F_o PERTURBATIONS IN HINDI

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ABSTRACT

F_o perturbations were measured for Hindi voiceless, voiceless aspirated, voiced, and breathy voiced stops combined with the phonemically long vowels /a e i o u/ in word-initial position and isolated word production. The analysis revealed: (i) significant differences between the stop manners of articulation for about 90 ms after release, (ii) significant influence of the tongue height of the vowel, and (ii) less influence of the place of articulation of the stop.

INTRODUCTION

F_o perturbations after stops have been thought of as unavoidable by-products of the stop articulation and have been treated as a secondary cue for the perception of stop's manner of articulation. Ohde's studies [3] for example revealed a falling F_o contour after voiceless and a lower F_o onset but still falling contour after voiced stops. It was shown by Lea [2] and Umeda [5] that the influence of the preceding stop had disappeared in non-tone languages like English after 75 to 100 ms. These analyses of F_o perturbations focused on voiced and voiceless aspirated stops; thus voiceless unaspirates and breathy voiced stops were rarely included in these studies. Moreover, little attention has been paid to the influence of the vowel on the F_o perturbations. Hence, the aim of our investigation is threefold: (i) to provide data from a language with a four-way contrast within the stop categories, (ii) to present results from breathy voiced stops, (iii) to test the influence of either the place of articulation of the stop and the tongue height and tongue position of the vowel on the F_o trajectory after stop release.

MATERIAL, INFORMANT AND PROCEDURE

A list of words was prepared containing the voiceless, voiceless aspirated, voiced, and breathy voiced stops in four places of articulation (labial, dental, retroflex, and velar) combined with the phonemically long vowels of Hindi in word-initial position in randomized order. There were some gaps in the material as only common words were chosen (cf. Table 3). One subject (female, 35 years) born in Simla (Himachal Pradesh) and raised in Simla and New Delhi served as informant. The material was tape-recorded in Munich (for further detail cf. Schiefer [4]), digitized on a PDP11/50 computer (sample rate 20 KHz) and filtered with a cut off frequency of 8 kHz. The periodic portions of the initial CV syllable were segmented manually into single pitch periods cf. [4], starting with the first visible period. The analysis was based on the first ten pitch periods after stop release. This covers a period of approximately 40-50 ms. F_o was measured additionaly for pitch period 20, which is about 80 to 90 ms away from the burst. Separate two-factorial analyses of variance were conducted for the stop and vowel conditions for (i) all stops in general, (ii) the voiceless, (iii) aspirated, (iv) voiced, and (v) breathy voiced stops over the first ten pitch periods. The results for the 20th pitch period were calculated separately.

RESULTS

The influence of stop-manner. Fig. 1 displays the results for the stops in general. All F-values and p-values for the main effects of place (A), vowel (B) and interaction (I), P1 to P10, and P20 are

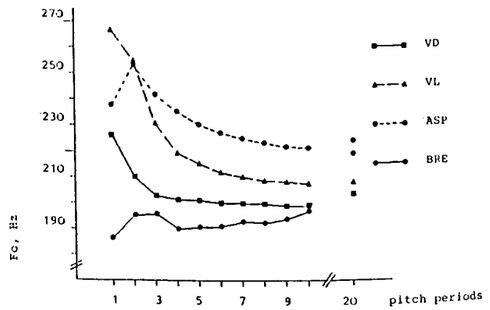


Fig.1: Fo values as a function of pitch periods and stop's manner of articulation

listed in Table 1 for the stop conditions. The difference between the stops remains significant till pitch period 20. All stops differ in respect to the F_o onset and F_o contour. The onset is highest in voiceless stops (henceforth VL), lower in aspirated (ASP) and voiced stops (VD), and lowest in breathy voiced stops (BRE). VL stops have a falling, ASP a rising-falling, VD a falling, and BRE stops a rising pattern. The fall is steepest in VL, less steep in VD stops. All stops differ significantly from each other in respect to the onset (P1). At pitch period P20 the stops fall into two groups: VD and VL with lower F_o and BRE and ASP with higher F_o values.

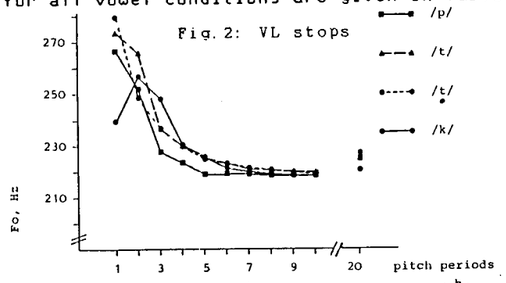
The influence of the place of articulation in VL stops. Figure 2 shows the results for the VL stops. The [+apic] stops /t/ and /ṭ/ show the highest F_o onset, whereas the [-apic] stops /p/ and /k/ have lower F_o

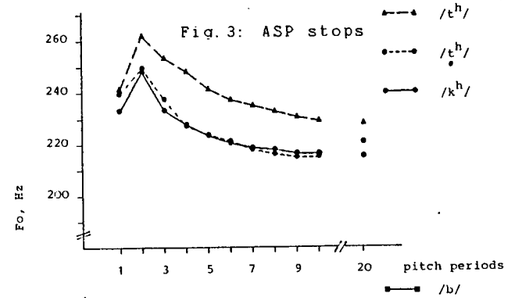
TABLE 1: Effect of place of articulation on F_o as a function of the number of pitch periods. A represents the overall effect of place, B that of the pitch periods, and I the interaction.

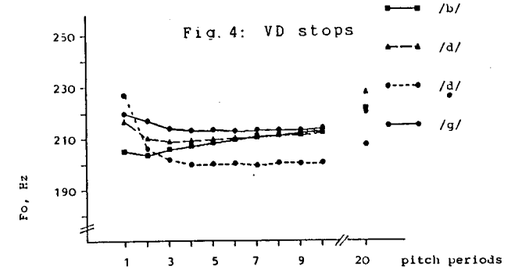
	VL stop		ASP stop		VD stop		BRE stop	
	F	p	F	p	F	p	F	p
P1	77.0	***	1.2	n.s.	33.3	***	4.2	*
P2	13.7	***	3.1	*	13.8	***	9.4	***
P3	17.1	***	7.0	**	10.4	***	10.2	***
P4	2.7	*	8.7	***	12.4	***	8.4	***
P5	2.4	n.s.	6.3	**	12.6	***	12.8	***
P6	0.9	n.s.	5.4	**	12.1	***	19.7	***
P7	0.3	n.s.	5.6	**	15.2	***	22.8	***
P8	0.3	n.s.	5.1	**	13.4	***	29.7	***
P9	0.2	n.s.	4.4	*	14.7	***	26.9	***
P10	0.1	n.s.	3.5	*	16.3	***	28.7	***
P20	0.7	n.s.	1.9	n.s.	3.9	n.s.	2.7	*
A	5.0	**	23.2	***	27.5	***	44.1	***
B	89.4	***	10.3	***	4.2	***	9.4	***
I	3.7	***	0.2	n.s.	2.6	**	1.5	n.s.

frequencies at the onset with an overlap between both groups. The contour is falling for all stops except /k/ which shows a rising-falling pattern. Fig. 3 shows the results for the ASP stops. All stops have high F_o values at vowel onset. F_o increases from pitch period P1 to P2, and decreases continously from P2 to P20. Only /th/ differs significantly from the other stops. VD stops show a different pattern (cf. Fig. 4 and Table 1) from either the VL or ASP stops as F_o is lower at the vowel onset, where the [-ant] stops /ṭ/ and /g/ have higher and the [+ant] stops /d/ and /b/ lower F_o frequencies. But only /b/ differs significantly from the other stops. The difference remains significant till pitch period P10. At P20 the difference fails to reach significance. All stops except /ḍ/ show a slightly falling F_o contour from P1 to P2/P3 and a slightly rising F_o from P4 to P20. /ḍ/ has a steeper fall from P1 to P2 and a falling/level pattern towards the end of the trajectory. In breathy voiced stops (cf. Fig. 5 and Table 1) the F_o is low at vowel onset and shows a rising pattern from P1 to P20. The differences at the onset are small; [+ant] stops have slightly higher F_o frequencies than [-ant] stops, but they do not differ significantly from each other. The differences between the stops in pitch periods P4 to P20 are caused by the significantly higher F_o values for the velar stop /gh/.

The influence of the vowel on the F_o contour. The results for the VL stops are shown in Fig. 6, the F-values and p-values for all vowel conditions are given in Table







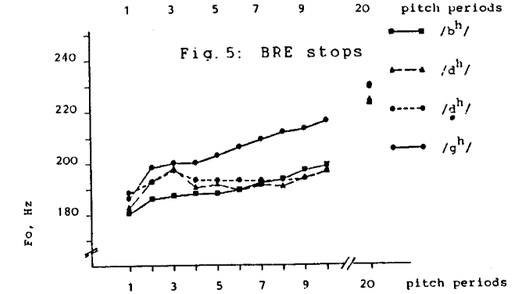
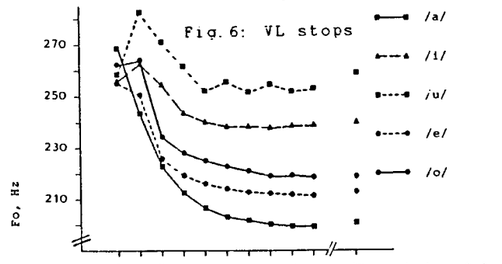
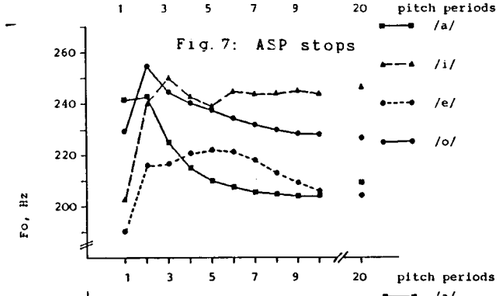
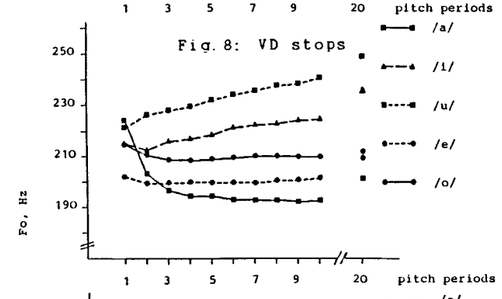


Fig. 2 to 5: Fo values as a function of pitch period and place of articulation of the stop

2. The F_0 at vowel onset is a function of the tongue position of the vowel: central and back vowels have higher F_0 frequencies than front vowels. The F_0 trajectory for the vowels differs: /a/ shows a steep falling, the mid vowels /e o/ a falling, and the high vowels /i u/ a rising-falling pattern. The difference between F_0 onset and endpoint of the trajectory is again a function of tongue height: it is greatest







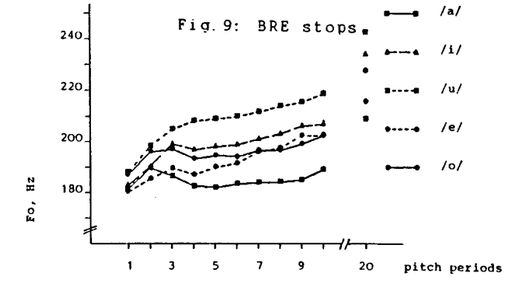


Fig.6 to 9: Fo values as a function of pitch period and the vowel

for /a/, less for the mid vowels, and smallest for /i u/. These results thus reflect the well known effect of "intrinsic pitch". Fig. 7 displays the results for the

TABLE 2: Effect of the vowel as function of the pitch periods.

	VL stop F	p	ASP stop F	p	VD stop F	p	BRE stop F	p
P1	9.8	***	75.5	***	50.7	***	3.9	*
P2	71.3	***	35.3	***	13.8	***	9.4	***
P3	140.6	***	33.8	***	115.8	***	18.9	***
P4	130.7	***	26.1	***	135.2	***	34.0	***
P5	112.6	***	26.2	***	157.3	***	34.3	***
P6	141.7	***	35.7	***	190.4	***	32.8	***
P7	132.6	***	37.6	***	207.6	***	34.2	***
P8	153.6	***	41.7	***	219.3	***	40.0	***
P9	146.2	***	48.3	***	235.4	***	42.8	***
P10	155.1	***	49.0	***	252.0	***	40.0	***
P20	61.1	***	20.0	***	35.4	***	14.8	***
A	252.2	***	82.0	***	355.5	***	61.6	***
B	87.0	***	8.0	***	2.9	*	13.3	***
I	5.2	***	6.0	***	6.0	***	1.8	n.s.

ASP stops. The differences between the vowels at F_0 onset are greater in ASP stops compared to the VL ones. F_0 is obviously determined by the tongue position of the vowel: central and back vowels lead to higher F_0 onset than do front vowels. All vowels differ significantly from each other: /a/ shows a nearly level contour for the first two pitch periods, and a falling contour from P2 to P10, whereas the mid vowels have a rising-falling and /i/ a rising-falling-rising pattern. In VD stops F_0 at vowel onset (cf. Fig. 8) is determined by the tongue position of the vowel: F_0 ist lowest for mid, higher for high, and highest for low vowels. But only /e/ differs significantly from the other vowels. The vowels differ, too, in respect to the F_0 trajectory: /a/ shows a steep fall, /e o i/ a short fall followed by a rising contour, whereas /u/ has a rising pattern throughout. In BRE stops (cf.Fig.9), the F_0 onset is low. The influence of the vowel is smallest but significant at vowel onset. Back vowels show a slightly higher F_0 than non-back vowels. For detailed discussion cf. [4].

Interaction between place of articulation and vowel. In order to compare our results with those from Ohde's studies we have calculated the F_0 difference between the first and second pitch period (cf. Tab. 3). Concerning the stop manners in general a F_0 fall was measured in VL and VD stops, whereas ASP and BRE stops show a rising pattern. This can be explained by the different timing and width pattern of the glottis for these two groups of stops (cf. [1]). The effect of place of articulation in general shows a falling pattern in VD and VL stops (with the exception of /k/), and again a rising pattern for the ASP and BRE stops. Concerning the interaction between place of articulation, vowel and stop's manner of articulation the results can be summarized as follows: (i) ASP stops cause a rise from P1 to P2. There is no interaction between place of articulation and vowel. (ii) The F_0 is rising after BRE stops with only a few exceptions which can be neglected due to the minimal differences between P1 and P2 in these examples. The results for /bho/ cannot be explained. (iii) VL and VD stops show similiar patterns and large interactions between place and vowel. In labial position [+back] vowels cause a rising F_0 contour, whereas in dental position the same effect is caused by [+front] vowels. In combination with the VL stop /u/ leads to a rising F_0 pattern, too. F_0 is falling in the retroflex position for both stop manners with the exception of /i/ after VL stops, which cause a rising F_0. The differences between both stop manners are greatest in the velar position: F_0 rises after VL stops, whereas after VD a rise can be observed only with [+high] vowels.

GENERAL DISCUSSION

Concerning the stop manners of articulation in general our results verify those found by Lea and Umeda, as the differences remain significant for about 90 ms, and they are in good agreement with those found by Ohde: VL, ASP and VD stops cause a falling F_0 after vowel onset. The F_0 onset is higher for VL than for ASP stops. The overall F_0 is on the other hand higher after ASP than after VL stops. The places of articulation do not influence the F_0 onset pattern in a systematic way. The stop manners form two different sets: (i) ASP and BRE stops on the one side and VL and VD on the other side pattern differently with respect to the F_0 onset and contour. Whereas ASP and BRE stops cause a F_0 rise from P1 to P2 (with only few exceptions within the BRE category) the VL and VD stops reflect similiar interactions between place of articulation and the vowel. This can be explained by the underlying difference in the laryngeal behavior during the production of these stops. In VL as well as VD stops the glottis is almost closed during the moment of articulatory release of the closure, whereas the glottis is open in BRE as well as ASP stops. Thus the F_0 onset is less affected by articulatory movements during the production of ASP and BRE stops, but is subject to greater influences in VL and VD stops. Some general differences between our results and Ohde's are obvious: (i) ASP stops cause a rising-falling pattern across all place and vowel conditions. This difference is systematic without any exception. It can be assumed that the different methods applied in these studies may be responsible for this effect. (ii) VL and VD stops do not cause a falling F_0 pattern in all place or vowel conditions. The pattern is a function of the place of articulation and the tongue height and tongue position of the vowel. (iii) Concerning the interaction between place of articulation and vowel we found, in contrast to Ohde, a similiar pattern for the VD and VL stops. This interaction is comparable to that of Ohde only in respect to the VD category.

TABLE 3: Interaction between place of articulation, vowel, and stop manner: difference between P1 and P2 in Hz. Positive values indicate a F_0 fall from P1 to P2, negative values a F_0 rise.

		VD	VL	ASP	BRE
means		7.9	8.7	-14.8	- 7.9
labial	/a/	11.2	50.5	---	-11.3
	/e/	3.3	31.0	---	- 6.4
	/o/	- 3.4	-14.6	---	6.9
	/i/	1.8	2.8	---	- 5.3
	/u/	- 4.2	-35.8	---	-11.5
	x	1.5	13.7	---	- 6.1
dental	/a/	13.8	49.0	- 5.0	0.4
	/e/	- 0.5	-14.1	-----	----
	/o/	11.4	9.3	-27.8	-15.3
	/i/	- 3.9	- 9.4	-----	-10.6
	/u/	1.7	-12.5	-35.0	-14.6
	x	6.6	7.7	-19.3	-10.1
retr.	/a/	42.7	51.7	- 0.8	- 5.4
	/e/	3.7	46.8	- 9.4	1.7
	/o/	8.4	36.7	-23.0	-13.6
	/i/	25.2	- 9.2	-24.0	2.1
	/u/	----	----	-----	- 6.7
	x	20.8	30.8	-10.0	- 4.1
velar	/a/	14.4	-20.5	- 1.5	-16.3
	/e/	4.3	-26.1	-37.2	- 4.4
	/o/	1.1	-31.1	-26.1	- 5.0
	/i/	- 2.2	-11.6	-42.9	-34.2
	/u/	-12.9	-17.4	-32.1	- 4.2
	x	2.9	-17.4	-15.0	- 3.0

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