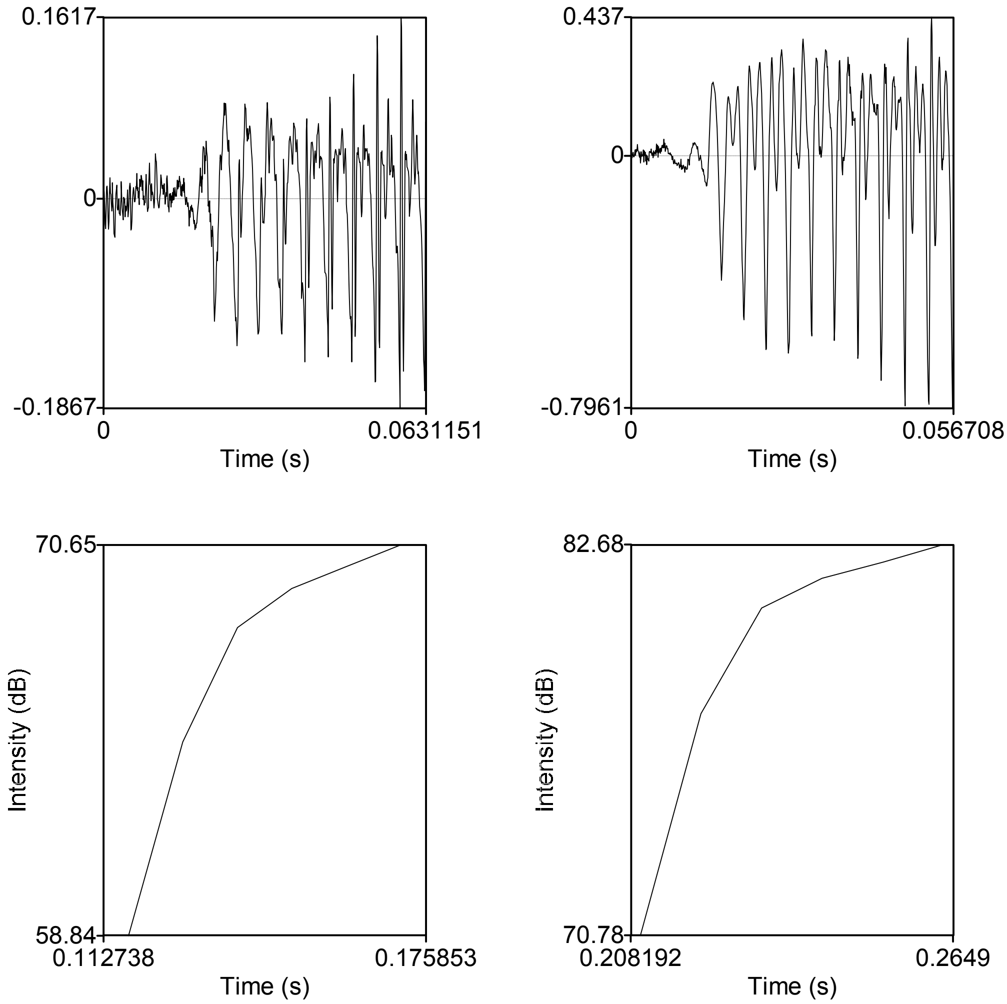
(25) Spectrograms of syllables with fricative onsets in Korean and Burmese: Korean /s^{h}a/ 'buy' (top L), Korean /s*a/ 'wrap' (top R), [s^{h}a] in Burmese /wĩ.s^{h}à/ 'Windsor' (bottom L), and Burmese /sà/ 'eat' (bottom R)



Two features of the Burmese spectrograms parallel properties of the Korean fricatives. For one, the extended duration of low-frequency noise in the spectrogram of [s^{h}à] is similar to that found in Korean /s^{h}a/. What stands out even more, though, is the similarity in the F1 onset patterns. In both Korean and Burmese, the F1 onset following the aspirated fricative is high, while the F1 onset following the unaspirated/fortis fricative is low.

Similarities between Korean and Burmese may also be found in intensity profiles. Waveforms and intensity contours of Burmese voiceless aspirated and voiceless unaspirated fricatives are given below to illustrate the intensity characteristics of the following vowels.

(26) Waveforms and intensity contours of [s^{h}à] in /wĩ̀.s^{h}à/ 'Windsor' (L) and /sà/ 'eat' (R)



From these figures one can see that the aspirated and unaspirated fricatives are remarkably similar to each other in their intensity characteristics, and, moreover, that they both resemble the intensity profile of the Korean fortis fricative more than that of the non-fortis fricative (cf. Figure 11).[12]

These facts are suggestive of two main conclusions. First, aspiration is not necessarily correlated with gradual intensity buildup, as seen in the relatively rapid intensity buildup following the Burmese aspirated fricative. On the other hand, aspiration does appear to be associated with high F1 onset, at least in the case of Burmese and Korean. The latter point in particular is significant because it implies that high F1 onset may be a more reliable cue than intensity buildup to an

[12] One might speculate that this may be an indication of a voiceless aspirated *fortis* fricative, in contrast to the voiceless aspirated *lenis* fricative of Korean.

aspirated/unaspirated, or non-fortis/fortis, distinction in fricatives. Thus, while there remains a confound between F1 onset, intensity buildup, and voice quality in Korean fricatives, the facts of Burmese suggest that F1 onset may really be the perceptually most important cue.

5. Conclusion

In summary, this study examined the production and perception of the two-way laryngeal contrast in Korean fricatives. The acoustic analysis showed that the two fricatives were differentiated from each other by segmental duration, aspiration duration, F1 onset, intensity buildup, and voice quality, but not by F0 onset, average intensity, or vowel length. The results of the perception experiment in turn demonstrated that the coalition of F1 onset, intensity buildup, and voice quality provides an important cue to the percept of these fricatives, outranking both segmental duration and aspiration duration.

These findings support an aspirated analysis of the non-fortis fricative, but do not rule out a lenis analysis. Korean constitutes an exception to Jansen's (2004) laryngeal typology in having a fricative contrast without a voiced member. Furthermore, the indeterminate nature of the contrast suggests that it may be typologically unique and necessitate the addition of an aspirated voiceless lenis category to the typology of laryngeal contrasts.

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Appendix: Judgment Data

STIMULUS				SUBJECTS' RESPONSES[13]															
SD	AD	F0	F1/IB	F1	F2	F3	F4	F5	F6	F7	F8	M1	M2	M3	M4	M5	M6	M7	M8
125ms	10ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	*	h	h	h	h	h
125ms	10ms	155Hz	s^ha	h	h	5	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	10ms	165Hz	s^ha	h	h	6	h	h	h	h	h	h	h	*	h	h	h	h	h
125ms	10ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	10ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	35ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	35ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	35ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	35ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	35ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	60ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	60ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	60ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	60ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	60ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	10ms	145Hz	s^ha	*	h	*	h	h	h	h	h	h	h	*	h	h	h	h	h
165ms	10ms	155Hz	s^ha	h	h	*	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	10ms	165Hz	s^ha	h	h	*	h	h	h	h	h	h	h	*	h	h	h	h	h
165ms	10ms	175Hz	s^ha	h	h	6	h	h	h	h	h	h	*	h	h	h	h	h	h
165ms	10ms	185Hz	s^ha	h	h	h	h	h	h	h	h	6	h	h	h	h	h	h	h
165ms	35ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	*	h
165ms	35ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	35ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	35ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	35ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	60ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	60ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	60ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	60ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
165ms	60ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	10ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	10ms	155Hz	s^ha	h	h	*	h	h	h	h	h	h	h	*	h	h	h	h	h
205ms	10ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	10ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	*	h	h	h	h	h
205ms	10ms	185Hz	s^ha	*	h	h	h	h	h	h	h	h	h	*	h	h	h	h	h
205ms	35ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	35ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	35ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h

[13] Abbreviations: h = /s^ha/, * = /s*a/, 3 = /a/, 4 = /da/, 5 = /t*a/, 6 = /t^ha/.

205ms	35ms	175Hz	s^ha	h	h	*	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	35ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	60ms	145Hz	s^ha	h	h	h	h	h	h	h	4	h	h	h	h	h	h	h	h
205ms	60ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	60ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	60ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
205ms	60ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	10ms	145Hz	s^ha	h	h	*	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	10ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	10ms	165Hz	s^ha	h	h	*	h	h	h	h	h	*	h	*	h	h	h	h	h
250ms	10ms	175Hz	s^ha	h	h	h	h	h	*	h	*	h	h	h	h	h	h	h	h
250ms	10ms	185Hz	s^ha	h	h	*	h	h	h	h	*	h	h	h	h	h	h	h	h
250ms	35ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	35ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	6	h	h	h	h	h	h
250ms	35ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	35ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	35ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	60ms	145Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	60ms	155Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	60ms	165Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	60ms	175Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
250ms	60ms	185Hz	s^ha	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
125ms	10ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	h	*	*	*	*
125ms	10ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
125ms	10ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
125ms	10ms	175Hz	s*a	*	*	*	*	*	h	*	*	*	*	*	*	*	*	*	*
125ms	10ms	185Hz	s*a	*	*	*	h	*	*	*	*	*	*	*	*	*	*	*	*
125ms	35ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
125ms	35ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
125ms	35ms	165Hz	s*a	h	*	*	*	*	*	*	*	h	*	*	5	*	*	*	*
125ms	35ms	175Hz	s*a	h	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
125ms	35ms	185Hz	s*a	*	*	*	*	*	h	*	*	*	*	*	*	*	*	*	*
125ms	60ms	145Hz	s*a	5	*	*	*	*	*	*	*	5	*	*	5	*	*	*	5
125ms	60ms	155Hz	s*a	*	*	*	*	5	*	*	*	*	*	*	5	*	*	*	*
125ms	60ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
125ms	60ms	175Hz	s*a	5	*	*	*	5	h	*	*	*	*	*	5	*	h	*	*
125ms	60ms	185Hz	s*a	5	*	*	*	*	*	*	5	*	*	*	5	*	*	*	*
165ms	10ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	10ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	10ms	165Hz	s*a	*	*	*	*	*	h	*	*	*	*	*	5	*	*	*	*
165ms	10ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
165ms	10ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
165ms	35ms	145Hz	s*a	*	*	*	*	*	*	*	h	*	*	*	*	*	*	*	*
165ms	35ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*

165ms	35ms	165Hz	s*a	*	*	*	*	*	h	*	*	*	*	*	*	*	*	*	*
165ms	35ms	175Hz	s*a	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
165ms	35ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	60ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	h	h	*
165ms	60ms	155Hz	s*a	5	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	60ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	60ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
165ms	60ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	10ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	10ms	155Hz	s*a	*	*	*	h	*	*	*	*	*	*	*	*	*	*	*	*
205ms	10ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	10ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	10ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	35ms	145Hz	s*a	*	*	*	*	*	*	*	h	*	*	*	*	*	*	*	*
205ms	35ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	35ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	35ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	35ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	60ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
205ms	60ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	60ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	60ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
205ms	60ms	185Hz	s*a	h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	10ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	10ms	155Hz	s*a	*	*	*	*	*	*	*	*	h	*	*	*	*	*	*	*
250ms	10ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
250ms	10ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	10ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	35ms	145Hz	s*a	*	*	*	*	*	h	*	*	*	*	*	*	*	*	*	*
250ms	35ms	155Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	h	*	*
250ms	35ms	165Hz	s*a	*	*	h	*	*	*	*	*	*	*	*	5	*	*	*	*
250ms	35ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	35ms	185Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	5	*	*	*	*
250ms	60ms	145Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	60ms	155Hz	s*a	*	*	*	*	*	*	*	6	*	*	*	*	*	*	*	*
250ms	60ms	165Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	60ms	175Hz	s*a	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250ms	60ms	185Hz	s*a	*	*	*	*	*	*	*	*	h	*	*	*	*	*	*	*