FO IN PHONATION TYPES OF INITIAL-STOPS

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ABSTRACT - Fo and the curves of phonation types of initial-stops in six Asian languages were examined. The cross-language study shows that difference of phonation types of stops has a different effect on the Fo perturbations of the following vowels. The general trend that voiceless types are associated with a higher Fo and voiced types are associated with a lower Fo was observed in these languages, but some language-specific characteristics were observed in Thai and Hindi. Their phonetic characteristics of each phonation type were examined.

INTRODUCTION

It is known that the difference of phonation types in the production of initial stops is variously manifested in several acoustic characteristics such as voice onset time (VOT), Fo and the curve, spectral features and F1 onset frequency values (Lisker and Abramson, 1964; Lisker, 1975). There have been a number of studies on acoustic characteristics of phonation types in such languages as English, Japanese, and Hindi. It is known that phonation types of consonants are closely related to Fo perturbations of the following vowels, and have been examined from physiological and acoustic points of view for such languages., but little has been done on cross-language studies of phonation types. The present study examines how the difference of phonation types of initial-stops in six Asian languages, including initial-nasals in Burmese, is correlated with fundamental frequency (Fo) and the curves, and attempt to clarify the phonetic characteristics of these types. The languages investigated include Japanese, Mandarin Chinese, Korean, Burmese, Thai, and Hindi. These languages can be classified into three types of category, depending on the phonological contrast of phonation types which they use, and can be shown as follows:

No. of category	Language	Stop consonant
Two-category	Japanese	voiceless /p, t, k/
		voiced /b, d, g/
	Mandarin	voiceless aspirated /p^h, t^h, k^h/
		voiceless unaspirated /p, t, k/
Three-category	Korean	voiceless tense /p^*, t^*, k^*/
		voiceless lax /p, t, k/
		voiceless aspirated /p^h, t^h, k^h/
	Burmese	voiced /b, d, g/
		voiceless unaspirated /p, t, k/
		voiceless aspirated /p^h, t^h, k^h/
		nasal /m, n, ŋ/
		voiceless nasal /hm, hn, hŋ/
	Thai	voiced /b, d /
		voiceless unaspirated /p, t, k/
		voiceless aspirated /p^h, t^h, k^h/
Four-category	Hindi	voiced /b, d, g /
		breathy /b^h, d^h, g^h/
		voiceless unaspirated /p, t, k/
		voiceless aspirated /p^h, t^h, k^h/

EXPERIMENTAL PROCEDURE

All of the experimental work in the present study was made at the Phonetics Laboratory, University of Edinburgh. Subjects in the present study are native speakers of each language and are speakers of the standard dialect. The number of subjects in each language is 6 for Japanese, 3 for Mandarin

Chinese, 3 for Korean, 2 for Burmese, 2 for Thai, and 3 for Hindi. The linguistic data were collected and recorded from word list containing minimal or near minimal contrasts of initial stops in these languages. Recorded linguistic materials were, after 5 kHz low-pass filtering, digitized at a sampling rate of 10 kHz, and were analyzed by linear prediction and Fo extraction. At each point of the analysis, Fo frequencies, formant frequencies, bandwidths and amplitude for the lower three formants were obtained.

RESULTS

As mentioned above, the differences of phonation types of initial-stops are closely related to pitch perturbations in the following vowels. The difference of pitch range is one of the properties for a distinction of phonation types. The measurement of Fo was made at the vowel onset following a stop release. Table 1 presents a pooled mean for major phonation types in each language.

Table 1 Mean Fo of major categories at vowel onset (Hz)
(s.d. in parenthesis)

Language	Major Category	Fo(Hz)	Difference
Japanese	voiced	213.8(6.2)	
(N=66)	voiceless	248.5(19.5)	34.7(vl. - vd.)
Mandarin	voiceless aspirated	151.0(5.9)	
(N=54)	voiceless unaspirated	158.0(8.1)	7.1(asp. - unasp.)
Korean	voiceless tense	175.1(16.7)	33.9(tense - lax)
(N=48)	voiceless lax	141.2(30.5)	
	voiceless aspirated	180.8(24.6)	39.6(asp. - lax)
Burmese	voiced	167.0(6.9)	
(N=18)	voiceless unaspirated	187.7(5.0)	20.7(unasp. - vd.)
	voiceless aspirated	186.8(6.6)	19.8(asp. - vd.)
	nasal	156.7(10.2)	
	voiceless nasal	204.5(15.3)	47.8(vl.nasal - nasal)
Thai	voiced	183.5(14.0)	
(N=48)	voiceless unaspirated	186.0(9.9)	2.5(unasp. - vd.)
	voiceless aspirated	205.1(14.2)	21.6(asp. - vd.)
Hindi	voiced	115.7(19.2)	
(N=36)	breathy	108.9(14.7)	6.8(vd. - breathy)
	voiceless unaspirated	130.4(27.6)	14.7(vl. - vd.)
	voiceless aspirated	122.3(28.8)	6.6(asp. - vd.)

There are several points to note in the Fo data in Table 1. Firstly, it can be seen as a general trend that Fo following voiceless unaspirated stops and voiceless aspirated stops is considerably higher than that following voiced ones. In Thai, however, there is no significant difference in Fo value between voiced stops and voiceless unaspirated stops. Secondly, voiceless tense stops in Korean show a higher Fo than voiceless lax stops. This implies that there is a difference in the initial glottal state between the two stops. According to Hirose et al. (1974), there is a sharp increase in the activity of thyroartytenoid for tense stops and this intrinsic muscle activity may be relevant for higher Fo. Thirdly, the Fo of breathy stops in Hindi is the lowest among the four categories of stops, and this agrees with the previous study (Kagaya and Hirose, 1975). Although the articulatory cause for this markedly low Fo of breathy stops needs further investigation, we can consider that the vocal folds do not close fully during vibration and vibrate loosely because of this incomplete closure. Further, the transglottal pressure difference may not be high enough to maintain a higher Fo. Lastly, it can be observed that there is a difference in the amount of variation between the voicing categories; in Japanese and Korean, the difference between the major categories is greater than that in Thai, Mandarin and Hindi. This implies that there is a difference in the initial glottal state and airflow between the categories in these languages.

As for the contrast of voiced nasal and voiceless nasal in Burmese, the Fo value following voiceless nasal is markedly higher than that following voiced nasal, and there is a difference of about 50 Hz in the contrast between the two types of nasals. A higher onset of Fo in voiceless nasals can be viewed as an attribute of a higher airflow rate by [h].

Associated with the differences in the onset Fo frequencies, there is a difference in the Fo curves from the onset of vowels to the steady-state portion of vowels. In the present study the Fo curves were examined for a period of 50 to 60 ms after the vowel onset. Figure 1 shows the schematized Fo curves for the vowels following the major voicing categories in six languages.

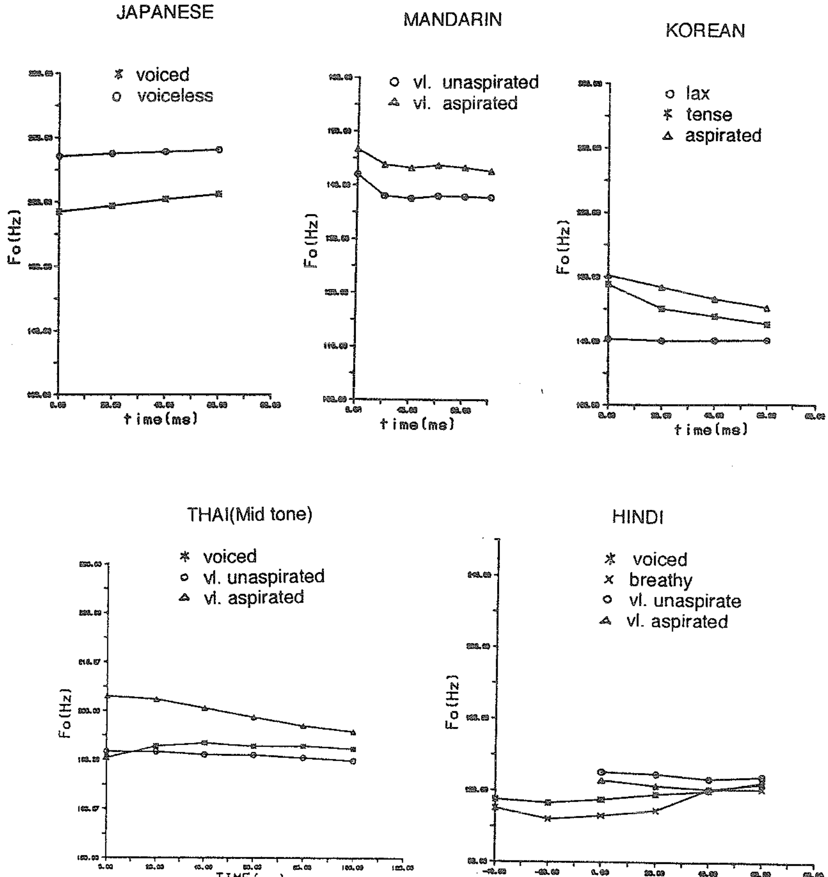

Figure 1 Fo curves of phonation types in Japanese, Mandarin, Korean, Thai and Hindi

From Figure 1, it is found that the Fo curves following the voiced stops in Japanese and Hindi show a gradual rising pattern, while the voiceless aspirated stops in Korean and Hindi show a gradual falling pattern in the same period. For voiceless unaspirated stops, the curve in Japanese shows a slight rising pattern within 50 to 60 ms, while the one in Hindi shows a steady fall. Furthermore, the Fo curve of the voiceless tense stop in Korean shows an abrupt drop during closure, and upon release gradually goes up. This fall-rise pattern of Fo seems to be characteristics of breathy stops. Although the two voiced stops in Hindi show s similar direction of change, those of breathy stops are more distinctive and pronounced than those of voiced unaspirated stops.

DISCUSSION

Based on the acoustic results on Fo and the curves, the frequency at vowel onset is relatively higher in the voiceless stops than in the voiced stops. The Fo curves are rising for the voiced categories, while those for the voiceless ones are level or falling. The voiceless aspirated stops show an initially high and then a gradual falling pattern. There are several points to note on the Fo and its curves. The Fo curves of the voiceless tense stops in Korean begin in a higher range and abruptly fall within a period of 30 ms after the vowel onset. As is known, physiological studies made by Hirose et al (1974) indicate that there is a sharp increase in the activity of the thyroarytenoid, and this increase of tension and the following relaxation are considered to be responsible for abrupt drop of the Fo. Furthermore, Kagaya (1974) indicates that aspirated stops in Korean are produced with a maximally opened glottis and high airflow rate. From these studies, there appear to be two different causes for a higher Fo in tense stops and aspirated stops in Korean. Secondly, it should be noted that the Fo at the breathy portion in Hindi is the lowest among the four types of stops, and the breathy stops show a distinctive fall-rise pattern of Fo. To explain this markedly low Fo, it can be considered that the vocal folds vibrate loosely with a narrowly opened glottis after the articulatory release, resulting in the low Fo at the onset. Although the influence of breathy stops on the following vowel was examined by Schiefer (1986), the pattern of fall-rise itself should be correlated with the breathy state of the glottis. As is known, there are two different views of the influence of the stop voicing on Fo curve; the rise-fall view and the no-rise view (Silverman, 1986). Silverman (1986) claims that the rise-fall view is not sufficient and segmental effect of stop voicing on Fo curve would be missed if the underlying prosodic structure is not taken into account. The present study provides further evidence that Fo falls in the initial period of 40 ms after voiceless stops, whether aspirated or unaspirated.

The physiological reason for the Fo perturbations of the vowel immediately following a consonant has been examined by several investigators (Hombert, 1978; Hombert et al., 1979; Ohala, 1978). Among these studies, the most comprehensive examination has been made by Hombert et al. (1979). They examined the two hypotheses in detail; namely aerodynamic and vocal-cord tension hypotheses, and mentioned that these are not sufficient to explain all aspects of Fo perturbations. Based on their experiments, they proposed a plausible explanation in terms of the vertical position of the larynx. Hombert et al.(1979) showed that there is a difference in larynx height between voiced and voiceless consonants and it is the larynx height which is most compatible with the Fo perturbations. The lowering of the larynx causes the lowering of the Fo, and expands the supralaryngeal cavity and by this expansion voicing is maintained. Although no measurement was made in the study of the position of the larynx, it seems that vertical movement of the larynx is more relevant for the causes of the perturbations, though the relation between Fo perturbations and a change of supralaryngeal configurations needs to be further examined.

Furthermore, it is interesting to note that the Fo value does not differ as a function of place of articulation in these languages. A change in the place of articulation affects the size of the supralaryngeal cavity, and this should result in a change of airflow rate in the cavity. The fact that the Fo does not differ as a function of place of articulation means that the aerodynamic hypothesis is rather weak for explaining the Fo perturbations at the consonantal release. The physiological and aerodynamic conditions related to Fo perturbations for phonation types can be shown as follows:

Lower Fo	Higher Fo
Lax larynx	Tense larynx
Lowered larynx	Raised larynx
Lower airflow rate	Higher airflow rate
Distended supra-laryngeal cavity	Reduced supra-laryngeal cavity

SUMMARY

The present study shows that difference of phonation types in the initial-stops has a different effect on the Fo perturbations of the following vowels, and, as has been known, voiceless stops are associated with a higher Fo, while voiced stops are associated with a lower Fo. In Korean, however, all stops are phonemically specified as voiceless, and the distinction between tense and lax stops affects the Fo perturbations, so that voiceless lax stops show the lowest Fo values compared to voiceless tense stops and voiceless aspirated stops. Furthermore, in Thai, there was no significant difference in Fo values between voiced stops and voiceless unaspirated stops. Voiceless unaspirated stops in Thai are articulated with almost simultaneous glottal closure and release, and the effect of this articulation may weaken the contrast between the two types of stops. Since onset Fo reflects the initial state of the glottis, the observation in Thai suggests that the overall laryngeal conditions in voiceless unaspirated stops at release are comparable to those of voiced stops. Further, it is pointed (Hombert et al., 1979) that there is a tendency in tone languages to minimize the intrinsic Fo perturbing effect of prevocalic consonants, but this tendency is not always apparent. In Chinese, there was no marked difference in Fo values between the two categories, but in Burmese and Thai (for the contrast between voiceless unaspirated stops and voiceless aspirated stops), there were significant differences between the categories, and the scale of differences in Fo values were not different from those of non-tonal languages such as Korean. For these observations, we can consider as follows:(1) the minimizing tendency depends on the types of tone systems of language, i.e., whether the tone types are contour or register, and whether the tone unit is syllable or word, and (2) the tone effect is considered to appear on the latter portion of tone unit, and the pitch perturbations in the initial portion are less effected by the difference in tone types.

It has also been demonstrated that there is a difference in the Fo curve from the onset to steady-state portion. As expected, voiceless stops tend to show a lowering pattern, and voiced stops show a rising one. In Japanese, the effect of voiceless stops is not apparent, and a level pattern was observed. In Korean, a clear-cut distinction between voiceless tense stops and voiceless lax ones is observed, and the tense stops show an abrupt falling Fo curve. Furthermore, in Hindi, Fo curves of the breathy stops show the lowest values and demonstrated a characteristic Fo pattern of fall-rise.

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