THE PROBLEM OF ASPIRATION IN HINDI PHONETICS[1)]

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Hindi and some other Indo-Aryan languages (e. g., Marathi) are unique among the world's languages in possessing contrasts between aspirated and non-aspirated stops in both the voiceless and the voiced series, i. e., /p/ vs. /p^h/ and /b/ vs. /b^h/.[2)] The exact physical correlates of the aspirates vis-a-vis the non-aspirates have been a subject of considerable interest to linguists for over 2000 years. In this paper we propose to test a recent description of the Hindi aspirates by Chomsky and Halle (1968).

Statement of the Problem

Specifically citing Hindi, Chomsky and Halle state that heightened subglottal air pressure (HSAP) is a necessary characteristic of all aspirated consonants, i. e., /b^h/ and /p^h/, a possible but non-essential characteristic of voiceless unaspirated consonants, i. e., /p/, and must necessarily be absent from voiced unaspirated consonants, i. e., /b/. Chomsky and Halle assume HSAP is an independent variable and is not a function of any laryngeal or supralaryngeal adjustment.

To test this hypothesis, the following test was performed.

Experimental Procedure

While a native speaker of Hindi (the first author of the present article) pronounced selected Hindi phrases, the speaker's subglottal air pressure was sampled using a large needle (approximately 0. 8 mm inner diameter) which was inserted through the cricothyroid membrane into the trachea such that the open end rested about 1 cm below the vocal cords (see Fig. 1). A pres-

1) This is an English translation and a slightly revised version of an article to appear in Hindi in Bhāshā.

2) Although we just mention the bilabials here and elsewhere our comments apply as well to the stops at other points of articulation.

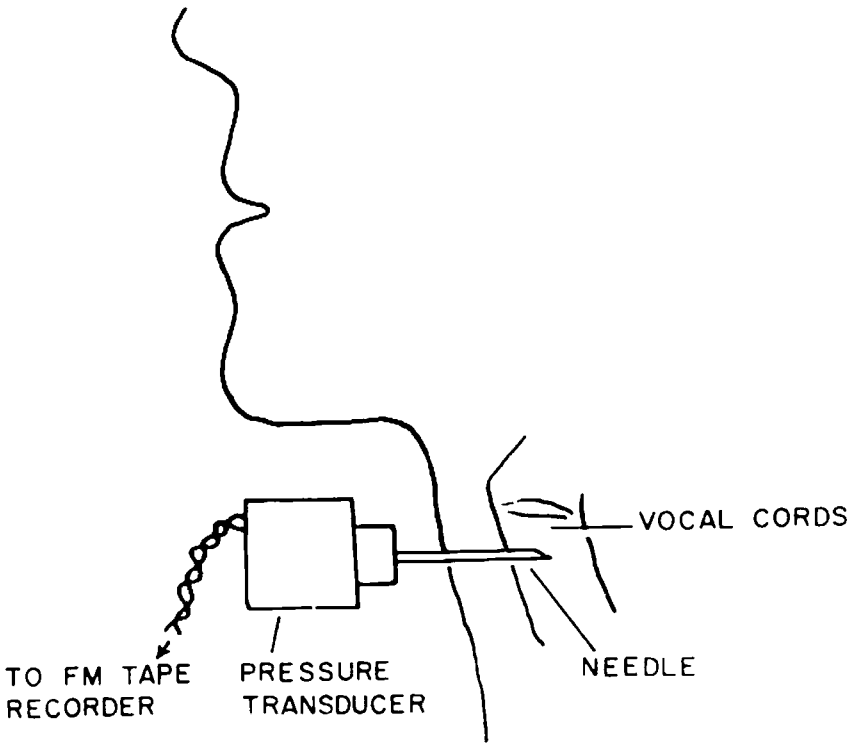

Fig. 1. The experimental setup used in the present study· subglottal air pressure was recorded via a large needle inserted through the subject's cricothyroid membrane into the trachea; the needle was attached to a pressure transducer whose output signal was recorded on magnetic tape by an FM-type tape recorder. A microphone placed in front of the subject's mouth (not shown here) picked up the speech wave, and this audio signal was simultaneously recorded on the same magnetic tape.

sure transducer, an FM-type condenser microphone, was connected to the outside end of the needle with a very small coupling space, and the electrical signal from this was fed to an FM tape recorder along with the signal from a microphone recording the subject's speech wave. These recorded signals were later written on paper using an ink-writing oscillograph after appropriate low pass filtering to remove the high frequency variations in the signal due to voicing; for this an integrator with a time constant of 22 ms was

used.[3)]

The following are the nonsense phrases spoken during the experiment:

Table 1

1.	vō āmā lāyā	(1)
2.	lālā lāb^{h} āyā	(3)
3.	lālā māl āyā	(2)
4.	lālā pāl āyā	(2)
5.	lālā lāh āyā	(3)
6.	lālā b^{h}āl āyā	(3)
7.	vō ābā lāyā	(3)
8.	vō āp^{h}ā lāyā	(3)
9.	vō āb^{h}ā lāyā	(2)
10.	vō āpā lāyā	(1)
11.	vō ālā lāyā	(1)
12.	lālā lāp^{h} āyā	(3)
13.	vō āhā lāyā	(2)
14.	lālā hāl āyā	(3)
15.	lālā lām āyā	(4)
16.	lālā lāb āyā	(3)
17.	lālā lāp āyā	(3)
18.	lālā bāl āyā	(2)
19.	lālā p^{h}āl āyā	(5)

3) This part of the study was performed at the Phonology Laboratory, University of California, Berkeley.

These were constructed so that the sounds b, b^h, p, p^h, m, l, h, were in initial, medial, and final position in a word and such that the consonant of interest was preceded and followed by the vowel ā. For the experiment these phrases were spoken 5 times each in a randomized order (the order given in Table 1). It was discovered after the experiment that the signal recorded during some of the samples contained artifacts due to intermittent blocking of the bore of the needle by an accumulation of mucus. The number of usable tokens obtained for each phrase is indicated by the number in the parenthesis after each phrase as listed in Table 1. Calibration of the pressure signal at the end of the experiment indicated a slow DC leak in the coupling between the needle and the pressure transducer. There is a possibility that this leak was present during the experiment, giving rise to quantitative errors that can be corrected by a roughly constant multiplicative factor for the observed pressure values. Since the data collection could not be repeated, it was unfortunately not possible to determine this factor; but even if this were the case, it could affect only the scale for pressure. Therefore, the subglottal pressure records obtained must be of sufficient quality to support the qualitative conclusions we derive from them.

Results

Some of the results are illustrated by the graphic traces in Fig. 2. In general, HSAP was occasionally noted during the closed portion of the aspirated consonants (see point labelled 3 in Fig. 2B) but it was not found consistently (see point 1 in Fig. 2A). Moreover, HSAP could sometimes be found on the voiced unaspirated /b/, where it was not supposed to be found (see point 5 in Fig. 2C). One consistent finding for /b^h/ and /p^h/ was the sudden decrease of air pressure upon the release of the consonant closure (see point 2 and 4 in Fig. 2A and 2B). There was also a consistent decrease of air pressure during /h/. In other respects the pressure curves are similar to those found for other languages (Ohala 1970).[4)]

4) There was also an occasional pressure increase during the closure portion of /p/, but there was never any pressure change during /l/ or /m/.

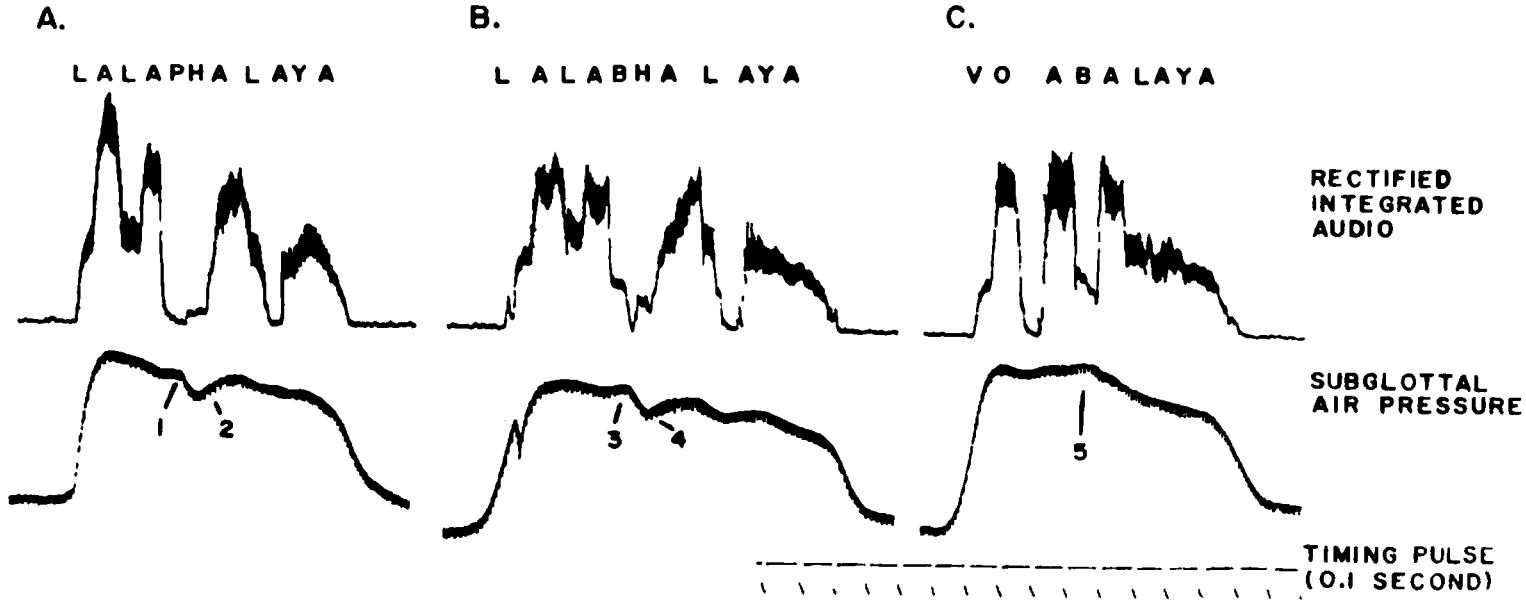

Fig. 2. Examples of signals obtained in this study. At top, the rectified and integrated audio signal from the microphone; at the bottom, the subglottal air pressure. The phrases spoken are: A. "lālā $p^hāl$ āyā," B. "lālā $b^hāl$ āyā," C. "vō ābā lāyā."

Discussion

Chomsky and Halle's claim that HSAP is a necessary correlate of aspirates was not confirmed. If we consider the pressure values during the actual moment of aspiration, i. e., when the stop is released, the subglottal air pressure is momentarily lower. The same is true for the /h/ which, like the "aspirates," is characterized by heavy air flow. Furthermore, HSAP appears inconsistently during the closure portion of both the aspirates and the voiced non-aspirate /b/, the latter of which the authors claimed may not possess HSAP.

In fact, it is curious that they should have made these claims since there is no indication in the classical or modern phonetic literature that HSAP accompanies aspiration. On the contrary, two recent studies dealing with subglottal pressure during the English voiced and voiceless aspirated sounds /p/ vs. /b/ and /t/ vs. /d/ show that there is no significant difference in the subglottal pressure during the two stops (Netsell 1969, Shipp and McGlone 1971). The increased air flow characteristic of the aspirates is not due to any increased activity of the respiratory muscles, rather it is simply due to the fact that during aspirates, unlike other speech sounds, there occurs a moment when the air under pressure in the lungs encounters very little resistance. That is, during the obstruent closures the air is blocked by an oral constriction, and during normal voicing, as during most sonorants, including vowels, the air is partially blocked by the vocal cords. But during /h/ and upon the release of the aspirated stops there occurs a moment when there is no oral constriction and when the glottal resistance is markedly lower than that for normal voicing. Given such lowered resistance to the lung air, the air naturally rushes out in great volume. And consequently the air pressure just below the glottis is momentarily lowered.

It is also possible to account for the occasionally found increase of subglottal air pressure during the closure portion of stops without assuming any increase in the activity of subglottal respiratory system. Let us assume that the task of the subglottal respiratory system is to provide a relatively constant pressure to the air in the lungs. Since air is constantly escaping from the lungs, at least during sonorants, this can be accomplished by producing a constant rate of volume decrease of the chest cavity. However when the

air is completely blocked, as it is during stop closures, this continuing decrement in lung volume would cause the air pressure in the system to increase momentarily.

Summary

The distinctive character of the aspirates including /h/, as observed in the time course of the subglottal air pressure, is not increased subglottal air pressure as proposed by Chomsky and Halle. Rather, the occurrence of reduced glottal resistance during a period when there is no accompanying oral constriction invariably causes a momentary lowering of the pressure. Those momentary increases in subglottal air pressure that do occasionally occur during the closure portion of stops, whether aspirated or not, can be explained without reference to any different behavior on the part of the respiratory system.[5)]

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5) After the research reported here was undertaken, Halle and Stevens (1971) apparently rejected the use of the feature HSAP for aspirates and posited instead the new feature composition $\begin{bmatrix} \text{+spread vocal cords} \\ \text{-constricted vocal cords} \end{bmatrix}$ as being common to the aspirates, the [b^h] being differentiated from [p^h] by means of additional features thus:

	b^h	p^h
stiff vocal cords	-	+
slack vocal cords	+	-

We believe the results in the present paper are useful in showing that the original feature of HSAP was wrong, because although it was adopted by Chomsky and Halle without empirical evidence, so it was discarded by Halle and Stevens also without any evidence. The present data reveal that [b^h], in accord with the Halle-Stevens proposal, is correctly considered to have 'slack' vocal cords and that [p^h] has 'spread' vocal cords; however there is no evidence that (nor is it necessary to assume that) [p^h] has 'stiff' vocal cords and [b^h] has spread vocal cords. However more experimental data rather than mere speculation are needed to settle this point.

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