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Base of Articulation of Indian Languages

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Introduction

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 help even in the perception of consonants and thus speech. Also, as the vowels are voiced and of longer duration, the speech prosody (intonation, stress and rhythm) is determined by the vowels. 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.

The term formant, a German word, was used first by physicist Hermann in the second half of the nineteenth century. A formant is a range of frequencies, but since a formant must give rise to a peak in the spectrum of sound produced, the term formant is commonly applied to the frequency at which the peak occurs. Fant (1960) defined formants as 'the spectral peaks of the sound spectrum'. In the literature, the term formant has been used principally to indicate a concentration of spectral energy in a narrow frequency region of a speech signal. Further more, it generally has been applied to only those portions of the speech signal called voiced, i.e., characterized by glottal excitation. For any vocalic sound, a number of formants may occur in the frequency range 0 to 8000 cps, but attention is usually focused on the lowest two or three. 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 tongue height and tongue position. Frequency of the first formant (Fl) 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, Fl 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 Fl 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).

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 Fl and F2 plane to provide quantitative indices of'acoustic vowel working space area' of individual speaker. The Fl 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.

The usage of oral tract (front and back cavity) in different western languages was reported in early 17th century. In the seventeenth century Wallis observed that: "It is worth noting, however, that differences in pronunciation occur in various languages, which are not attributable so much to the individual letters, as to the whole style of speech of the community. For instance, the English as it were push forward the whole of their pronunciation into the front part of the mouth, speaking with the wide mouth cavity, so that their sounds are more distinct. The Germans, on the other hand, retract their pronunciation to the back of the mouth and the bottom of the throat, so that they have a stronger and more forceful pronunciation. The French articulate all their sounds nearer the palate, and the mouth cavity is not so wide; so their pronunciation is less distinct, muffled as it were by an accompanying murmur. The Italians and the Spaniards even more, speak with a low tempo, the French speak faster and the English are in-between. The French and the Scots equally, raise or sharpen the pitch of the last syllables of sentences and clauses, while the English lower or deepen it; this is a characteristic not of individual words but of the sentence taken as a continuous whole. I leave it to others to observe differences of this kind among other people, as the opportunity presents itself [Wallis (1653), Translation by Kemp (1972)].

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. In the past, Dispersion Theory and Quantal Theory of Speech (Stevens, 1972, 1989) have been proposed to account for the cross-linguistic variations in vowel inventory size and structure. But, recently the notion of a language specific base-of-articulation is used to account for the observation that similar sounds across two languages can differ due to a consistent, language-specific adjustment of the articulators.

Languages differ in the size and organization of their vowel inventories; they differ from 3 to 24 distinct vowels (Maddieson, 1984; and Vallee, 1994). Cross-linguistic investigations revealed that the general organization of vowel inventories is governed by auditory and articulatory constraints. Theoretical studies tried to predict the effect of vowel inventory size on the general organization of vowel systems. Given the non-linear relationship between articulatory movements and their acoustic correlates the Quantal theory of speech (Stevens, 1989) states that there are certain regions of stability in the phonetic space, corresponding to the point vowels /a/, /i/, and /u/. These point vowels (or Hot-Spot) should be in approximately the same location across all languages, independently of vowel inventory size and since these point vowels are in phonetically stable regions, there should be less intra-category variability than for other vowels.

On the contrary, the Dispersion theory (Lindblom, 1989) claims that "Adaptive Dispersion" of their elements, following a "Sufficient Perceptual Contrast" principle, rules out speech sound organization. According to this theory, 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. Lindblom (1989) explained that phonetic values of vowel phonemes should exhibit more variation in small than in large systems. With different visions about the general organization of vowel inventories, these two theories proposed some common universal principles to account for the cross-linguistic tendencies observed in vowel inventories.

That languages differ in their general pronunciation tendencies have been noted by scholars since at least the 7th century AD (Laver, 1978). Sweet (1890) called such a tendency the 'organic basis' of a language and he stated: "Every language has certain tendencies which control its organic movements and positions, constituting its organic basis or base-of-articulation". 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) investigated vowels of three related Nigerian languages, Yoruba, Edo and Ghotuo, all of which have phonemically equivalent 7-vowel systems, and found that the vowel space of Edo and Ghotuo are very similar. But the vowel space of Yoruba deviates from the structure of the other two seven-vowel systems. Disner (1983) found that the 7-vowel systems of Yoruba and Italian differ from each in their locations of the seven vowels in the acoustic space. She also documented differences in the vowels of several Germanic languages; for e.g. vowels of Danish are systematically articulated with a higher tongue position, as it is reflected by Fl, than the vowels of English. Disner claims that these data demonstrate the role of a language specific base-of-articulation property in the phonetic realization of vowel phonemes.

Honikman claims about the differences in Germanic bases of articulation. She found that F2 of German rounded vowels are significantly lower than that of English rounded vowels. Also, the data claim that German employs greater pharyngeal contraction than do English and French. Bradlow (1995) studied cross-linguistic comparison of acoustic vowel categories of two languages that differ in vowel inventory size, namely English and Spanish. He took four male subjects in each language and used meaningful words, which were all monosyllabic in English and disyllabic in Spanish. He found that the English and Spanish vowel spaces differ systematically in the location defined by F1 and F2. Also common vowels (/a/, /i/, *lul, /e/* and /o/) between English and Spanish showed that the English vowels were all significantly higher in the F2 dimension than their Spanish counterparts, and suggested that the English vowels are all articulated with a fronted tongue position relative to the Spanish vowels. In the above study, the participants were very less (four in each language) and the words accounted were meaningful i.e. the structure of the words were not same across those two languages. The gender influence/difference was not taken into consideration in this study.

Knowledge of the organic basis is a great help in acquiring the pronunciation of a language. Honikman (1964) revived the study of organic basis in the English literature, and she gave it a new name: "Articulatory Setting" (AS). She defined 'AS' as the 'gross oral posture and mechanics' required for the 'economic and fluent' production of the 'established pronunciation of a language' (Honikman, 1964, p.73). Indeed, if such a postural basis underlies every language, this must not only contribute in large part to the overall 'sound' of a language or dialect, but must also interact with its phonetic and phonological patterns where, both influencing and being influenced by them - in as yet ,-unknown ways.

Despite its prominence in the literature, AS has proven very elusive to direct measurement. In the past, this was because necessary measurement techniques did not exist. Heffner (1950, p.99) says: 'No method of measurement has been devised that would permit the mathematical description of a basis of articulation. O'connor (1973, p.289) calls for the future studies of 'bases of articulation' and says: 'we know a good deal more about the detailed articulatory movements in a language than we know about the general articulatory background on which they are superimposed'. More recently, Collins and Mees (1995, p.422) point out that 'at the moment, much of the description of AS features- including our own - is largely impressionistic'. A confounding reason behind the lack of qualitative evidence for articulatory settings is the fact that 'no articulatory setting normally applies to every single segment a speaker utters' [Laver, 1978, p.11]. In other words, segmental context has an overriding effect on the position of the articulators at any given time, making it difficult, if possible, to analyze speech with the aim of ascertaining the underlying AS of a given language.

According to Disner (1983) German has a uniformly higher neutral tongue position than English does. Also, German front vowels have low Fl compared to English front vowels, which indicated that height of the tongue is high in German than English. In a report by Disner (1978) of Monolingual data, the vowels of German are higher than the vowels of Dutch, though the differences is not uniform: high vowels display smaller cross-linguistic differences than the mid vowels, and the low vowel /a/ is nearly identical in these two languages. She pointed out that this non-uniformity might be attributed to the geometry of the vocal tract. But the same is not true for Bilingual data, as she claimed that due to the limited number of German-Dutch bilingual speaker one should interpret the findings with some caution.

Disner (1983) stated that the vowels of Eastern central Bavarian are all more advanced in the phonetic space than the corresponding vowels of German. She added that this tendency might reflect a base of articulation difference. She also stated that there was a weak tendency in the monolingual data for the vowels of Swedish to be higher and more retracted than the vowels of Norwegian. But in bilingual data, the trends are rather different. The majority of vowels tend to be higher and more retracted in Norwegian than the Swedish vowels. She compared the vowels of English and Danish and found that the vowels of Danish are all higher than those of English, and are more likely more peripheral as well. It is said (colloquially) that Danish is spoken 'higher in the mouth' than English. Disner also compared German-Swedish vowels and found that the German vowels in the monolingual sample tend to be higher than the corresponding vowels of Swedish. But, the bilingual data (from two speakers) showed much less of a height difference between these two languages. She added that the cross-linguistic differences among the high vowels are especially small, perhaps due to a boundary effect and the distance between the front rounded and front unrounded vowels is greater in German than in Swedish, in both samples.

Disner (1983) compared common vowels of English and Swedish languages, and found that the Swedish are more peripheral than those of English. She added that the bilingual data indicate that the greatest differences in Fl are found in the front vowels and the greatest differences in F2 are found in the back vowels. She also reported about the Norwegian-German vowels such as the German vowels tend to be more retracted in the F2 and F3 space than the Norwegian vowels. Wherein, these differences are small but consistent across the monolingual and bilingual speakers. She also described about the vowels of English and Norwegian languages. She explained that the Norwegian front vowels are lower than the corresponding vowels of English in the monolingual sample and higher than the corresponding vowels of English in the bilingual sample. She suggests a uniformly higher and more horizontally expanded vowel system in Norwegian.

Gick, Wilson, Koch and Cook (2004) studied the articulatory settings (ASs) by using X-ray technique. They measured the inter-speech posture (ISP) from five English (2 males and 3 females) and five French speakers and they hypothesized that speech rest positions are language-dependent. All the speakers read about 25 - 30 sentences. X-ray images were recorded at a constant distance away from the subjects and measurements that were taken include pharynx width, velopharyngeal port width, tongue body distance from hard palate, tongue tip distance from alveolar ridge, lower-to-upper jaw distance, and upper and lower lip protrusion. They found a significant difference between French and English speakers for five of the seven measurements (except velopharyngeal port width and jaw aperture). They found that both the tongue body and tongue tip are significantly lower in French than in English. They concluded from the study that there are language-specific differences in default vocal tract settings. In the above study, the researchers consider very less number of subjects and unequal number of male to female ratio. Also, the subject's inhalation between utterances had a greater physiological effect on velum position than on other articulators, masking any language-specific differences that may otherwise have appeared.

Liu, Tsao and Kuhl (2005) studied the relation between vowel working space and speech intelligibility in Mandarin young adults with cerebral palsy. They found that there was smaller vowel working space and more centralized articulation reflect more restricted vertical and horizontal tongue movements in subjects with cerebral palsy compared to normal speakers during vowel production. They also found that there was a positive correlation between vowel working space and speech intelligibility. That is, subjects with larger vowel working space were judged to be more intelligible than subjects with reduced vowel working space.

Japanese have five pairs of vowels that are temporarily distinctive (1-mora Vs 2-mora), but spectrally similar, whereas American English has at least 11 spectrally distinguishable vowels. Hisagi, Nishi, and Strange (2003) investigated the influence of consonantal context on the variability of Japanese and American

English vowels that may influence their perception. The project explored acoustic differences in vowels produced in /hVba/ disyllables and in multisyllabic nonsense words /C1VC2CV)/ in carrier sentences. They analyzed multiple tokens of the 10 Japanese vowels produced by Kansai Japanese speakers and compared spectral and temporal characteristics with 11 American English vowels produced by four native American English speakers (2 males and 2 females in both groups). Variables under examination were (1) immediate phonetic context (Cl = b, d; C2 = p, t), (2) sentence prominence (narrow focus vs. post focus), and (3) speaking rate (normal vs. rapid). Results showed that both languages showed acoustic "fronting" of back vowels in /dVt/ context (higher second formants (F2)). American English high and mid back vowels shifted their targets due to allophonic variation, which resulted in a dramatic change in the overall shape in vowel space. On the other hand, as for Japanese back vowels, /a/ was raised and /o, w/ were fronted so that the overall shape in vowel space did not change. The spectral differences between narrow and post-focus vowels were minimal for both languages. Differences between narrow focus and post-focus speaking conditions were observed for both American English and Japanese. Focus in Japanese was achieved mainly by increased pitch, while American English used a combination of increased pitch-and vocalic duration. American English vowels were shortened by approximately 30% when spoken at a faster rate. In the same condition, Japanese long vowels became shorter by roughly 20%, but no difference was found for short vowels.

In a study, Bradlow (1995) compared the acoustic vowel spaces of English (11 monophthongs) and Spanish (5 vowels) in CVC and CVCV sequences. She found that the location of similar vowels in the acoustic vowel spaces was determined, in part, by a language-specific base-of-articulation; the English crowded vowel system occupied a greater space than that of Spanish (she notes

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that his effect depends on the syllabic structure of English vowels), and there was no difference in the tightness of within-category clusters for large versus small vowel inventories

Al-Tamimi and Ferragne (2005) investigated the effect of vowel inventory size on the general organization of acoustic vowel spaces, in two Arabic (2 dialects: Moroccan and Jordanian) and French. French has 11 vowel inventories, Jordanian Arabic dialect (JA) have 8 vowel inventories and 5 for Moroccan Arabic dialect (MA). They took five subjects per language (or dialect) and recorded a list of vowels in three conditions: words, syllables and isolation. They found that the FR vowel space is larger than that of JA or MA. And the point vowels have approximately the same position in the acoustic vowel spaces across the three languages in only two conditions (in syllable and isolation). They concluded from the results of the study that, the larger the vowel inventory, the bigger the acoustic vowel space.

Formant frequencies in several Indian languages have also been studied, Some of them are, acoustic parameters of Hindi vowels (Ganesan, Agarwal, Ansari and Pavat'e, 1985), Maithili (only nasal vowels by Jha, 1986), 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 these researchers.

The notion of base-of-articulation is intuitively very appealing. It would be accounting in a very natural way for much of the variation between languages, as a global adaptation of the articulators to the phonological processes of a particular language. Indeed, this basic concept is a familiar one; those persons with a gift for mimicry can recreate the base-of-articulation of various languages with great success, and most individuals can convey some semblance of a 'French accent' or 'Italian accent' with some adjustments of the articulators. However, the question of what adjustments (if any) characterize the base-of-articulation in different languages has not received adequate attention.

If base-of-articulation property (organic basis) exists, it becomes relevant to ask whether they are specified to any gender differences or functionally derived properties of vowel inventories. There were very many studies accounted for the gender-related differences in vocal tract morphology. For example, Fitch and Giedd (1999). and Fant (1973) found that adult males have a disproportionately longer pharynx in comparison with adult females. According to Chiba and Kajiyama (1941), the total length of an average female vocal tract is about 15% shorter than an average male vocal tract. Thus, it becomes an important issue in their general pronunciation tendencies in different languages.

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, Malayalam, Marathi, Oriya, Punjabi, Rajasthani, Tamil and Telugu 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 Assamese, Bengali, Hindi, Kannada, Kashmiri, Kodava, Malayalam, Marathi, Oriya, Punjabi, Rajasthani, Tamil and Telugu participated in the experiment.

Material: Vowels of these 13 languages are as shown in Table 1.

Sl. no.	Vowel description	Kannada Tamil Telugu Malayalam Kodava	Bengali Assamese Oriya Kashmiri	Punjabi	Hindi Rajasthani Marathi
1	Low mid short	a	a	a	a
2	Low mid long	a:	-	-	a:
3	Front high short	i	i	i	i
4	Front high long	i:	-	-	i:
5	Back high rounded short	u	u	u	u
6	Back high rounded long	u:	-	-	u:
7	Front mid high short	e	e	e	e
8	Front mid high long	e:	-	-	-
9	Back mid high rounded short	o	o	o	o
10	Back mid high rounded long	o:	-	-	-
11	High front nasalized	-	i˜	i˜	-
12	High back nasalized	-	u˜	u˜	-
13	High-Mid nasalized	-	e˜	e˜	-
14	Low mid short nasalized	-	a˜	-	-
15	Low mid back	-	ɛ, ɔ	ɛ, ɔ	-
16	Low-mid back nasalized	-	ɛ~, ɔ˜	ɛ~, ɔ~	-
17	Lower-high short	-	-	U,I	-
18	Lower-high nasalized	-	-	U˜,I˜	-

Table 1: List of vowels in 13 Indian languages.

Selecting natural words might be very advantageous, but has some problems. First, the project requires words that have vowel + consonant + vowel combination (VCV). The constancy of the consonant and second vowel is very doubtful in naturally occurring words. For example, a combination of/o/, /k/ and /a/ may not be prevailing in all the languages.

Second, if such a combination is available, it is difficult to keep the number of syllables constant. The consonants and the vowels following such a combination will contribute to co-articulatory effects.

Third, the number of syllables in a word determines the duration of a vowel. The longer the word shorter is the duration of the vowel. Shorter the vowel, lesser is the articulatory precision with which it is uttered. Formant frequencies are different in precise and normalized articulation.

Fourth, most of the Dravidian and Indo-European languages are syllable based and follow Devanagari script. While learning the orthography, the language user will have to learn to articulate these vowels or consonant vowel combinations. Therefore, though the token is a non-word the production of it will not be different from that in a word. Hence non-words were selected in the project.

Non-sense V1CV2 words with these vowels in the initial position (V|) were considered for the study. The final vowel (V2) 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/, *fatal* and /apa/. Therefore, there were 50 non-sense words each for Kannada, Tamil, Telugu, Kodava and Malayalam, 65 non-sense words for Bengali, 64 non-sense words for Assamese, 70 non-sense words for Oriya, 150 non-sense words for Kashmiri, 100 non-sense words for Punjabi and 40 non-sense words each for Hindi, Rajasthani and Marathi. 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 or in a quite place. 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 Fi - F_2 plane and compared across languages. Figure 1 illustrates the waveform and spectrograph with LPC superimposition in the non-word [ika].

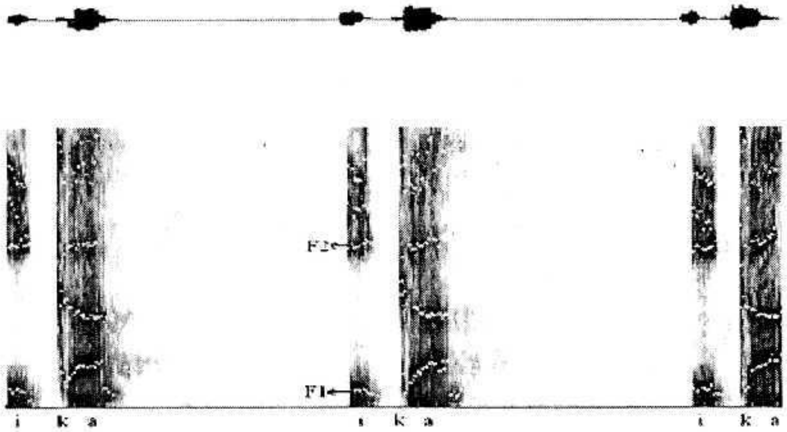

Figure 1: Waveform, wideband spectrogram with LPC superimposition of non-word /ika/.

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

Statistical Analysis: The mean of F1 and F2 in each language was calculated. Univariate analysis of variance was done for F1 and F2 comparison between subjects. 3-way ANOVA was carried out to find out interaction effect of three factors (gender x vowel x language). Duncan post-hoc test was used to see vowel difference. Point vowels (a, i and u) of all the 13 languages was compared for mean Fi and F_2 for base of articulation effect across languages. Discriminant analysis was performed to identify acoustically similar languages

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 *Id* and *lol* 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 {F1 = [F (12,3070)=47.39, p<O.OOl], F_2 = [F (12,3070)=23.35, p<O.OOl]}, vowel {F1 = [F (4,3070)=4642.85, p<O.OOl], F_2 = [F (4,3070)=15884.90, pO.OOl]}, and gender {F, = [F (l,3070)=654, pO.OOl], F_2 = [F (l,3070)=1625.38, p<O.OOl]}. Also, language x vowel interaction {F1 = [F (48,3070)=17.62, p<O.OOl], F_2 = [F (48,3070)=18.81, p<O.OOl]}, gender x language interaction {F1 = [F (12,3070)=14.47, p<O.OOl], F_2 = [F (12,3070)=9.28, p<O.OOl]}, vowel x gender interaction {F1 = [F (4,3070)=73.49, p<O.OOl], F_2 = [F (4,3070)=292.38, p<O.OOl]} and vowel x gender x language interaction {F, = [F (48,3070)=4.27, p<O.OOl], F_2= [F (48,3070)=5.32, p<O.OOl]} were significant.

The result indicated that Oriya had the lowest F1 and Kannada had the highest F1. Also, Kashmiri had the lowest F_2 and Bengali had the highest F_2 compared to other languages. Vowel /i/ had the lowest F1 and vowel /a/ had the highest F). Also, vowel /u/ had the lowest F_2 and vowel /i/ had the highest F_2 compared to other vowels. Females had higher F1 and F_2 values compared to males in all languages. Table 2 shows mean F1 and F_2 of common vowels /a/, /i/, /u/, *lol,* and /e/ in 13 languages. Appendix I shows the mean F1 and F_2 of five common vowels in both genders and in all languages. Appendix II shows 95 % confidence intervals of mean of F1 and F2.

Sl. No.	Languages	F_1 (in Hz)		Average (F_1)	F_2 (in Hz)		Average (F_2)
		M	F		M	F	
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 F1 and F_2 of common vowels in thirteen languages.

Results of Duncan's post-hoc test showed significant difference between languages on F1 and F2. Tables 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 Fi, 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 F1 (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 F2 (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 F1. Vowels in the same column are not significantly different in tables 5 (vowel /o/ and *Id).* Table 6 shows results of post-hoc (Duncan's) test for F2. Results indicated significant difference between vowels. Vowel /u/ has low F2 whereas vowel /i/ has high F2.

Sub-sets			
1	2	-i	4
i			
	u		
		0	
		e	
			a

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

Sub-sets				
1	2	3	4	5
u				
	0			
		a		
			e	
				i

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

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Discriminant analysis showed two functions. Based on combined effects of 2 functions four language clusters 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 cluster 3 and 4. Cluster 3 had Hindi, Marathi, and Oriya. These languages were 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. Eigan values of both the functions were significant at 0.05 level.

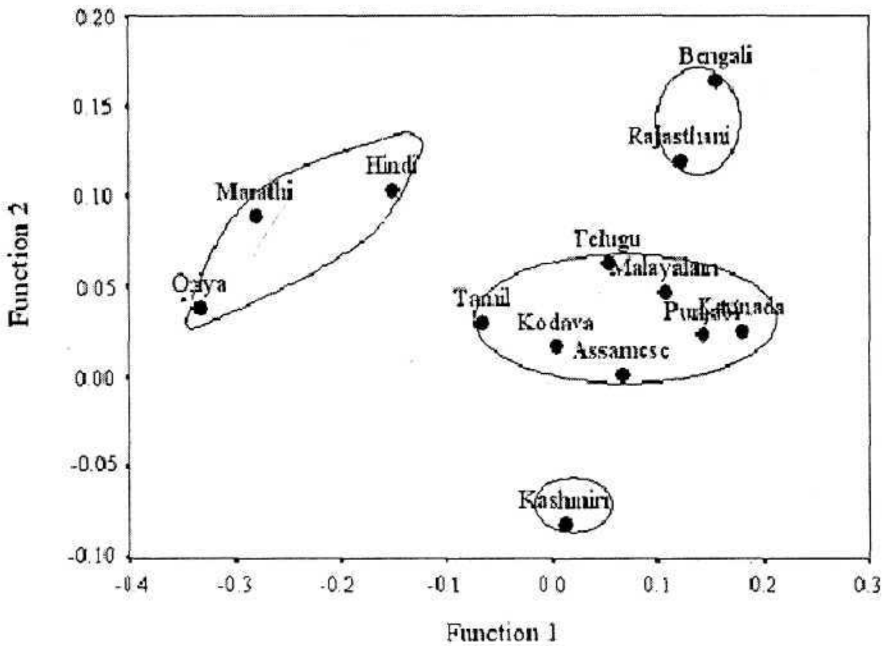

Figure 2: Graphical representation of Canonical discrimination functions of languages (group centroid is shown).

Functions	Eigan values
	0.026
2	0.004

Table 7: Eigan values of function 1 and function 2.

Discussion

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. The present study highlights some of the interesting findings regarding base-of-articulation in Indian languages, which are as follows:

First, F1 was higher in Kannada, Punjabi and Bengali compared to 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 speakers of these languages have smaller vocal tracts compared to others. Thus, the high F1 can be attributed to low tongue position and smaller back cavity volume. Whereas, Oriya, Marathi, Hindi and Tamil had lower F1, indicating that speakers of these languages 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 compared to other languages. This can be attributed to fronting of tongue position, or difference in co-articulatory 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 ordered from back to front (in terms of tongue advancement) as 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.

Third, vowel /i/ has low F1 whereas vowel /a/ has high F1. According to Fant (1960) 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, in the production of vowel /a/, tongue height is low, which results in higher F1. 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 are in agreement with the findings of other acoustic studies reported in the literature (Fant, 1960 among others).).

Fourth, females had higher F1 and F2 values compared to males in all languages (Appendices I, II). These findings are in consonance with the findings of Eguchi and Hirsh (1969), Fant (1973), Venkatesh (1995) and Sreedevi (2000) who reported higher formant frequencies 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.

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/, Id* and *lol,* 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 *lol,* is 467 Hz and average F2 for vowels /a/, /i/, */u/, /e/* and *lol,* is found to be 1595 Hz. In Indian languages F1 is found to be higher than in Spanish and English whereas F2 falls in-between Spanish and English. Therefore, it can be inferred that the base-of-articulation of Indian languages 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.

Conclusions

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, Malayalam, Marathi, Oriya, Punjabi, Rajasthani, Tamil and Telugu 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 spectrographoic display on CSL 4500. The five common vowels existing 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 (Fl) is high in Oriya and Marathi and it is low in Bengali, Punjabi and Kannada; others are in between. Prominently, the *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. The results are 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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Appendix I -Mean formant frequencies in 13 languages.

		F1 (in Hz)					F2 (in Hz)				
		/a/	/i/	/u/	/e/	/o/	/a/	/i/	/u/	/e/	/o/
Ass	M	731	21A	317	481	488	1284	2478	787	2165	906
	F	882	317	330	563	416	1407	2717	812	2263	869
	A	807	296	323	522	452	1346	2597	799	2214	888
Beni	M	806	306	313	391	409	1297	2376	1160	2268	871
	F	1003	288	364	508	476	1536	2973	861	2617	932
	A	905	297	338	450	443	1416	2675	1010	2442	902
Hin	M	642	289	299	380	377	1364	2241	827	2095	883
	F	775	337	384	461	451	1604	2716	896	2606	944
	A	709	314	341	421	414	1484	2479	861	2350	913
Kan	M	693	331	349	459	506	1369	2141	929	1907	841
	F	830	384	409	504	508	1482	2661	946	2409	1062
	A	761	357	379	481	507	1426	2401	937	2158	1059
Kas	M	676	335	350	484	416	1245	2135	923	1925	942
	F	777	370	399	498	444	1305	2441	891	2310	948
	A	726	352	374	491	430	1275	2288	907	2117	945
Kod	M	638	306	326	438	446	1271	2175	898	1939	947
	F	879	361	389	435	470	1545	2598	943	2415	1002
	A	758	334	358	436	458	1408	2387	921	2177	975
Mai	M	766	405	318	464	459	1358	2021	877	1994	1012
	F	827	332	347	488	438	1595	2709	979	2430	1063
	A	796	368	332	476	448	1477	2365	928	2212	1038
Mar	M	611	296	332	389	401	1282	2341	807	2198	846
	F	638	303	346	436	438	1326	2804	787	2602	956
	A	625	299	339	413	419	1304	2572	797	2400	901
Ori	M	540	259	282	394	358	994	2369	796	2210	841
	F	698	335	381	444	439	1348	2697	877	2498	917
	A	761	357	379	481	507	1426	2401	937	2158	1059
Pun	M	730	305	319	381	477	1207	2307	2142	907	1471
	F	880	355	378	526	561	1421	2824	855	2459	1002
	A	805	330	348	454	519	1314	2566	822	2300	955
Raj	M	636	338	354	448	474	1516	2229	1151	2090	913
	F	772	354	380	544	529	1571	2677	912	2460	1032
	A	704	346	367	496	502	1544	2453	1031	2275	972
Tam	M	684	317	332	454	436	1371	2219	876	1996	976
	F	766	344	355	439	441	1538	2495	908	2376	999
	A	725	331	343	447	438	1455	2357	892	2186	987
Tel	M	712	321	335	471	464	1323	2234	928	1931	1017
	F	812	343	363	464	462	1461	2732	990	2395	1084
	A	762	332	349	468	463	1392	2483	959	2163	1050

Ass - Assamese, Ben - Bengali, Hin -Hindi, Kan - Kannada, Kas - Kashmiri, Kod - Kodava, Mai - Malayalam, Mar - Marathi, Ori - Oriya, Pun - Punjabi, Raj - Rajasthani, Tam - Tamil, Tel - Telugu. M - Male, F - Female.

Appendix II - Mean formant frequencies with 95 % CI of mean LB — Lower boundary, UB - Upper boundary

Assamese

Sl. no	Vowel	Mean (F1)	Mean (F2)	Fi		F_2	
				LB	UB	LB	UB
1	a	807	1346	767	846	1315	1377
2	i	296	2597	282	310	2531	2664
3	u	323	799	307	340	770	828
4	e	522	2214	490	554	2182	2246
5	0	452	888	425	479	848	927
6	}	571	983	546	595	960	1007
7	D~	566	987	532	599	960	1014
8	a~	792	1321	761	822	1291	1351
9	i~	299	2609	289	310	2545	2673
10	u~	321	805	305	337	770	840
11	e~	524	2270	490	558	2212	2327
12	0~	433	907	405	461	883	931
13	£	553	2225	513	593	2176	2273
14	t~	551	2227	512	590	2183	2271
15	U)	382	838	361	402	812	1377
16	OJ~	386	853	365	406	826	2664

Bengali

SI. no	Vowel	Mean(F1)	Mean (F2)	F1		F2	
				LB	UB	LB	UB
1	a	905	1417	871	939	1454	1379
2	i	298	2675	288	307	2768	2582
3	i:	289	2685	280	298	2779	2590
4	u	339	855	310	368	882	827
5	u:	312	839	302	322	867	812
6	e	450	2443	418	482	2518	2368
7	0	443	902	424	461	935	869
8	D	651	1076	626	676	1106	1047
9	D~	634	1086	597	672	1112	1061
10	a~	1013	1433	983	1042	1463	1402
11	i~	315	2765	305	325	2860	2671
12	li-	360	1089	327	392	1227	951
13	e-	468	2492	435	501	2554	2430

Hindi

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	709	1485	684	735	1432	1538
2	a:	798	1360	765	832	1321	1399
3	i	313	2479	302	326	2402	2555
4	• i:	281	2625	276	288	2535	2715
5	u	341	861	326	357	833	889
6	u:	300	753	293	308	731	773
7	e	421	2350	404	438	1432	2428
8	0	414	914	398	430	1321	936

Kannada

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	761	1426	736	788	1383	1469
2	a:	818	1289	789	846	1256	1322
3	i	358	2401	346	369	2313	2489
4	i:	332	2523	321	342	2430	2616
5	u	379	937	367	392	908	966
6	u:	360	801	348	371	783	820
7	e	482	2158	465	497	2075	2241
8	e:	450	2337	441	459	2255	2419
9	o	507	1059	494	520	1030	1090
10	o:	464	916	455	473	900	932

Kashmiri

Sl. no	Vowel	Mean (F2)	Mean (F3)	F1		F_2	
				LB	UB	LB	UB
1	a	727	1276	698	756	1246	1304
2	a:	764	1263	738	790	1240	1285
3	i	353	2289	344	362	2237	2339
4	i:	341	2312	331	351	2256	2366
5	u	375	907	365	385	886	929
6	u:	384	904	371	397	885	922
7	e	491	2118	473	509	2057	2178
8	e:	464	2126	446	483	2064	2187
9	0	430	945	416	444	926	964
10	o:	428	903	413	443	870	936
11	ɔ	490	954	469	511	935	972
12	D~	456	972	431	481	956	987
13	a˜	705	1234	673	737	1203	1264
14	ĩ	351	2277	336	367	2234	2320
15	u˜	358	919	344	371	897	940
16	e˜	438	2163	416	460	2102	2222
17	0˜	456	940	436	477	922	958
18	9	744	1298	712	775	1257	1337
19	*a*~	647	1237	614	679	1210	1263
20	a:˜	685	1230	662	708	1213	1247
21	• i:˜	353	2231	339	366	2140	2321
22	u:˜	363	905	350	376	886	924
23	t	376	2243	363	388	2188	2296
24	t:	354	2239	341	367	2189	2288
25	t:~	377	2258	363	390	2210	2305
26	8:	746	1289	716	776	1256	1319
27	a:˜	673	1242	642	703	1215	1269
28	D:	487	966	471	504	953	979
29	e:˜	462	2145	438	486	2091	2199
30	o:˜	451	958	435	468	941	974

Kodava

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	759	1408	720	798	1356	1460
2	a:	821	1278	783	859	1244	1312
3	i	335	2387	323	346	2319	2455
4	i:	287	2503	277	298	2429	2579
5	u	358	921	345	370	897	945
6	u:	332	798	320	343	766	829
7	e	437	2177	420	453	2101	2253
8	e:	410	2326	390	428	2245	2402
9	o	458	975	442	475	943	1007
10	o:	428	870	415	441	849	892

Malayalam

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	797	1477	773	820	1431	1523
2	a:	816	1370	784	847	1336	1405
3	i	369	2366	327	410	2238	2493
4	i:	298	2527	289	306	2447	2606
5	u	333	929	321	344	900	957
6	u:	316	875	305	327	845	905
7	e	476	2213	451	502	2132	2293
8	e:	426	2354	412	440	2269	2439
9	o	449	1038	429	469	1016	1059
10	o:	428	971	411	444	946	995

Marathi

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	625	1304	610	641	1282	1327
2	a:	865	1365	837	894	1329	1400
3	i	300	2573	284	315	2500	2645
4	i:	295	2597	280	310	2517	2676
5	u	340	797	321	358	776	818
6	u:	330	770	312	348	745	794
7	e	413	2400	401	425	2335	2465
8	o	419	901	409	431	874	928

Oriya

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	619	1171	585	653	1111	1230
2	a;	809	1395	777	840	1353	1437
3	i	297	2533	284	310	2467	2599
4	i:	284	2500	272	296	2391	2610
5	u	332	836	313	350	807	866
6	u:	314	842	301	327	819	865
7	e	419	2354	408	430	2297	2411
8	o	398	879	383	414	855	903
9	ã	651	1149	615	687	1090	1208
10	ĩ	313	2594	297	330	2535	2652
11	u~	332	845	315	350	818	873
12	a:~	795	1380	752	838	1333	1426
13	ĩ:	304	2553	290	317	2462	2643
14	u:~	325	842	308	342	810	874

Punjabi

SI. no	Vowel	Mean(F1)	Mean (F2)	F1		F2	
				LB	UB	LB	UB
1	a	805	1314	774	835	1274	1354
2	i	330	2566	318	341	2476	2655
3	u	348	822	334	363	790	855
4	e	454	2300	426	481	2229	2371
5	0	519	955	487	551	919	990
6	D	586	1026	554	619	968	1085
7	D˜	585	992	552	618	960	1024
8	a"	764	1284	727	801	1250	1318
9	i˜	365	2632	349	381	2560	2704
10	if	345	842	331	360	815	870
11	e˜	477	2307	446	508	2252	2362
12	o"	517	955	481	552	926	984
13	I	373	2422	357	389	2338	2506
14	U	392	892	373	412	857	928
15	£	647	2089	621	674	2008	2170
16	3	705	1436	678	731	1280	1593
17	r	380	2491	364	396	2408	2574
18	ir	373	908	355	392	877	938
19	£˜	622	2076	595	649	1995	2157
20	8˜	681	1312	649	713	1267	1357

Rajasthani

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F2	
				LB	UB	LB	UB
1	a	704	1544	676	733	1490	1598
2	a:	817	1374	784	850	1345	1404
3	i	347	2453	333	360	2361	2546
4	i:	335	2515	321	348	2438	2593
5	u	368	1032	354	381	907	1157
6	u:	361	855	338	383	828	882
7	e	496	2275	467	526	2212	2338
8	0	502	972	482	523	941	1004

Tamil

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	725	1455	705	745	1415	1495
2	a:	756	1314	734	778	1275	1352
3	i	331	2358	322	341	2305	2410
4	i:	312	2411	303	322	2363	2459
5	u	343	893	332	356	863	923
6	u:	330	818	321	340	786	850
7	e	447	2187	434	461	2121	2251
8	e:	440	2281	426	454	2213	2348
9	o	439	988	425	453	961	1014
10	o:	434	910	419	448	884	936

Telugu

SI. no	Vowel	Mean (F1)	Mean (F2)	F1		F_2	
				LB	UB	LB	UB
1	a	762	1392	730	795	1325	1460
2	a:	808	1358	*111*	838	1301	1416
3	i	332	2484	320	345	2404	2563
4	i:	319	2590	306	331	2505	2675
5	• u	350	959	334	366	931	987
6	u:	350	895	336	364	871	919
7	e	468	2164	453	483	2090	2238
8	e:	440	2333	428	453	2256	2411
9	o	464	1051	445	482	1029	1073
10	o:	453	985	440	466	964	1005