kansas working papers in linguistics

volume 4 1979 no. 2

edited by

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Acknowledgements

The editors would like to express their thanks to the faculty and staff of the Linguistics Department for their invaluable assistance in the preparation of this volume. Funding for this journal is provided by the Graduate Student Council from the Student Activity Fee.

CONTENTS

A FIBEROPTIC STUDY OF STOP PRODUCTION IN MAITHILI

Ramawatar Yadav

Abstract: A fiberoptic study was made to investigate the temporal course and width of the glottis during the production of four types of Maithili stops in initial, medial and final positions. The results show that the voiced-voiceless distinction correlates with the adduction-abduction gesture of the larynx. The study also suggests that glottal width is the key factor for aspiration and that sounds which are produced by a combination of vibrating vocal cords and aspiration should, in fact, be called 'voiced aspirated' consonants.

Introduction

Since Sawashima and Hirose (1968) first reported on a new laryngoscopic technique using fiberoptics, the glottal opening during the production of various types of speech sounds has been studied in a number of languages. Observations of glottal activity during stop production have been reported for English by Sawashima, M.; Abramson, A. S.; Cooper, F. S. and Lisker, L. (1970), Lisker, L.; Sawashima, M.; Abramson, A. S.; and Cooper, F. S., (1970), and Cooper, F. S.; Abramson, A. S.; Sawashima, M.; and Lisker, L. (1971); for Korean by Hirose, H.; Lee, C. Y., and Ushijima, T. (1974) and Kagaya (1971, 1976); for Japanese by Sawashima (1968), Sawashima and Niimi (1974), and Niimi and Sawashima (1974); for Hindi by Kagaya and Hirose (1975); for Mandarin by Iwata and Hirose (1976); for Tibetan by Kjellin (1977); for French by Benguerel, A.P.; Hirose, H.; Sawashima, M., and Ushijima, T. (1978); and for stops produced by a phonetician by Hirose, H.; Lisker, L., and Abrahmson, A. S. (1972). The present study examines by direct observation of larynx through a fiberscope the temporal course and the width of the glottis during stop production in Maithili--an Indo-Aryan language spoken in Nepal and India.

In Maithili there is a four-way contrast involving aspiration and voice at bilabial, dental, retroflex and velar places of articulation, producing 16 stop consonants. There is also a four-way distinction in the manner of articulation of the affricate; traditionally affricates have been treated as palatal stops--thus increasing the number of stops to 20 (the data for affricates will not be presented here).

Little has been published on the phonetics and phonology of Maithili. The only studies that I know of are: Jha (1941, 1958); Yadav (1976), Ingemann and Yadav (1977), and Yadav (1978). The author is currently undertaking an experimental phonetic study of Maithili as spoken in the Tarai of Nepal.

Kansas Working Papers in Linguistics, Vol. 4, No. 2, pp.55 - 69.

initial		medial		final	
[pɔl]	'moment'	[itir]	'this arrow'	[bap]	'father'
[p^{h}ɔl]	'fruit'	[it^{h}ir]	'this patient (person)'	[b^{h}ap^{h}]	'vapor'
[bɔl]	'strength'	[didi]	'this elder sister'	[ab]	'now'
[b^{h}ɔl]	'good'	[id^{h}ia]	'this daughter'	[lab^{h}]	'profit'
[ʈik]	'pigtail'			[hɔʈ]	'move'
[ʈ^{h}ik]	'true'			[hɔʈ^{h}]	'obstinacy'
[ɖik]	'huge pool of water'			[bik]	'sell'
[ɖ^{h}il]	'louse'			[bik^{h}]	'poison'
[kam]	'job'			[bag]	'garden'
[k^{h}am^{h}]	'housepole'			[bag^{h}]	'tiger'
[gam]	'village'				
[g^{h}am]	'sunrays; sweat'				

Table 1 Test Utterances

Maximum glottal width during oral closure and the following segment is given on an arbitrary scale. For voiceless sounds, it is measured at the vocal processes. In voiced aspirated sounds, the vocal processes normally remain adducted but an opening at the posterior end of the glottis is observed. Therefore, measurements of glottal width for voiced aspirated sounds represent the widest part of this posterior opening.

Oral closure duration was measured from the wave form and is given in milliseconds. Because the wave form was reproduced at approximately 2 inches per second, measurement error may be as much as 15-20 msec.

The figures show temporal changes in the glottal width both for typical tokens and for averaged measurements. Time is represented by frames (60 per second) on the horizontal axis and glottal width is shown on an arbitrary scale on the vertical axis. R represents the point of oral release. Voiced unaspirated consonants are not shown in these figures when there is no glottal opening because lines drawn for them would be identical with the baseline.

Intervocalic stops [t, t^{h}, d, d^{h}]

Measurements for 8 tokens each of the intervocalic stops [t, t^{h}, d, d^{h}] are shown in Table II. Glottal width contours for typical tokens are given in Figure 1 and averaged measurements of the 8 tokens in Table II in Figure 2.

	tokens	closure duration (in msec)	onset of glottal opening* (in frames)	Maximum Glottal Width **	Offset of Glottal Opening (in frames)
[t]	1	160	-7	8	2
	2	145	-7	7	1
	3	145	-6	8	2
	4	145	-7	6	2
	5	145	-7	8	1
	6	145	-7	8	1
	7	145	-5	6	2
	8	145	-8	6	1
[t^h]	1	100	-2	22	8
	2	100	-4	18	7
	3	100	-2	21	7
	4	100	-5	18	5
	5	100	-6	20	7
	6	100	-4	16	8
	7	100	-6	20	7
	8	100	-5	14	7
[d]	1	100	--	--	--
	2	100	--	--	--
	3	100	--	--	--
	4	100	--	--	--
	5	75	--	--	--
	6	100	--	--	--
	7	85	--	--	--
	8	100	--	--	--
[d^h]	1	100	-1	7	6
	2	100	-1	7	5
	3	85	-1	5	6
	4	100	-1	6	7
	5	100	0	4	4
	6	100	-1	7	6
	7	85	0	7	7
	8	75	0	6	6

* With reference to release of oral closure.

** Measured on an arbitrary scale.

Table II Intervocalic [t, t^h, d, d^h]

For [t], the vocal processes can first be observed to separate about 7 frames before oral release whereas for [t^h] the separation is first observed 6 to 2 frames before release. This difference is probably related to the fact that oral closure duration is longer for [t] than for [t^h]. For [t] the glottal opening is relatively narrow and one or two frames after the oral release, the vocal cords are adducted to vibrate for the following vowel. Voicing continues to linger for the

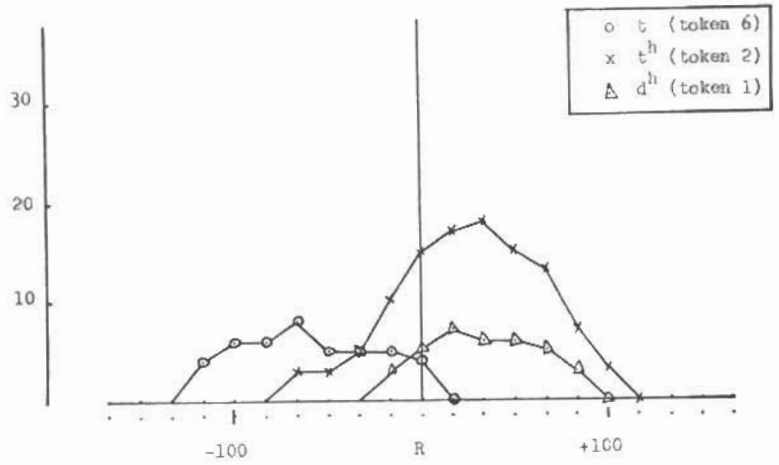

Fig. 1. Typical glottal width contours for intervocalic [t, t^h, d^h]

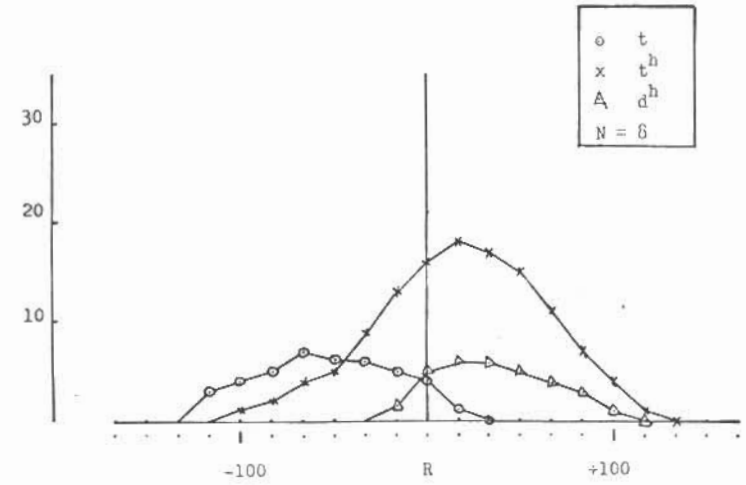

Fig. 2. Average glottal width contours for intervocalic [t, t^h, d^h]

initial 2 frames of the onset of oral closure after which no vibration of the vocal cords is observed during the entire oral closure period.

A well-defined bell-shaped contour chracterizes the temporal course of glottal width for [t^h]. The glottis opens much wider than for [t], reaching its maximum width immediately after the oral release. The vocal cords are adducted to vibrate for the following vowel about 7 frames after the release of the oral closure. No vibration of the vocal cords is observed during the oral closure, except for the first frame of the onset of oral closure.

For [d] the vocal cords vibrate normally throughout the production of the stop. For [d^h], the vocal cords continue to be adducted with no observable difference in vibration until just at or immediately before the oral release, at which point an opening at the posterior part of the glottis is observed. As for the voiced aspirated, the opening reaches its maximum width one or two frames after the articulatory release and then a dark shadow envelopes the entire vocal cords, suggesting incomplete closure. In 3 of the 8 tokens, a narrow slit extending almost the entire length of the vocal cords could be observed in one frame. Normal voicing resumes 4 to 6 frames after the oral release.

The temporal characteristics of glottal opening are similar to those reported by Hirose, H.; Lisker, L., and Abramson, A. S. (1972) and Kagaya and Hirose (1975).

Oral closure duration is longer for [t] than for [d]; on the average, oral closure duration is also somewhat longer for [t^h] than for [d^h].

Initial Stops

The temporal change in glottal width is shown in Figures 3 - 5 for four tokens of the initial [p, p^h, b, b^h; t̪, $t̪^h$, d̪, $d̪^h$; k, k^h, g, g^h]. Since in initial position there is no way to determine the point of oral closure from the film or the wave form, measurements have arbitrarily been made starting 10 frames (approximately 165 msec) prior to the release of oral closure. Measurements therefore always start before the onset of voicing for voiced stops and before the oral closure in most, if not all, stops.

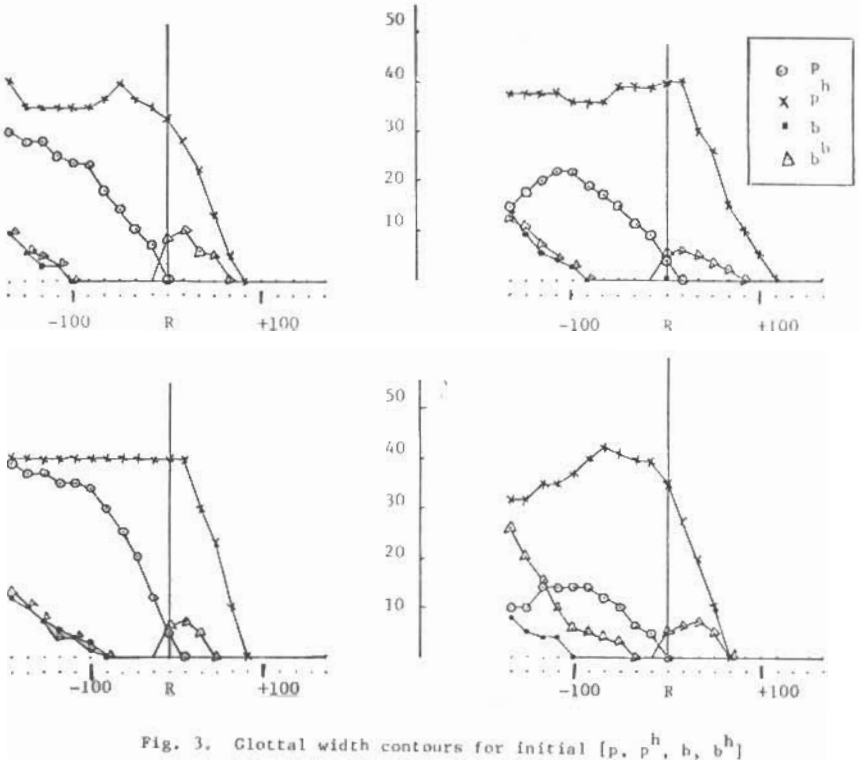

Fig. 3. Glottal width contours for initial [p, p^h, b, b^h]

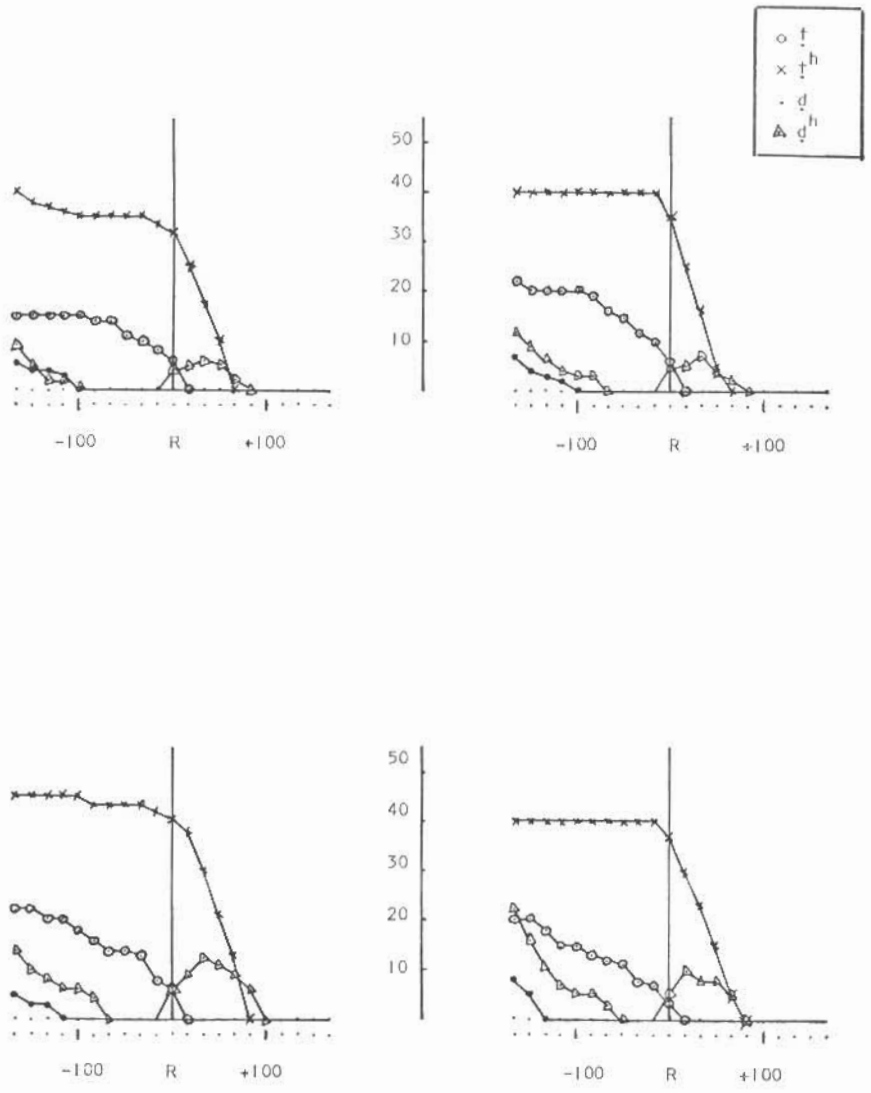

Fig. 4. Glottal width contours for initial [ʈ, ʈʰ, ɖ, ɖʰ]

For the voiceless aspirated stops, the vocal processes are observed to be wide apart during the initial phase of the utterance and remain so until the release of the oral closure. But, the vocal processes begin to narrow rapidly immediately after the oral release. The vocal cords are completely adducted for the following vowel after approximately 6 frames (i.e., 100 msec) for [p^h], and 4 frames (i.e., 66 msec) for both [$ʈ^h$] and [k^h] following the oral release.

For the voiceless unaspirated stops, too, the vocal processes begin fairly wide apart but narrow rapidly before the release of the oral closure. The vocal processes come into close contact for the following vowel immediately after the release of oral closure.

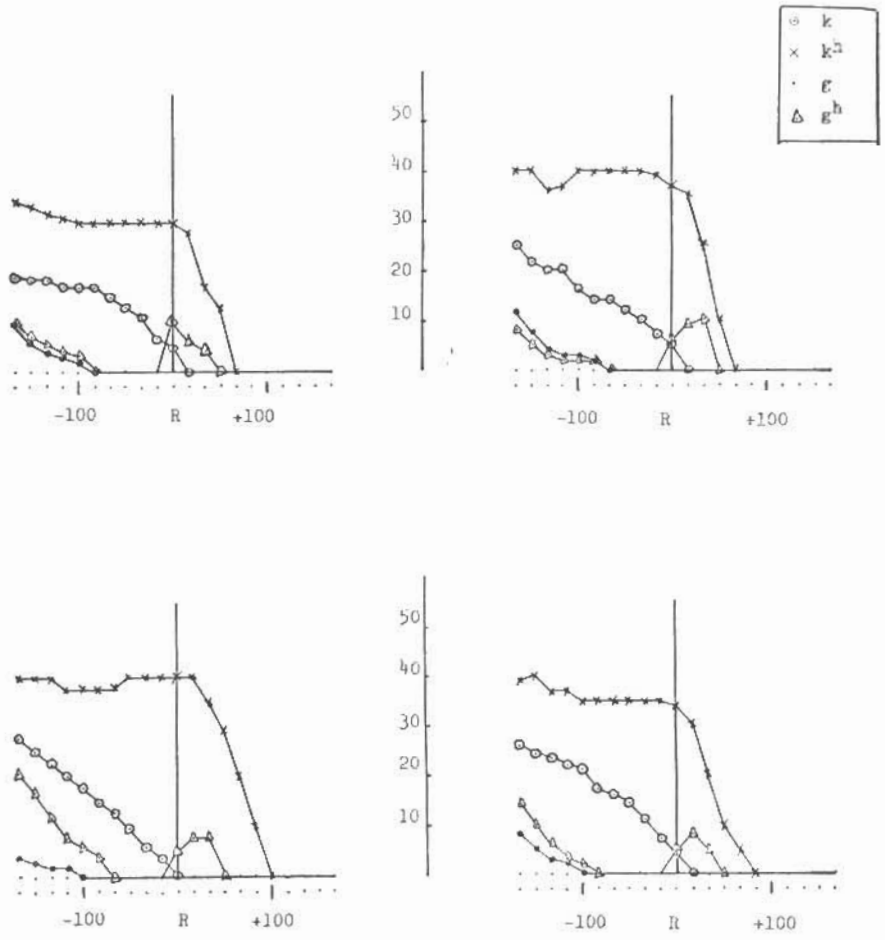

Fig. 5. Glottal width contours for initial [k, k^h, g, g^h]

For both the voiced unaspirated and aspirated types, the complete contact of the vocal processes is observed during the oral closure period. For voiced unaspirated stops, adduction is achieved about 5 frames (i.e., around 80 msec.) prior to the oral release for [b] and [g], and about 7 frames (i.e., 115 msec.) prior to the release of the oral closure for [d]. After this point no change is observed in the glottal width during the production of voiced unaspirated stops.

For the voiced aspirated type, complete contact of the vocal processes is achieved at 4 - 5 frames prior to the oral release. At the oral release, a posterior opening of the arytenoids was observed in all the samples used in this study. Such a posterior opening lasted for about 3 frames (i.e., 50 msec.) after the articulatory release. Occasionally, a shadow covered the vocal cords and lasted for just one frame (2 out of 5 cases for the oral release of [b^h] and 1 out of 5 cases prior to the oral release of [g^h] and [b^h]).

	Tokens	Closure Duration (in msec)	Onset of Glottal Opening* (in frames)	Maximum Glottal Width **	Duration of the Stop Release (in frames)
[t̪]	1	145	-4	7	4
	2	135	-7	9	6
	3	100	-5	11	4
	4	110	not visible	10	3
	5	125	-6	8	5
	6	125	-6	9	4
[t̪^{h}]	1	100	-4	30	7
	2	125	-6	40	6
	3	100	-5	37	6
	4	100	-4	40	6
	5	100	-3	30	7
	6	100	-5	34	7
	7	100	-5	28	6

* With reference to onset of the release of oral closure.

** Measured on an arbitrary scale up until the end of the stop release.

Table IV Word Final [t̪, t̪^{h}]

	Tokens	Closure Duration (in msec)	Onset of Glottal Opening* (in frames)	Maximum Glottal Width **	Duration of the Stop Release (in frames)
[k]	1	145	-8	7	6
	2	125	-6	7	4
	3	125	-5	9	4
	4	125	-6	10	4
	5	125	-5	10	5
	6	135	-6	6	5
[k^h]	1	100	-4	39	9
	2	100	-4	42	9
	3	100	-4	45	9
	4	100	-4	40	9
	5	75	-4	39	9
	6	85	-4	40	10
[g]	1	75	1	15	6
	2	100	3	20	8
	3	100	1	15	5
	4	85	1	32	8
	5	100	3	23	7
	6	100	1	15	7
	7	100	2	11	5
[g^h]	1	75	-1	27	9
	2	75	0	20	11
	3	60	-1	18	10
	4	60	-1	12	13
	5	50	0	23	6
	6	60	-1	20	5

* With reference to onset of the release of oral closure.

** Measured on an arbitrary scale up until the end of the stop release.

Table V World Final [k, k^h, g, g^h]

also the vibration of the vocal cords lingered for 2 to 3 frames after the onset of the oral closure. The state of the glottis during the onset of the oral closure for the retroflex stops [ṭ] and [ṭʰ], which were preceded by [ə], could also be observed in 12 out of 14 instances. For both [ṭ] and [ṭʰ] the vocal cords continued to vibrate until 2 frames after the onset of the oral closure.

For the voiceless unaspirated type, the vocal processes began to separate with a slightly open glottis on the average about 5 to 6 frames prior to the oral release for [ṭ] and 7 frames for [k]. The vocal processes remained separated throughout the sound. Following the release, the glottal width increased slightly for an average of 2 frames for [p], 3 frames for [ṭ] and 4 frames for [k]. Then the glottis widened for breath for a while and finally narrowed in readiness for the next utterance.

For the voiceless aspirated type, the vocal processes were observed to be apart with a wide open glottis on the average about 4 - 5 frames prior to the stop release and they remained wide apart during the stop release. The glottal width increased immediately after the onset of the release and reached its maximum about 2 to 3 frames after the release onset for both [tʰ] and [kʰ]. For [pʰ], however, the glottal width

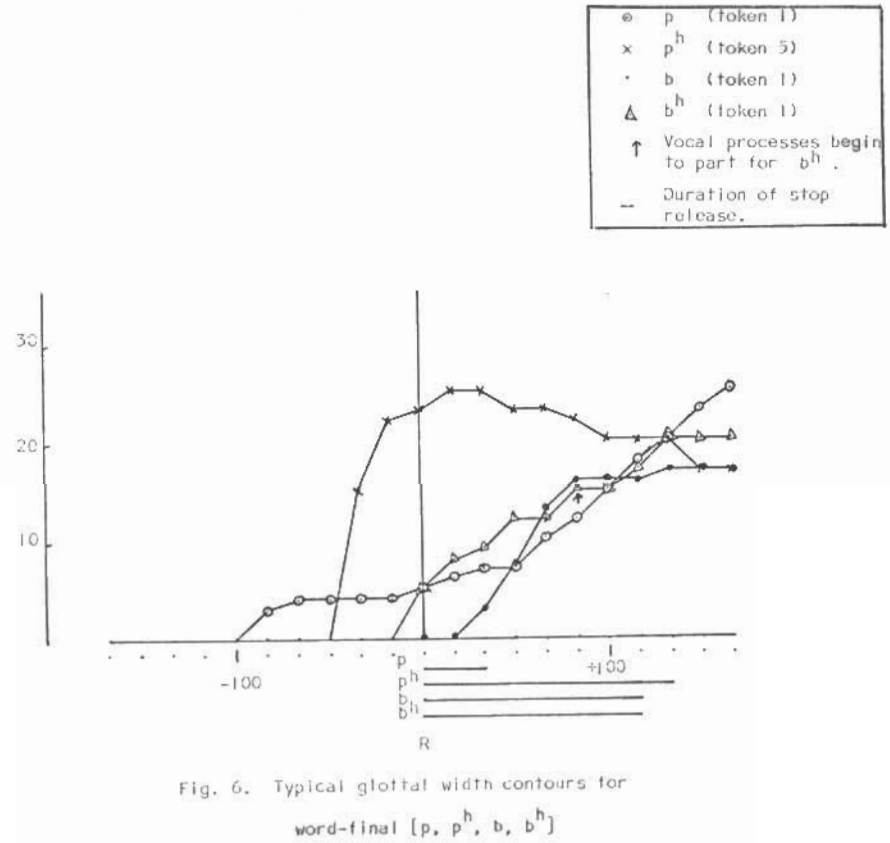

Fig. 6. Typical glottal width contours for word-final [p, pʰ, b, bʰ]

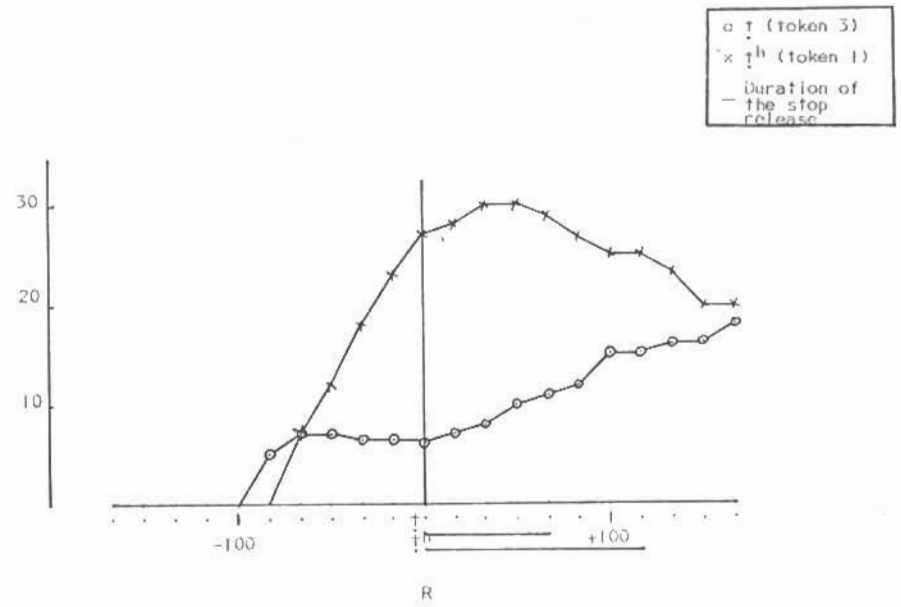

Fig. 7. Typical glottal width contours for word-final [t, t^h]

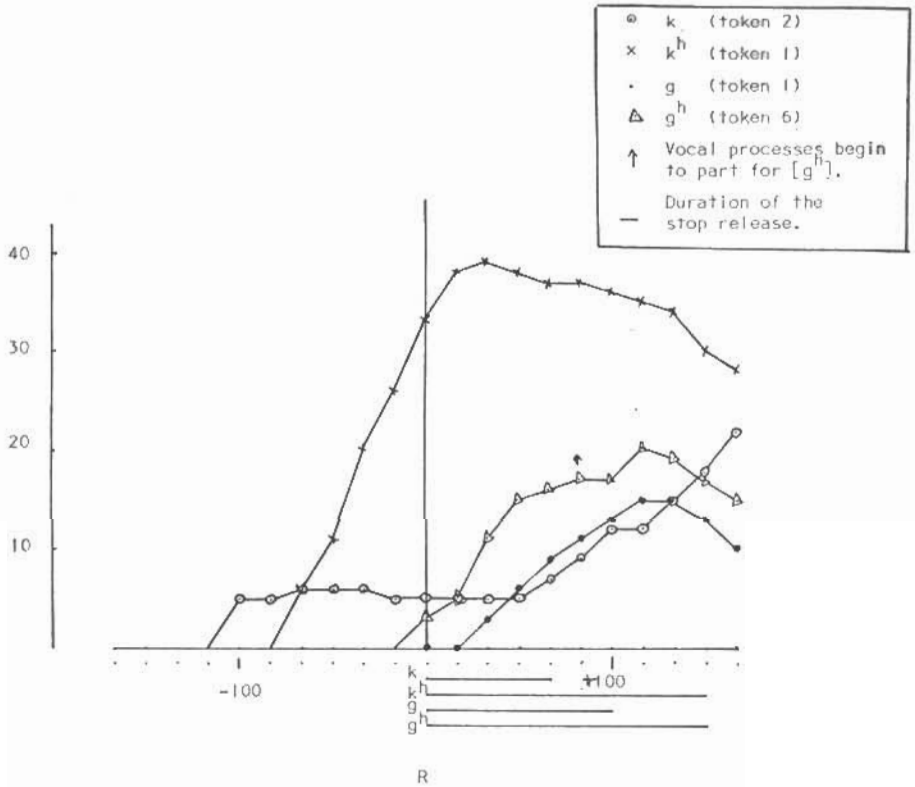

Fig. 8. Typical glottal width contours for word final [k, k^h, g, g^h]

began to decrease almost immediately after the release onset. In one instance, the glottal width for [p^h] narrowed rapidly in readiness for the next utterance. The glottis was much wider for the voiceless aspirated type than for the voiceless unaspirated type both during the oral closure and the release period. It was also wider than the glottal opening between words.

For the voiced unaspirated stops, the vocal processes were observed to be in close contact with vibrating vocal cords both during the oral closure and the release period. The vocal processes, however, began to separate about 2 frames following the release onset so that the final portion of the release was devoiced. The glottis widened for breath for a while and then narrowed in readiness for the next utterance.

For the voiced aspirated type, the vocal cords were in vibration both during the oral closure (lasting 4 - 5 frames) and the oral release. At the oral release or immediately before it, a posterior opening of the arytenoids was observed in all the samples used in this study. Such a posterior opening, while the anterior remained adducted as for regular voice, lasted for about 2 frames for [b^h] and about 5 frames for [g^h] after the articulatory release--at which point the vocal processes began to part. For the sake of comparison with initial and medial stops, glottal width given in the tables and figures was measured at the posterior end of the glottis. The glottis remained open in a state of breath for a while and then narrowed in readiness for the next utterance.

Conclusion

Examination of the results of these fiberoptic experiments reveals the following:

1. The voiceless unaspirated type is characterized by a narrow open glottis with no vibration of the vocal cords during the oral closure period.
2. The voiceless aspirated type is characterized by a wide open glottis with no vibration of the vocal cords during the oral closure and the release period.
3. The voiced unaspirated type is characterized by a closed glottis during the oral closure period.
4. The voiced aspirated type is characterized by a closed glottis during the oral closure period and a posterior opening of the arytenoids at or immediately before the articulatory release. Voicing is observed to be present throughout, including the time when there is a posterior opening.
5. The present study suggests that glottal width is the key factor for aspiration. A modification of the definition of aspiration as glottal width will enable us once again to include both types of aspiration in the same phonetic category: aspiration is greater glottal width than there would otherwise be for the corresponding voiced and voiceless stops.