Acoustic, Intraoral Air Pressure and EMG Studies of Vowel Devoicing in Korean

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ABSTRACT

The devoicing vowel is a phonological process whose contrast in sonority is lost or reduces in a particular phonetic environment. Phonetically, the vocal fold vibration originates from the abduction/adduction of the glottis in relation to supraglottal articulatory movements. The purpose of this study is to investigate Korean vowel devoicing by means of experimental instruments. The interrelated laryngeal adjustments and aerodynamic effects for this voicing can clarify the redundant articulatory gestures relevant to the distinctive feature of sonority. Five test words were selected, being composed of the high vowel /i/, between the fricative and strong aspirated or lenis affricated consonants. The subjects uttered the test words successively at a normal or at a faster speed. The EMG, the sensing tube Gaeltec S7b and the High-Speech Analysis system and MSL II were used in these studies. Acoustically, three different types of speech waveforms and spectrograms were classified, based on the voicing variation. The intraoral air pressure curves showed differences, depending on the voicing variations. The activity patterns of the PCA and the CT for devoicing vowels appeared differently from those showing the partially devoicing vowels and the voicing vowels.

Keywords: Korean Vowel Devoicing, Acoustic, Intraoral Air Pressure, EMG

1. Intoduction

One of the controversial phonetic explanations in some phonological rules, the devoicing vowel is a phonological process whose contrast in sonority is lost or reduced in a particular phonetic environment. Studies show that devoicing high vowels have been found in word final positions, preceded by fricative voiceless consonants (German, Köhler, 1990; French, Carton, 1973). In Japanese, the devoicing vowel-depending on whether the vowel is accented or not-occurred between voiceless consonants (Bloch, 1950; Han, 1962; Sawashima, 1971; Hirose, 1971; Fromkin, 1983). Recently, an experimental study of Korean (Kim, Niimi and Hirose, 1993) demonstrated that the devoicing high vowel /i/ can be found between the noise level consonants: fricative,

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aspirated and the affricated consonants.

On phonetic view points, it is universally recognized that the vocal fold vibration originates from the abduction/adduction of the glottis in relation to supraglottal articulatory movements. But the devoicing vowel cases do not show glottal vibration phenomena during acoustic and physiological productions. Han (1962) mentioned that the harmonics of devoiced vowels in Japanese did not show their characteristics, depending on the type of adjacent voiceless consonants. Maekawa (1989) noted that a high vowel preceded by a voiceless consonant was devoiced, not only by following a voiceless consonant, but also by a voiced vowel at a normal speaking rate and a faster speaking rate.

Concerning the interrelation between acoustic and glottal gestures, Sawashima (1971) found, by means of fiberopic observations, that the glottis was opened wide without any gesture of adduction throughout the period of a devoiced vowel, and that the segment had shown turbulent noise with some characteristic formant patterns on the spectrogram.

Electromyographic (EMG) studies (Hirose, 1971; Yoshioka, 1981) have confirmed that the activity pattern of intrinsic laryngeal muscles was controlled reciprocally, with respect to opening and closing glottal gestures and the presence or absence of vowel devoicing. Namely, the posterior cricoarytenoid (PCA) and the interarytenoid (INT) muscle activity during a devoiced vowel are different from those of a voiced vowel, respectively. Moreover, the electromyographic and fiberopic studies of devoicing vowels in Korean (Hirose, 1974) show that interarytenoid muscle (INT) activity is markedly suppressed by the voiceless segments of [sɨ̥] after an initial increase for the voiced segment. And in this phonetic environment, the glottal gesture of a voiceless segment [s ɨ̥] seems to be wide open.

The purpose of this paper is to investigate the properties of vowel devoicing in Korean by means of acoustic, intraoral air pressure and electromyographic methods. The interrelated laryngeal adjustments and aerodynamic effects of these voicing variations can clarify the redundant articulatory gestures relevant to the distinctive feature of sonority.

2. Method and Procedure

One male and two female adult native speakers of the Cholla dialect served as subjects. Five meaningful words were selected on the basis of spectrographic phenomena containing the high vowel /i/, between the fricative consonant and strong aspirated or lenis affricated consonants.

The five test words were uttered successively 10 times at a normal speed and 20 times at a faster speed. Table 1 is the list of the test words.

Table 1. The test words for the devoiced vowels

1. /sip^{h}ita/	"be chewed"
2. /sit^{h}ita/	"is a city"
3. /sic^{h}ita/	"sew with a needle temporarily"
4. /sik^{h}ita/	"let do"
5. /siʦita/	"be soured"

The EMG recording was made from the posterior cricoarytenoid (PCA), thyroarytenoid (VOC) and cricothyroid (CT) muscles. The EMG signals were recorded through hooked wire electrodes. The electrodes were inserted through the mouth to the PCA muscles perorally, and then to the VOC muscles and the CT muscles percutaneously. Then, intraoral air pressure (Po) was measured with a sensing tube (Gaeltec S7b) which was inserted through the nostrils to the oropharynx. A multichannel cassette recorder (Sony PC-108 M) recorded simultaneously the EMG, intraoral air pressure and speech signals. After that, the EMG and acoustic signals were rectified and integrated at a 10ms interval. The sampling rate of the signals was 5 kHz for the acoustic data and 1kHz for the EMG data. In this study, the voice onset of the final vowel in the test words was selected as the line-up and was defined by an inspection of the acoustic form. On the other hand, intraoral air pressure signals were calibrated at each 5 cm H_2O between 0 cm H_2O and 20 cm H_2O with 38°C water. Figure 1 shows a block diagram of processing for integrated acoustic, intraoral air pressure and EMG signals.

The sound spectrographic analysis was obtained by means of a High-Speed Speech Analysis System using an NEC PC computer and an MSL II Macintosh computer, a process that was separate from the intraoral air pressure and the EMG experiments.

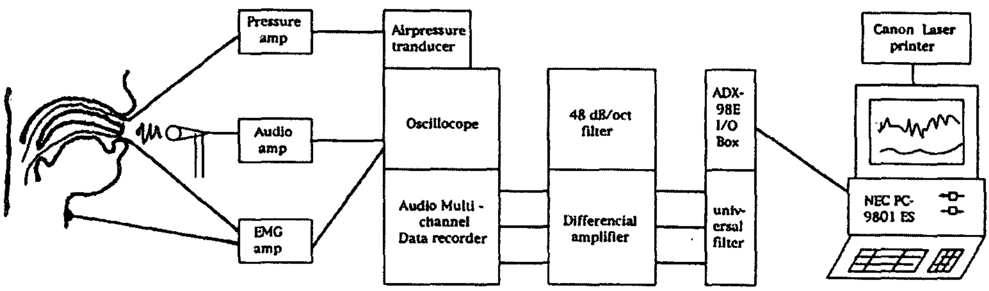

Figure 1. Block diagram of the processing for the integrated acoustic, intraoral air pressure and EMG signals.

3. Results

3.1 Acoustic characteristics

The vowel formant on the spectrogram represented a primary acoustic cue to verify the voiced, partially voiced and devoiced vowels, according with the formant types. Figure 2 shows three different types of formants in the phonetic environment to the high vowel /i/ between the fricative or strong aspirated consonants. The duration of the formant /i/ distinguished the partially devoicing vowels from the voicing ones by the degree of the glottal pulse on the spectrogram. The devoicing vowel, [si̥] in the case of /sip^{h}ita/ (Figure 2-A), maintains a continued turbulent formant-like noise in high frequency regions, while the partially devoiced and voiced vowels presented one or two vertical striations just before the beginning of the oral closure for the following voiceless consonant (Figure 2-B and C). We observed that the second vowel formant /i/ had a tendency to reduce or partially devoice the vowel in [si].

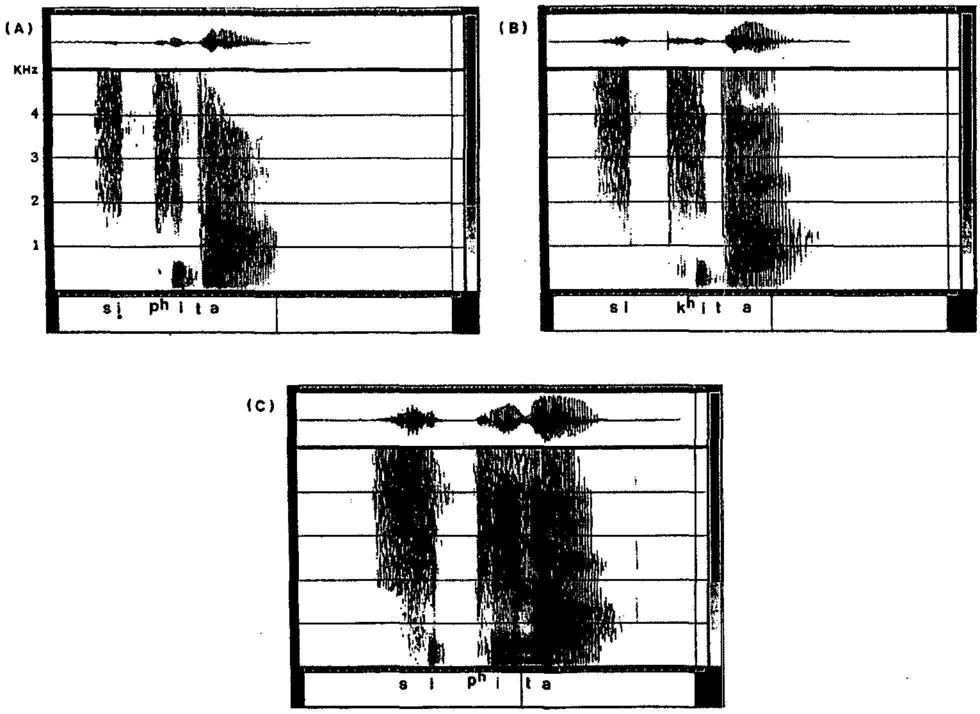

Figure 2. The three different types of formants in the phonetic environment of the high vowel /i/, between the fricative or strong aspirated consonants. (A) devoicing vowel (B) partially devoicing vowel (C) voicing vowel only.

Concerning the relationship between the formant types and the compared acoustic wave forms, the one or two striations of formant correspond to the periodicities on wave forms. Figure 3 shows these different types of waveforms between the fricative /s/ and the strong aspirated consonants on the segment [si] areas. The devoicing vowel (A) showed quasiperiodicities throughout the segment [si̥], while the partially devoicing vowel (B) and the voicing vowel (C) showed several periodicities in this phonetic environment [si].

Table 2 indicates the average rate of the devoicing, partially devoicing and voicing vowels, based on the male and female subjects uttering the test words at normal speed and faster speed. The rate of the devoicing vowel changed on the adjacent voiceless consonant. The high percentage of devoicing [i] was when it was preceding /s/ and following a strong aspirated consonant or lenis affricated consonant.

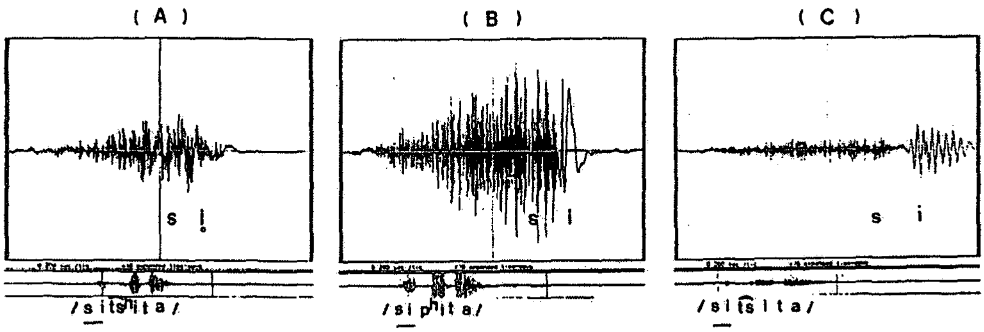

Figure 3. Three different types of acoustic waveforms according to the voicing degree. (A) devoicing vowel (B) partially devoicing vowel (C) voicing vowel only cases.

Table 2. The average rate of devoiced vowel cases when the subjects repeated the test words ten times at normal speed and twenty times at faster speed.

Word \ speed	normal speed			faster speed		
	DV	PV	VO	DV	PV	VO
/sipʰita/	5	22	3	5	55	0
/sitʰita/	25	4	1	55	5	0
/sicʰita/	25	4	1	59	1	0
/sikʰita/	24	6	0	41	19	0
/si t͡sita/	13	2	15	51	5	4
total	92	38	20	211	85	4
percentage	61.3%	25.3%	13.4%	70.4%	28.3%	1.3%

DV: devoicing vowel, PV:Partially devoicing vowel, VO:voicing vowel only

The total rate of devoiced vowels, with respect to the speech speed evidence, was devoicing vowels at normal speed were 62%; partially devoicing vowels were 13%. On the other hand, devoicing vowels at faster speed were 71%; partially devoicing vowels were 28%; voicing vowels were only 1%. We mentioned that the rate of devoicing and partially devoicing vowels increased according to faster speeds. However, voicing vowels decreased according to faster speeds.

The occurrence of devoicing vowels in a sequence of CV1CV2CV3 (C: voiceless consonants, V1 and V2:closed vowels /i/, V3:open vowel /a/) showed the order as follows: $c^h>t^h>k^h>p^h$. However, that of partially devoicing vowels showed the reverse order: $p^h>t^h>k^h>c^h$.

3.2 Intraoral air pressure curves

A sensing tube placed in the oropharynx can measure intraoral air pressure without interference with the movement of the articulators in speech.

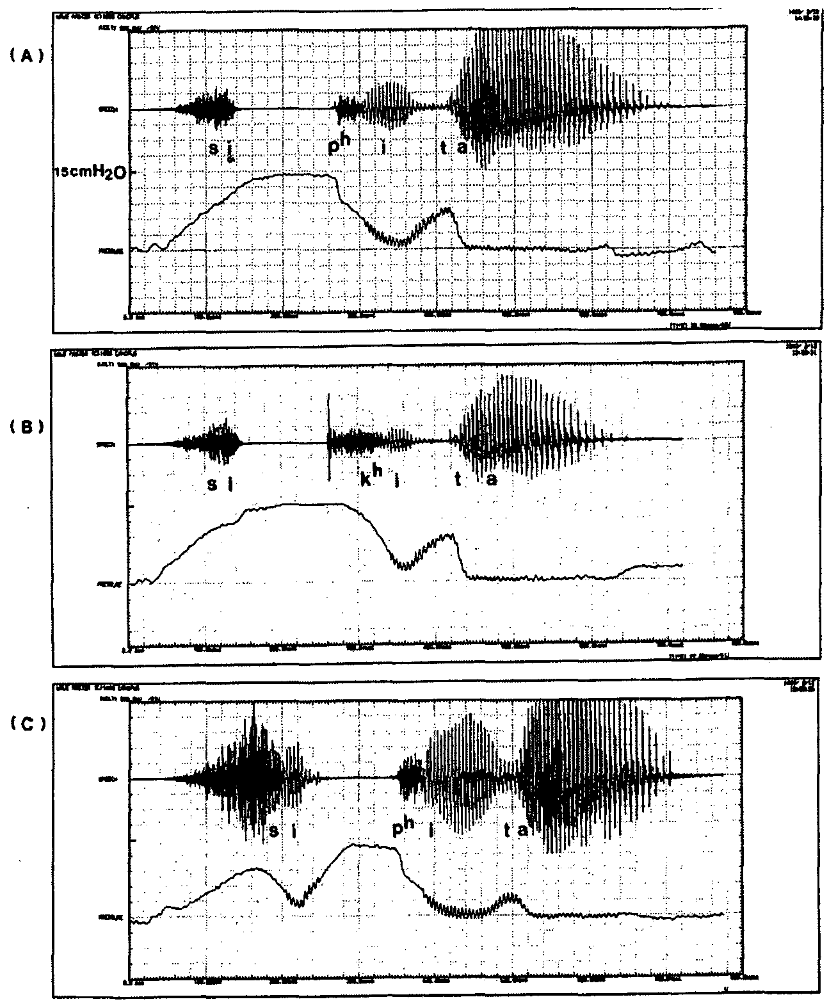

Figure 4. The three different types of the intraoral air pressure curves with respect to the voicing variations. (A) Devoicing vowel (B) Partially devoicing vowel (C) Voicing vowel only.

Figure 4 shows three different types of intraoral air pressure configurations, with respect to voicing variations. The intraoral air pressure of devoicing vowel cases (A) increased from the beginning of frication to the burst of the strong aspirated consonant, about 15 cm H_20, and decreased with the voice onset of the second vowel /i/. The partially devoicing vowels (B) showed similar intraoral air pressure curves, compared with devoicing vowel cases in this segment [si]. However, a deeper curve appeared during the segment [si], which was a typical aerodynamic cue for partially devoicing vowels. The voicing vowel (C) went up from bottom to the peak of intraoral air pressure, about 9 cm H_20, and fell until the voice onset of the vowel /i/.

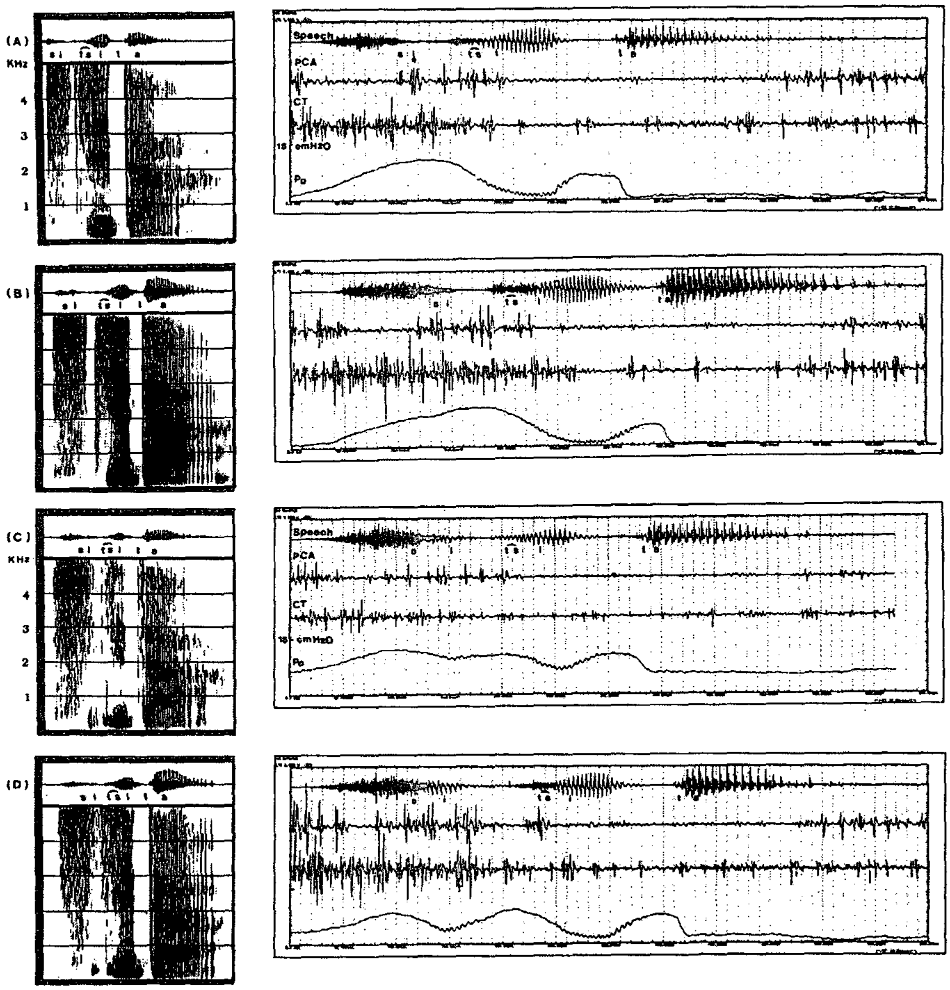

Figure 5. The four different types of intraoral air pressure curves according to the voicing degree of the first vowel /i/. The left sides show the spectrogram and the right sides from the top to the bottom show the speech wave forms, PCA and CT patterns and the intraoral air pressure curves in the same phonetic environments/si t͡s ita/.

Differing from the above mentioned air pressure curves, Figure 5 shows the four different types of intraoral air pressure curves, according to the voicing degree of the high vowel /i/ between the fricative /s/ and the voiced affricated consonant [ʥ]. The left sides show the wide band spectrograms and the right sides, from the top to the bottom, show speech wave forms, EMG raw data (PCA and CT) and intraoral air pressure curves in the same phonetic environment /siʥita/. It is mentioned that the partially devoicing vowels show the two different types of intraoral air pressure configurations. The first type (B), the slightly partially devoicing, shows a similar intraoral air pressure configuration as the above mentioned partially devoiced vowel (Figure 5-B). However, the second type (Figure 5-C) shows a similar intraoral air pressure curve of the voicing vowel (Figure 5-D), on which we can find some periodicities of intraoral air pressure corresponding to the quasiperiodicities of acousitc waveforms on 6 cm H_2O.

3.3 EMG patterns

Comparing the PCA raw data with the acoustic waveforms, formant types and intraoral air pressure curves during the segment area of [si], the PCA pattern of devoicing vowel (A) showed the activity in the final segment of [si̥]. However, the slightly partially devoicing vowel (B), the partially devoicing vowel (C) and the voicing vowel (D) did not show the activity of PCA in this final segment of [si], regardless of whether the periodicities on acoustic signals appeared or not.

Figure 6 shows the average EMG curve of PCA and CT for the devoicing vowels (dashed lines), partially devoicing vowels (dashed and pointed lines) and voicing vowels only (pointed lines) in the tested word /siʥita/. The filled triangle under the times axis indicated the voiced onset of the first high vowel /i/. The pattern of PCA muscles showed activation during devoicing vowel cases in the segment [si̥]. Moreover, the activity of PCA muscles during partially devoicing and voicing vowels only showed the suppression for this comparable segment [si̥]. We mentioned that the patterns of CT muscles for devoicing vowels produced lower activity than that of the partially voicing and the voicing vowels only in this segment [si̥].

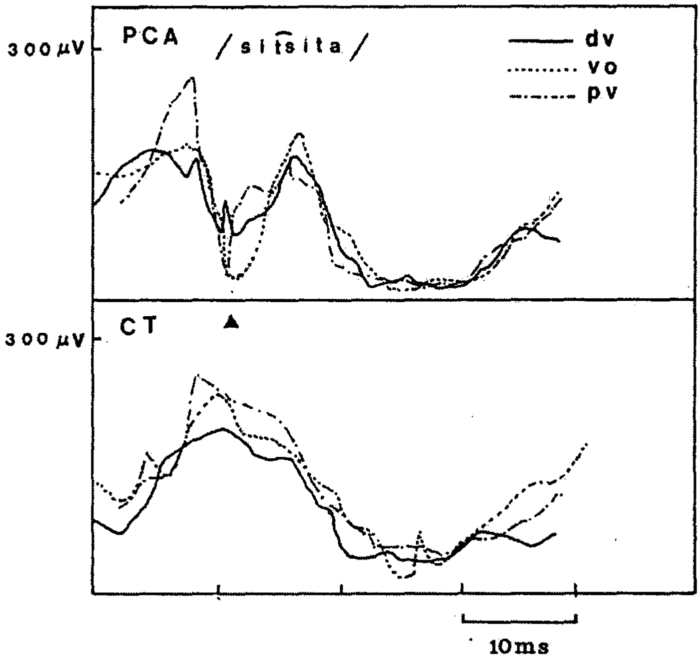

Figure 6. Average EMG patterns of PCA and CT for the devoicing vowels (dashed lines), partially devoicing (dashed and pointed lines) and voicing vowels only (pointed lines) in the tested word /sitsita/. The filled triangle under the time axis indicates the voice onset of high vowel /i/.

4. Discussion

Vowel devoicing has been generally accepted, in phonological view, as an allophone of voiced vowels. This variation supports a criticism relevant to the phonetic explanation in some phonological rules (Dinner, 1980). The rule of progressive devoicing is an example of universal phonetic constraints (Harms, 1973).

From the phonetic viewpoint, the acoustic and physiological characteristics of devoicing vowels were reported, mainly in some Japanese dialects. The devoicing high vowels did not show glottal pulses on a spectrogram. The glottal gestures were displayed by means of a fiberscopic investigation during the corresponding acoustic segment. The activity patterns of EMG showed positive for the PCA with the suppression of the INT (Yoshioka, 1981).

The present studies classified three different types of voicing variations in speech events. The occurrences of these in Korean occurred mainly when the high vowel /i/ preceded the fricative /s/ and following strong aspirated or lenis affricated consonants. On a spectrogram, the devoiced vowels and the voiced vowels were not controversial, respectively, as mentioned in the literature. However, partially devoicing vowels appeared as two types, depending on the phonetic environments. The first type, on a slightly partially devoicing vowel preceded by a fricative /s/ and followed by a strong aspirated consonant, showed only one or two vertical striations. The second type, on a partially devoicing vowel preceded by a fricative /s/ and followed by a lenis affricated consonant, showed very short periodicities.

The speaking rate of devoiced vowels increased according to faster speeds. The introral air pressure curves were classified by the voicing variations. The devoicing vowel cases appeared during continuous increasing intraoral air pressure from the bottom to the top, about 11 cm H_2O during the segment [sį]. However, partially devoicing vowels were shown to be two different types in the same phonetic environment. One type, slightly partially devoicing vowels, was shown to be deeper during continuous increasing intraoral air pressure configuration; the other type, partially devoicing vowels, appeared with some periodicities on high intraoral air pressure levels, about 6 cm H_2O. In those cases, some quasiperiodicities were shown in the final segment of [si] on acoustic wave forms.

The activity patterns of the PCA and the CT for devoicing vowels appeared different from those for partially devoicing vowels and voicing vowels only. This means that the laryngeal adjustment of the devoicing vowels was quite different from that of the voicing vowel only. However, some partially devoicing vowel cases might have similar laryngeal adjustment, in comparison with those of voicing vowels only.

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