



ACOUSTIC PHONETIC STUDY OF BENGALI NASALS

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ABSTRACT

This paper presents the results of the investigations on the formant frequencies and durations of nasal murmurs in different vowel context. Spectrographic analysis of 150 multisyllabic Bengali words spoken by three male and three female informants constitute the data base for this study.

1. INTRODUCTION

The present work is a part of the project on acoustic phonetic studies of speech sounds of major Indian Languages and is a continuation of earlier works on Telugu [1,2], Hindi [3] and Bengali [4] speech sounds. This work owes its origin to (1) the lack of reliable acoustic phonetic data needed for computer recognition and synthesis of speech for Bengali (2) establishment of statistical data base for this language (3) assistance to the effort in standardisation of phonetic quality for educational and cultural use of voice media. Most of the work so far reported include non nasal vowels and consonants. So the present investigation gives emphasis mainly on nasal murmurs coarticulated with different vowels. Beside studying formant structures of nasal murmurs, the program includes the investigation of interesting features like the introduction of nasal formants and antiformants in adjacent vowels. The durational behaviour of nasal murmurs are also a part of the present analysis. The acoustic features selected for this study are based on the findings of previous experiments [5,6,7].

2. EXPERIMENTAL PROCEDURE

The nasal murmurs /m/, /n/ and /ŋ/ of standard Bengali (SB) in combination with seven vowels were selected from about 150 spoken words. The 3 male and 3 female informants, all educated teachers, highly acclaimed in the field of recitation recorded these words on Cosmic Akai tape recorder. The spectrographic analysis of these sounds was done on DSP Sonagraph Model 5500 in the range 80Hz to 8kHz using band filter (300Hz). For accurate measurements the other bands are also selected whenever required. The extraction of formant frequencies for vowels and nasals has been done at the steady state of the formants [1,4]. The frequency cursor of the DSP sonagraph is used for these measurements. The time cursor is used for the measurement of duration. The accuracy of measurement are 20Hz and 2.5ms respectively in frequency and time scale.

3. RESULTS AND DISCUSSION

3.1 Formant frequency structure of nasal murmurs

The table 1 and 2 show the formant positions

of nasal murmurs for three male and three female informants. The vowelwise distributions and their averages are reported. The vowels occur in the following positions. Four almost disjoint regions for the four formants are observed, namely, 200Hz-400Hz for first formant (R_1), 800Hz-1500Hz for second formant (R_2), 1600Hz-2900Hz for third formant (R_3) and 3000Hz-4000Hz for fourth formant (R_4). Split formants for /ŋ/ are a common phenomenon in the R_3 region and an occasional event in R_2 region. The details study of the frequency regions shows that the first nasal formant (R_1) does not possess any dependence on the place of articulation, the nature of the following vowel or on the speaker. The second formant region R_2 exhibits some discrimination with respect to the place of articulation for both male and female informants. The dental /n/ has a mean value of R_2 which is about 120Hz higher than the bilabial /m/. For the male informants a clear separation between /m/ and /n/ can be done on the basis of R_4 as the difference of about 400Hz are noted in this case. /ŋ/ can also be discriminated from /m/, /n/ on the basis of R_4 as it has the largest R_4 value. For female informants the effectiveness of R_4 as discriminating power is marginal. It is also noted that for /ŋ/, R_3 has average value slightly higher than other two nasal murmurs. Moreover the additional R_2^* around 750Hz and the additional R_3^* around 1700Hz may be considered as characteristics of nasal /ŋ/ whenever they occur for informants of both the sexes.

The study of vowelwise frequency distribution shows that from back vowel /u/ to central vowel /æ/ R_2 is large for /n/ than that of /m/ and reverse case is noted for /e/ and /i/. Similar study exhibits that R_4 for /m/ is greater than that of /n/ for all the vowels.

Informantwise investigation indicates that male informant 3 has the minimum frequency values for all the vowels and thus can be identified among the informants of same sex. Again, discrimination can be done between first two male informants as R_4 is higher for the first one. Regarding female informants informant 3 has lower value of R_2 for most of the cases and thus provide a feature for classification of speakers. All the above investigations were done for the consonants /m/ and /n/ only and not for /ŋ/ due to insufficient data. However, for the confirmations of these indications the number of informants should be more.

In general, it was observed that the first formant was the most intense, the frequency of which is in the vicinity of 250Hz to 300Hz. The higher formants are found to be less intense and this is in agreement with the earlier investigations [6,7].

Table 1. Frequency of nasal formants for male informants (Hz)

Vowel	Informant	/m/				/n/				/ŋ/					
		R ₁	R ₂	R ₃	R ₄	R ₁	R ₂	R ₃	R ₄	R ₁	*R ₂	R ₂	*R ₃	R ₃	R ₄
/u/	1	300	-	2250	4000	250	-	2100	3600	-	-	-	-	-	-
	2	266	1083	2350	3533	250	975	2250	-	300	-	-	1900	2500	3100
	3	316	870	2300	3000	300	900	2260	2850	-	-	-	-	-	-
/o/	1	-	-	-	-	267	1233	2340	3800	300	-	-	-	2400	4000
	2	275	1100	2500	3700	290	1290	2516	3450	-	-	-	-	-	-
	3	300	850	2400	3100	300	900	2100	2900	300	-	900	-	2200	3200
/ɔ/	1	300	1000	2100	3950	250	1400	2200	-	-	-	-	-	-	-
	2	270	1040	2675	3650	250	1070	2470	-	300	-	1100	1700	2500	3000
	3	300	850	2300	2900	300	1000	2270	2930	-	-	-	-	-	-
/ɑ/	1	260	1100	2180	3820	260	1400	2300	-	300	700	-	-	2230	4067
	2	280	1014	2433	3540	290	1150	2610	3400	300	-	1033	1760	-	3720
	3	380	920	2310	2860	300	950	2230	2870	310	-	900	-	2000	3430
/æ/	1	260	1215	2120	3812	270	1300	2200	-	-	-	-	-	-	-
	2	280	1010	2433	3540	270	1130	2120	3550	-	-	-	-	-	-
	3	400	800	2150	3010	300	930	2300	2900	-	-	-	-	-	-
/e/	1	250	1100	2100	3300	300	-	2200	-	300	-	-	-	2200	4100
	2	270	1120	2215	3500	300	1100	2370	-	310	-	1100	-	2300	-
	3	310	800	2150	3100	300	900	2200	2800	305	800	-	-	2200	3600
/i/	1	300	1150	2100	3200	250	-	2150	3100	-	-	-	-	-	-
	2	250	1125	2350	3650	270	1030	2250	3600	-	-	-	-	-	-
	3	300	1000	2020	3060	300	950	2170	3000	-	-	-	-	-	-
Average		295	1007	2268	3410	279	1130	2266	3030	304	800	1033	1785	2280	3574

Table 2. Frequency of nasal formants for female informants (Hz)

Vowel	Informant	/m/				/n/				/ŋ/					
		R ₁	R ₂	R ₃	R ₄	R ₁	R ₂	R ₃	R ₄	R ₁	*R ₂	R ₂	*R ₃	R ₃	R ₄
/u/	1	300	1150	-	3000	250	1300	2300	-	250	700	-	1600	2200	-
	2	230	1100	2100	3250	250	-	2000	2900	-	-	-	-	-	-
	3	250	900	1700	3000	400	-	1700	3000	-	-	-	-	-	-
/o/	1	275	1100	-	2950	300	1400	2600	3300	300	800	-	1700	2400	2900
	2	250	1100	1900	3400	300	-	1750	-	-	-	-	-	-	-
	3	250	1000	1800	-	300	900	1700	3100	-	-	-	-	-	-
/ɔ/	1	275	-	-	-	-	-	-	-	275	750	-	1550	2100	2700
	2	260	1050	2130	-	270	-	1830	3030	250	-	-	-	1950	3200
	3	400	950	1600	2900	300	-	1900	-	-	-	-	-	-	-
/ɑ/	1	300	1110	2120	2680	260	1350	2430	3040	300	780	1100	1630	2170	2800
	2	260	1100	2200	-	250	1250	2100	-	300	600	-	-	2300	3500
	3	350	1400	1700	2500	350	-	1800	2900	400	800	-	-	2050	3100
/æ/	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	250	-	2050	-	250	-	2000	3100	-	-	-	-	-	-
	3	400	-	1800	-	300	900	1800	2900	-	-	-	-	-	-
/e/	1	310	1070	2230	2830	300	1300	2100	2800	-	-	-	-	-	-
	2	260	950	2200	-	280	1200	2050	-	250	550	-	-	2010	2900
	3	350	800	1700	2600	300	900	1900	2900	400	700	-	-	2100	3100
/i/	1	250	900	-	2800	280	1230	2200	2700	-	-	-	-	-	-
	2	300	850	2100	-	280	-	2100	-	-	-	-	-	-	-
	3	300	850	1650	2700	300	850	1800	2800	-	-	-	-	-	-
Average		291	1020	1940	2880	289	1140	2008	2960	304	710	1100	1620	2135	3025

3.2 Antiformants for nasal murmurs.

Table 3 contains the antiformant frequency positions of nasal murmurs for both the sexes. The nasal consonant /ŋ/ is not included in the table as

the number of observations in this case are small. For convenience of analysis and presentation the frequency span throughout which the antiformants were found to occur may be divided in three regions e.g. R₁ (900Hz to 2200Hz), R₂ (2400Hz to <2900Hz)

and R₃ (300Hz) to 4000Hz). Sometimes two antifor-
mants³ are observed in R₁, these are bracketed
together in the table. It may be clearly observed
from the table that there is no visible correlation
of the distribution of antiformants with respect to
the vowel class. However the antiformants in R₁

and R₃ exhibit significant sensitivity with respect to
speaker. R₂ also shows some speakerwise variation.
Informant²₁ (male) seldom produces an antiformant
in R₂ and has an abundance of antiformants in R₃.
For Informant 3 (male) antiformants are absent in
R₃ and seldom in R₂. Moreover the antiformants of

Table 3. Antiformant of nasal murmur(Hz)

Vowel	Infor- mant	Male						Female					
		R ₁	/m/ R ₂	R ₃	R ₁	/n/ R ₂	R ₃	R ₁	/m/ R ₂	R ₃	R ₁	/n/ R ₂	R ₃
/u/	1	-	-	3400	1300	-	3100	(1200,1900)	-	-	2100	-	-
	2	1400	2800	3200	1700	-	-	1000	-	-	1300	-	-
	3	1600	-	-	1700	-	-	-	-	-	-	-	-
/o/	1	-	-	-	1035	-	3500	-	2500	-	2000	2700	-
	2	2000	-	-	2000	-	-	1500	2800	-	1200	-	-
	3	1700	-	-	1670	-	-	1500	2500	-	1200	-	3600
/ɔ/	1	-	-	3350	1200	-	-	-	-	-	-	-	-
	2	(1650,2200)	-	-	(1750,2200)	-	-	(900,1500)	2700	-	1100	-	-
	3	1650	2700	-	1700	-	-	-	2900	-	-	-	-
/ɑ/	1	-	-	3200	1000	-	-	2000	2500	-	(1150,2200)	3700	-
	2	1700	2700	-	(1450,2200)	-	-	900	-	-	1200	-	-
	3	-	2760	-	1700	-	-	1000	-	-	1300	-	-
/æ/	1	-	-	-	-	-	3400	-	-	-	-	-	-
	2	-	2800	-	(1600,2000)	3100	-	900	-	-	1200	-	4000
	3	-	-	-	1700	-	-	1100	-	-	1300	-	-
/e/	1	1250	2800	3400	-	-	3400	2050	2500	-	-	2500	-
	2	1670	2900	-	1750	-	-	(1000,1500)	-	-	1200	-	-
	3	1600	-	-	-	-	-	(1200,2200)	-	-	1300	2500	3600
/i/	1	-	2700	3700	1400	-	3000	-	2400	-	(1800,2100)	-	-
	2	-	-	3100	1550	-	-	(1130,1600)	-	-	1200	-	-
	3	-	-	-	1470	-	-	-	-	3500	-	-	-

Table 4. Nasal formant and antiformant in nasalised vowel (Hz)

Vowel	Infor- mant	Male					Female					
		Formant NF ₁	NF ₂	Antiformant R ₁	R ₂	R ₃	Formant NF ₁	NF ₂	NF ₃	Antiformant R ₁	R ₂	R ₃
/u/	1	700	1650	2000	2500	3000	800	-	-	2000	2600	-
	2	-	-	-	-	3300	-	-	-	-	-	-
	3	1250	-	-	1630	-	-	-	-	-	2400	-
/o/	1	700	1600	-	2200	3100	650	-	-	-	2500	3100
	2	600	-	-	-	3150	-	1600	-	-	2700	-
	3	-	1400	-	-	-	-	-	-	-	2600	-
/ɔ/	1	1000	-	-	2200	-	900	-	-	2100	-	3100
	2	-	-	-	-	3000	-	-	2070	-	2650	-
	3	-	1350	-	-	-	-	-	-	-	2550	-
/ɑ/	1	850	1750	2000	2700	3200	950	1400	-	2100	2450	3200
	2	-	-	-	-	3100	-	-	2100	1900	-	-
	3	-	-	-	-	-	-	-	-	-	2700	-
/æ/	1	1300	-	-	-	3200	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	2300	-	-	-
	3	-	-	-	-	-	-	-	-	-	-	-
/e/	1	1000	1600	1400	-	3000	950	1400	-	1900	2900	-
	2	900	1400	-	2900	-	-	-	2550	1200	-	-
	3	700	-	1300	-	-	1000	-	-	1600	-	-
/i/	1	900	-	1150	-	-	900	1400	-	1800	2400	-
	2	-	-	-	-	-	-	-	2100	1400	2700	-
	3	900	-	1350	-	-	-	-	-	-	-	3500

are always higher than the other informants. As far as place of articulation contrast is concerned R_1 and R_2 have some contribution. In this respect, one important finding is that the region R_2 is totally absent for male speaker of /n/ and for the female there are only three cases. In R_3 no evidence for such contrast is found.

3.3 Antiformants and formants for nasal vowels

Table 4 presents a picture of antiformants and formants of nasal vowels for informants of both sexes. As like previous study, the frequency span throughout which the antiformants in nasal vowels occur are divided into three regions, e.g. R_1 (1150Hz to 2100Hz), R_2 (2200Hz to 2900Hz) and R_3 (3000Hz to 4000Hz). Similarly the nasal formants are also grouped into three other regions, namely, NF_1 (700Hz to 1300Hz), NF_2 (1400Hz to 1750Hz) and NF_3 (2000Hz to 2550Hz). It is to be noted first, for the male informants the antiformants are mostly occur in R_3 region (9 cases) and for female informants in R_2 region (12 cases). This may be considered as a feature for sex identification. The range of variation of these regions being low, the effect of vowel positions on the antiformants are not remarkable. For female informants the frequency region R_1 are found to have some discriminating power for informant classification.

The nasal formants occur in three regions for female informants as against two for male informants. The number of occurrences are also abundant for male informants. The male informants can be discriminated on the basis of the frequency position of NF_1 region. Due to the lack of adequate volume of data, analysis cannot be done satisfactorily on this part.

The nasalisation is known to weaken vowel formants [5]. The analysis of the spectrogram indicates that this weakening is speaker dependent. For example, the male informant 1 exhibits less frequent weakening of NF_3 whereas for female informant 1 the least frequent weakening is found to occur with NF_1 .

Table 5 Duration of nasal murmurs(ms)

Nasal	Sex	/u/	/o/	/ɔ/	/ɑ/	/æ/	/e/	/i/	Average
/m/	M	60	71	67	58	70	83	65	67
	F	72	73	75	71	65	81	78	74
/n/	M	83	75	65	72	99	59	80	76
	F	70	77	76	71	92	70	83	77
/ŋ/	M								105
	F								123

4. DURATION OF NASAL MURMURS

Table 5 represents the duration of nasal murmurs. /ŋ/ is not tabulated vowelwise due to lack of adequate volume of data. The effect of following vowels on the duration of nasal murmurs is studied first. The durations of /m/ when followed by vowel /e/ are found to be large for all the informants of both sexes. The maximum duration of 99ms occurs with consonant /n/ and vowel /æ/ combination for both male and female informants. It is interesting to note that the lowest amount of duration of /n/ occur with /e/ which is just reverse to /m/ where the largest amount of duration takes place with the same combination.

The role of duration for discrimination of place of articulation are reported here. It is clear from the result that /m/ can be separated from /n/ on the basis of average duration as the duration of former is less than that of the later one. The consonant /ŋ/ can be grouped to a separate class as it is found to have the largest duration.

5. CONCLUSION

The spectrographic investigations confirmed the presence of formants in nasal murmurs and nasal formants and antiformants in adjacent vowels. A data base such generated may provide a knowledge base for an expert system for automatic speech recognition [8]. The formation of this acoustic data base may require some modification to fulfil the conditions of an efficient expert system.

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