Base of Articulation of 13 Indian Languages

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Abstract

Honikman (1964) defined base-of-articulation of a language as an articulatory setting that reflects the settings of the most frequently occurring segments and segmental combinations in the language. The present study investigated the nature of cross-language differences in base-of-articulation in 13 Indian languages namely, Assamese, Bengali, Hindi, Kannada, Kashmiri, Kodava, Oriya, Rajasthani, Malayalam, Marathi, Tamil, Telugu, and Punjabi that have phonemically unequal vowel inventories. Five males and five females speaking each language participated in the study. Non-sense V_1CV_2 syllables were recorded from ten normal native speakers in each of the 13 languages. Frequencies of the first and second formants were measured using CSL 4500. The five common vowels existing in all languages were compared for base-of-articulation. Difference. Results indicated significant difference between languages, vowels, and gender. In brief, F_1 was high in Oriya and Marathi, and was low in Bengali, Punjabi and Kannada; others were in between. Prominently base-of-articulation (position of tongue, F_2) is fronted in Bengali, is back in Kashmiri and other Indian languages are in between. The results of the present study have augmented the knowledge about cross-language differences in base-of-articulation in Indian languages. Also, the results help in rehabilitation process.

Key words: Vowels, Formant frequency, cross-language, acoustic analysis, Indian languages

Vowels are speech sounds produced by voiced excitement of the open vocal tract. The vocal tract normally maintains a relatively stable shape and offers minimal obstruction to the airflow. Vowel is a speech sound resulting from the unrestricted passage of the laryngeally modulated air stream, radiated through the mouth or nasal cavity without audible friction or stoppage. Vowels are the segmental sounds of speech. They carry information, as the vowels are longer in duration and higher in energy, they carry the speech for a longer distance. i.e., in speech transmission, the vowels act like carriers. Even though the consonants carry more information, due to their non-linearity, shorter duration and low energy they damp very fast. Hence it is difficult for the listener to perceive them. Vowels like string bind the consonants together and helps even in the perception of consonants and thus speech. Acoustically vowels can be classified by formant pattern, spectrum, duration and formant frequency. The formants are the resonance of the vocal tract and depend on the size and shape of vocal tract.

Fant (1960) defined formants as ‘the spectral peaks of the sound spectrum’. It is the presence of formants that enable us to recognize different speech sounds, which are associated with different positions of the vocal tract (Ladefoged, 1975). Formant frequencies of vowels depend on the tongue height and tongue position. Frequency of the first formant (F1) is inversely related to tongue height, and frequency of the second formant (F2) is inversely related to the tongue position. In the production of vowels, oral tract is roughly divided into two cavities, namely back and front cavity. Back cavity refers to the space behind articulatory constriction and front cavity refers to the space in front of articulatory constriction. Though erroneously, F1 depends largely on the volume of the back cavity and F2 depends largely on the volume of the front cavity (Fant, 1960). Thus, one will get a high F1 if the tongue is positioned low at the back of the oral tract. High F2 is obtained when tongue is positioned in the front of the oral tract. Also, one can expect high formant frequencies in oral tracts that are smaller in size (for e.g. female compared to male).

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The vowel inventories of the vast majority of the world's languages include three vowels that define the extremes of the general vowel space, namely /a, i, u/. Accordingly, these three vowels are known as "point vowels," and have been afforded a special status in theories of vowel systems. The formant frequencies of the vowels are plotted on a F1 and F2 plane to provide quantitative indices of 'acoustic vowel working space area' of individual speaker. The F1 and F2 pairs of each vowel were viewed as coordinates in the x - y plane. The acoustic vowel space has been used in very many research studies both in normal as well as in clinical population.

Several investigators have pointed to the importance of the notion of a base-of-articulation for providing insightful analyses of both phonological and phonetic observations. According to the Dispersion Theory (Lindblom, 1989), the vowels of a given language are organized in the acoustic vowel space in such a way that they be sufficiently distinct on the perceptual level. Honikman (1964) defined the base-of-articulation of a language as an articulatory setting that reflects the settings of the most frequently occurring segments and segmental combinations in the language. Lindau and Wood (1977), Disner (1977), Bradlow (1995), Gick, Wilson, Koch and cook (2004), Al-Tamimi and Ferrangne (2005) and Huei-Mei Liu, Feng-Ming Tsao and Kuhl (2005) have reported differences in base-of –articulation in Nigerian languages, French, German, English, Spanish and two dialects of Arabic. The results of these studies are based on measures of the first two formant frequencies.

Formant frequencies in several Indian languages have also been studied. Some of them are, acoustic parameters of Hindi vowels (Ganesan, Agarwal, Ansari and Pavate, 1985), Telugu (Majumdar, Datta and Ganguli, 1978), and Kannada (Rajapurohit, 1982; Savithri, 1989; Venkatesh, 1995; and Sreedevi, 2000). These studies were aimed to analyze some of the temporal as well as spectral properties of vowels in the respective languages. But the observation regarding the base-of-articulation was not contemplated by those researchers. While there are some studies on Asian languages, the nature and origin of cross-language differences in Indian languages are not explored. But it is possible that these languages have a distinct base-of-articulation. In this context, the present study investigated the base-of-articulation in thirteen Indian languages namely Assamese, Bengali, Hindi, Kannada, Kashmiri, Kodava, Oriya, Rajasthani, Malayalam, Marathi, Tamil, Telugu, and Punjabi that have phonemically unequal vowel inventories. It was hypothesized (Ho) that there will be no significant difference between the base-of-articulation of thirteen languages.

Method

Subjects: Ten normal native speakers each (5 males and 5 females) in the age range of 18 to 35 years speaking Kannada, Kodava, Tamil, Telugu, Malayalam, Hindi, Rajasthani, Marathi, Bengali, Kashmiri, Assamese, Oriya and Punjabi participated in the experiment.

Material: Non-sense V_1CV_2 words with these vowels in the initial position (V_1) were considered for the study. The final vowel (V_2) was always /a/. The intervocalic consonants were from five places of articulation viz.- velar, palatal, retroflex, dental, and bilabial (excluding Assamese, which does not have dental place of articulation). For example, if the target vowel is /a/, the non-sense words would be /aka/, /aca/, /at.a/, /ata/ and /apa/. Therefore, there were 40 non-sense words for Hindi, Rajasthani and Marathi, 50 non-sense words for Kannada, Tamil, Telugu, Kodava and Malayalam, 64 non-sense words for Assamese, 65 non-sense words for Bengali, 70 non-sense words for Oriya, 100 non-sense words for Punjabi and 150 non-sense words for kashmiri. These non-sense words were embedded in a phrase, "Say the word ______ now" and a total of 819 phrases, each written in their respective language on a card, formed the material.

Procedure: A post-test only design was used. Subjects were instructed to say each phrase three times in their respective languages with normal rate and intonation into the microphone kept at a distance of 10 cm from their mouth. All these utterances were recorded using MZ-R30 digital Sony recorder. Also, the recordings were made in a sound-attenuated booth/chamber in speech acoustic laboratory at AIISH. These recordings were digitized with a sampling rate of 12000 Hz. These target words/tokens were stored onto the computer. Wideband spectrograms with LPC superimpositions obtained from CSL 4500 were used to extract formant frequencies. Frequencies of the first two formants were plotted on a F_1 - F_2 plane and compared across languages. Figure 1 illustrates the waveform and spectrograph with LPC superimposition and the non-word (ika).

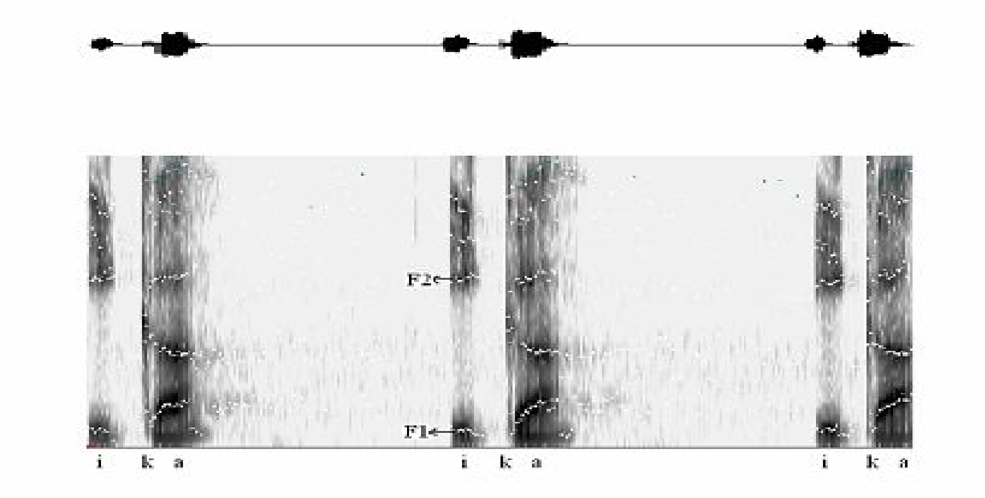

Figure 1: Waveform, Wideband spectrogram with LPC superimposition of non-word /ika/.

The corpus consisted of a total of 1200 tokens each (8 x 5 x 3 x 10) for Hindi, Rajasthani & Marathi, 1500 tokens each (10 x 5 x 3 x 10) for Kannada, Tamil, Telugu, Kodava and Malayalam, 1920 tokens (16 x 4 x 3 x 10) for Assamese, 1950 tokens (13 x 5 x 3 x 10) for Bengali, 2100 tokens (14 x 5 x 3 x 10) for Oriya, 3000 tokens (20 x 5 x 3 x 10) for Punjabi and 4500 tokens (30 x 5 x 3 x 10) for Kashmiri.

Results

The vowel inventories of the vast majority of the world's languages include mainly the three vowels, namely /a, i, u/. Accordingly, these vowels are known as the "point vowels" and have been afforded a special status in theories of vowel systems. In the present study, vowels like /e/ and /o/ as well exist along with three point vowels were studied in thirteen Indian languages. Hence the results were compared across languages on the basis of these five common vowels /a, i, u, e, o/.

Results of 3-way repeated ANOVA showed significant main effect of language, vowel and gender. Also, language x vowel interaction, gender x language, vowel x gender interaction and vowel x gender x language interaction were significant at 0.01 level. Table 1 shows the F and P values.

Parameter		F value	P value
Main effect of language	F_1	F (12,3070)=47.39	< 0.001
	F_2	F (12,3070)=23.35,	< 0.001
Main effect of vowel	F_1	F (4,3070)=4642.85	< 0.001
	F_2	F (4,3070)=15884.90	< 0.001
Language x vowel interaction	F_1	F (48,3070)=17.62	< 0.001
	F_2	F (48,3070)=18.81	< 0.001
Gender x language interaction	F_1	F (12,3070)=14.47	< 0.001
	F_2	F (12,3070)=9.28	< 0.001
Vowel x gender interaction	F_1	F (4,3070)=73.49	< 0.001
	F_2	F (4,3070)=292.38	< 0.001
Vowel x gender x language interaction	F_1	F (48,3070)=4.27	< 0.001
	F_2	48,3070)=5.32	< 0.001

Table 1: F values on 3-way repeated measures ANOVA.

The results indicated that Oriya had the lowest F_1 and Kannada had the highest F_1. Also, Kashmiri had the lowest F_2 and Bengali had the highest F_2 compared to other languages. Vowel /i/ had the least F_1 and vowel /a/ had the highest F_1. Also, vowel /u/ had the lowest F_2 and vowel /i/ had the highest F_2 compared to other vowels. Females had higher F_1 and F_2 values compared to males in all languages. Table 2 shows mean F_1 and F_2 in 13 languages.

Sl.No	***Languages***	***F_1 (in Hz)***		***Average***	***F_2 (in Hz)***		***Average***
		M	***F***	***(F_1)***	***M***	***F***	***(F_2)***
1.	Kannada	467	527	**497**	1480	1712	**1596**
2.	Tamil	445	469	**457**	1488	1663	**1576**
3.	Telugu	461	489	**475**	1487	1732	**1609**
4.	Malayalam	482	486	**484**	1453	1755	**1604**
5.	Hindi	397	482	**440**	1482	1753	**1617**
6.	Rajasthani	450	516	**483**	1580	1730	**1655**
7.	Marathi	406	432	**419**	1495	1695	**1595**
8.	Bengali	445	528	**486**	1595	1784	**1689**
9.	Kodava	431	507	**469**	1446	1700	**1573**
10.	Oriya	367	460	**413**	1442	1667	**1555**
11.	Assamese	458	502	**480**	1524	1613	**1569**
12.	Punjabi	442	540	**491**	1471	1712	**1591**
13.	Kashmiri	452	497	**475**	1434	1579	**1507**
Average:				**467**			**1595**

Table 2: Mean F_1 and F_2 of common vowels in thirteen languages between genders.

Results of Duncan's post-hoc test showed significant difference between languages on F1 and F2. Table 3 and 4 show results of post-hoc (Duncan's) test for F1 and F2. Languages in the same column are not significantly different in tables 3 and 4. Results indicated significant difference between Oriya, Marathi, Hindi and Tamil and other languages. These languages had low F1 compared to other languages. Rajasthani, Malayalam, Bengali, Punjabi and Kannada were significantly different from other languages on F1, in that these languages had high F1. Similarly, Kashmiri, Oriya, Assamese, Kodava and Tamil were significantly different from other languages in that they had low F2. Also, Telugu, Hindi, Rajasthani and Bengali were significantly different from other languages in that they had high F2.

Sub-sets						
1	2	3	4	5	6	7
Oriya						
Marathi						
	Hindi					
		Tamil				
			Kodava			
			Telugu	Telugu		
			Kashmiri	Kashmiri		
			Assamese	Assamese		
				Rajasthani	Rajasthani	
				Malayalam	Malayalam	
					Bengali	Bengali
					Punjabi	Punjabi
						Kannada

Table 3: Results of Duncan post-hoc test for F_1 (Languages in same columns are not significantly different).

Sub-sets						
1	2	3	4	5	6	7
Kashmiri						
	Oriya					
	Assamese	Assamese				
	Kodava	Kodava				
	Tamil	Tamil	Tamil			
		Punjabi	Punjabi	Punjabi		
		Marathi	Marathi	Marathi		
		Kannada	Kannada	Kannada		
			Malayalam	Malayalam		
				Telugu		
				Hindi		
					Rajasthani	
						Bengali

Table 4: Results of Duncan post-hoc test for F_2 (Languages in same columns are not significantly different).

Results of Duncan's post-hoc test for the vowels showed significant difference between vowels. Table 5 shows results of post-hoc (Duncan's) test for F_1. Vowels in the same column are not significantly different in tables 5 (vowel /o/ and /e/). Results indicated significant difference between vowels /a/, /i/, /u/, /e/ and /o/. Vowel /i/ has low F_1 whereas vowel /a/ has high F_1.

Sub-sets			
1	2	3	4
i			
	u		
		o	
		e	
			a

Table 5: Results of Duncan's Post hoc test for F1 (Vowels in same columns are not significantly different).

Table 6 shows results of post-hoc (Duncan's) test for F_2. Results indicated significant difference between these common vowels /a/, /i/, /u/, /e/ and /o/. Vowel /u/ has low F_2 whereas vowel /i/ has high F_2.

Sub-sets				
1	2	3	4	5
u				
	o			
		a		
			e	
				i

Table 6: Results of Duncan's Post hoc test for F2 (Vowels in same columns are not significantly different).

Discriminant analysis showed two functions namely function 1 and function 2. Based on combined effects of 2 functions, four clusters of languages were identified. Cluster 1 included Bengali and Rajasthani; but there was a vast distance between these two languages. Bengali had higher function 1 and function 2 compared to Rajasthani. Cluster 2 consisted of Kannada, Tamil, Telugu, Kodava, Malayalam (all Dravidian languages), Assamese and Punjabi. Languages in cluster 2 had relatively high function 1 compared to other clusters. Cluster 3 had Hindi, Marathi, and Oriya. These languages are not closely clustered, but were dispersed widely. Languages in cluster 3 had typically low function 1. Cluster 4 consisted of Kashmiri with a low function 1 and function 2. Figure 2 shows Canonical Discriminant functions and table 7 shows Eigan values of function 1 and function 2. Both the function 1 and function 2 of Eigan values were significant at 0.05 level.

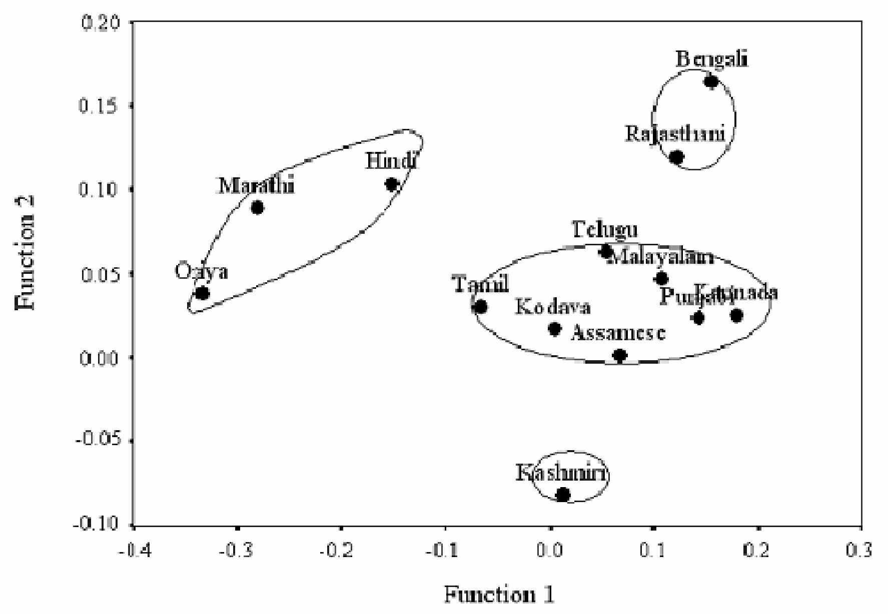

Figure 2: Graphical representation of Canonical discrimination functions of languages shows group centroid.

Functions	Eigan values
1	0.026
2	0.004

Table 7: Eigan values of function 1 and function 2

Discussion

The results indicated several points of interest. ***First***, F1 was higher in Kannada, Punjabi and Bengali than other languages. This indicates that the Kannada, Punjabi and Bengali speakers tend to use lower tongue position or have smaller vocal tracts. As the subjects are selected randomly, it cannot be generalized that those speakers have smaller vocal tracts compared to other speakers. Thus, it can be concluded that high F1 is because of low tongue position and lesser back cavity volume. Whereas, Oriya, Marathi, Hindi and Tamil had lower F1, that indicates that Oriya, Marathi, Hindi and Tamil speakers tend to use higher tongue position. Consequently, languages ordered from low to high (in terms of tongue height) are Kannada, Punjabi, Bengali, Malayalam, Rajasthani, Assamese, Kashmiri, Telugu, Kodava, Tamil, Hindi, Marathi, and Oriya. In brief, height of the tongue is high in Oriya and Marathi and it is low in Bengali, Punjabi and Kannada; others are in between.

Second, F2 was higher in Bengali than in other languages. This can be attributed to fronting of tongue position, or difference in co-articulation effect. The values of first two formants were taken from the steady state of the vowels. Hence, the effect of co-articulation will be negligible. Therefore, it could be predicted that high F2 in Bengali is because of tongue fronting. Hence, the languages can be orders from back to front (in terms of tongue advancement) are Bengali, Rajasthani, Hindi, Telugu, Malayalam, Kannada, Marathi, Punjabi, Tamil, Kodava, Assamese, Oriya, and Kashmiri. In short, position of the tongue is fronted in Bengali and it is back in Kashmiri; others are in between. From the literature (Honikman, 1964; Sweet, 1890 and laver, 1978), only F2 counts for the base-of-articulation differences. Hence, the base-of-articulation is fronted in Bengali and back in Kashmiri; rest of the languages is in-between. The significant differences between these languages can be attributed to the organic basis, Sweet (1890) and Laver (1978) who observed differences in general pronunciation tendencies of languages in seventh century AD. Sweet (1890) defined organic basis of a language, "Every language has certain tendencies which control its organic movements and positions, constituting its organic basis or base of articulation".

Third, vowel /i/ has low F1 whereas vowel /a/ has high F1. According to Fant (1960) the F1 is inversely related to tongue height. In the production of vowel /i/ the height of the tongue is high, which results in lower F1 whereas, for the production of vowel /a/ the tongue height is low, which results in higher F1. The obtained results are in agreement with the findings of (Fant, 1960). The second formant frequency (F2) is inversely related to tongue advancement. In the production of vowel /u/, formants tend to be lower due to lip rounding effect. In the production of vowel /i/ tongue is more fronted which results in high F2 (Fant, 1960). The results obtained supports the findings of Fant (1960).

Fourth, females had higher F1 and F2 values compared to males in all languages (table 2 and appendices I, II). These present findings are in consonant with the findings of Peterson and Barney (1952), Eguchi and Hirsh (1969), Fant (1973), Venkatesh (1995) and Sreedevi (2000) who reported higher formants in females than in males. In adult females, vocal tract tend to be smaller than adult males, which results in higher resonance and accordingly female formants tend to be higher in frequency. This can be attributed to differences in vocal tract morphology for example, Fitch and Giedd (1999) who found that adult males have a disproportionately longer pharynx in comparison with adult females.

Very limited cross-linguistic studies in Indian languages have been reported in literature. Bradlow (1995) reported average F1 and F2 for the vowels /a/, /i/, /u/, /e/ and /o/, in Spanish which is 432 Hz and 1465 Hz, respectively; and in English, it is 457 Hz and 1647 Hz, respectively. From table 2, the average F1 for the vowels /a/, /i/, /u/, /e/ and /o/, is 467 Hz and average F2 for vowels /a/, /i/, /u/, /e/ and /o/, is found to be 1595 Hz. In Indian languages F1 is found to be higher than Spanish and English whereas F2 falls in-between Spanish and English. Therefore, it can be inferred that the base-of-articulation is in-between Spanish and English. The results of the present study support the notion of base of articulation proposed by Honikman (1964), Sweet (1890) and laver (1978). Based on the results the null hypothesis that there is no significant difference between base-of-articulation of Indian languages was rejected.

Conclusion

The present study investigated the nature of cross language differences in base-of-articulation in thirteen Indian languages namely Assamese, Bengali, Hindi, Kannada, Kashmiri, Kodava, Oriya, Rajasthani, Malayalam, Marathi, Tamil, Telugu, and Punjabi that have phonemically unequal vowel inventories. Equal number of males and females participated in the study. Non-sense V1CV2 words were recorded from ten normal-native speakers in each of the thirteen languages. The first and second formant frequency was measured using the software CSL 4500. The five common vowels exists in all languages were compared for base-of-articulation difference. The results indicated significant difference between languages, vowels and gender. In brief, height of the tongue (F1) is high in Oriya and Marathi and it is low in Bengali, Punjabi and Kannada; others are in between. Prominently, base-of-articulation (position of the tongue, F2) is fronted in Bengali and it is back in Kashmiri; other Indian languages are in between. The results of the study have augmented the knowledge about the cross-language differences in base-of-articulation in Indian language. Also, the results help in rehabilitation process. For example, if the base-of-articulation is towards the extremes of oral cavity, then articulatory references could be set towards the extremes of the oral cavity and also applicable in learning second language (L2). Also, the findings obtained from the present study provide normative data for clinical purposes

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