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CROSS LINGUISTIC STUDY OF COARTICULATORY RESISTANCE OF RETROFLEX

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ABSTRACT

Speech production system experiences complex dynamic tongue movements for the production of retroflexes. This makes retroflexes distinct from other phonemes. Present study aimed to analyze the articulatory dynamics and coarticulatory pattern of retroflexes across three major languages of India: Hindi, Kannada, and Malayalam. Ninety adult speakers having equal number of native speakers for each language participated as subjects. The stimuli consisted of VCV sequences with C corresponding to voiced/ unvoiced counterparts of retroflex (/ʈ/, /ɖ/) in the context of vowels /a, i, u/. Tongue contours of each phoneme was obtained using Mindray 6600 Ultrasound module and further, coarticulation measurements were done using Articulate Assistance Advanced (AAA). Results indicated that the tongue contour of vowels imitated the pattern of retroflexes, especially in the following context than in preceding context. Coarticulation resistance of retroflexes were more in Hindi compared to Dravidian languages.

KEYWORDS: *Retroflex, Coarticulation Resistance, Hindi, Dravidian Languages*

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INTRODUCTION

Retroflexes are of study interest because of its complex pattern of articulatory dynamics and its trivial occurrence in world's languages. As per Bhat (1973), the occurrence of retroflexes was noticed mostly in the Australian and South Asian geographical area. Within South Asian languages, Dravidian languages and some of the Indo Aryan languages are sanctified to have abundant retroflexes which are phonemic in nature. Shape of tongue has been reported in many studies during the production of retroflexes and findings were interesting across languages.

Literature showed that some of the south Asian languages had apparent cross-language differences in the degree of retroflexion. As per the report of Švarný and Zvelebil (1955), Ladefoged and Bhaskararao (1983), Telugu speakers produced retroflexes with a low blade/front angle consistently. Tamil speaker also followed similar pattern of tongue movement where the curling of tongue was relatively high in Tamil speakers than Telugu. However Hindi, Indo Aryan language, had higher angle value indicating less curling of tongue. But this trend was similar to Urdu, which is another language from the same language family i.e. Indo Aryan. The authors concluded that the retroflexes of Telugu and Tamil were similar, and those of the Indo-Aryan languages Hindi/Urdu, had different articulatory targets, and correspondingly different degrees of retroflexion. Similar to this, Dart and Nihalani (1999) confirmed sub-apical palatal realization in Dravidian languages i.e. Malayalam and Toda. Findings of the study by Sindusha, Irfana, and Sreedevi (2014) are in agreement with the concept of sub-apicality of retroflex production and reported of contrast among Malayalam and Kannada speakers. Also the area beneath the tongue was constrained when the production of retroflexes made more acute angle. Cavity beneath the tongue cavity also varied in voiced and unvoiced retroflex counterparts in Kannada and Malayalam.

Australian languages also reported of similar production of retroflex with the underside of the tongue in the post-alveolar or prepalatal area of the roof of the mouth (Butcher, 1992). However, Anderson (2000) reported that the lack of contact on the sides of the tongue indicative of a considerably lower position of the tongue body is the characteristic of retroflexes compared to other consonants. Across- and within-language variation in the exact location (post-alveolar or prepalatal) and the type of constriction (apical or sub-apical) were noticed in most of the studies. Palatogram and X-ray were the most commonly used methods in these studies.

In this similar line of articulatory dynamics, retroflexes showed complexity and diversity in their coarticulatory pattern also. More fronting of adjacent vowel, especially for following vowel was observed in Tamil and Hindi (Dixit, 1990; Dixit & Flege, 1991; Krull & Lindblom, 1996). This established that retroflexes were strong enough to exert influence on vowels (Tabain, 2009), contrary to this, researchers reported that atleast some of the vowels are capable of influencing retroflexes (Dixit, 1990; Krull & Lindblom, 1996). As per Recasens' (1997) articulatory constraint model, coarticulation of lingual consonants varies as a property of tongue constriction or closure. This was confirmed for retroflexes in Kannada (Kochetov & Sreedevi, 2013).

Concern of the present study was to find the articulatory pattern and coarticulation of retroflexes crosslinguistically. The languages considered were Malayalam, Kannada, and Hindi with profuse presence of retroflex in their phonemic inventory. Articulatory dynamics have been studied in many of the world's languages including Dravidian languages such as Malayalam (Scobbie, Punnoose, & Khattab, 2013; Sindusha, Irfana & Sreedevi, 2014), Kannada (Kochetov, & Sreedevi, 2013) and Indo Aryan language, Hindi (Švarný & Zvelebil, 1955; Ladefoged & Bhaskararao, 1983; Krull & Lindblom, 1996), but support of relation between articulatory dynamics and coarticulation is lacking in these languages except Kannada (Kochetov & Sreedevi, 2013). Each of these studies adapted different methods and parameters to analyze the pattern of retroflexes. Studies of Malayalam and Kannada adapted ultrasound imaging technique to explore the articulatory variability of retroflexes compared to other consonants, whereas more of static methods such as X-ray, electropalatography, and MRI were used in Hindi. Also, the number of subjects varied across these studies; Scoobie et al, (2013) considered a single subject study whereas Sindusha et al (2014) and Kochetov and Sreedevi (2013) considered 10 participants. Unlike Dravidian languages, Indo-Aryan languages do not have 3-way retroflex/alveolar/dental place contrast (Masica, 1991), and the preference for apical post-alveolar realization of retroflexes was observed by Švarný and Zvelebil's (1955) and Ladefoged and Bhaskararao (1983) for Urdu/Hindi.

METHOD

Participants

A total of 90 speakers in the age range of 20-30 years with equal number of participants in each of the three languages, Malayalam, Kannada and Hindi, served as participants of the study. All the subjects had a normal oro-motor mechanism and were free of speech, language, hearing, neurological, or any other cognitive impediments.

Material

The test material consisted of VCV sequences with C corresponding to geminate forms of voiced and unvoiced counterparts of retroflex (/ʈ/, /ɖ/). The vowels in the VCV stimulus form were high front vowel /i/, low central vowel /a/ or high back vowel /u/. Table 1 depicts the test items.

Table 1: Stimuli List of V_1CV_2 Sequences with Retroflexes in the Context of Vowels V1 and V2 (/a, i, u/)

Vowels	Retroflex	
	Voiced	Unvoiced
Low Central	/aɖɖa/	/aʈʈa/
High Front	/iɖɖi/	/iʈʈi/
High Back	/uɖɖu/	/uʈʈu/

The methodology for collecting and analysing ultrasound data in this paper was adopted from the previous study by Irfana and Sreedevi (2016). An ultrasound instrument works on the reflective principle of sound waves. When a pulse of acoustic energy is directed at an object with suitable conductivity, it puts the object into oscillation and elicits echoes. In an ultrasound tongue imaging technique, when the sound wave travels upward from the probe through the tongue body, it is reflected downward from the upper tongue surface. The upper tongue surface interface is typically with the palate bone and airway, both of which have very different densities from the tongue and cause a strong echo. When the signal passes through air or bone, the sound wave is lost and no echo is passed back to the transducer because the conductivity for the sound is either too low (bone) or too high (air) (Bressmann, Ackloo, Heng & Irish, 2007). This resultant absence of echo leads to the formation of ultrasound tongue image.

In the present study, the instrument Mindray Ultrasound 6600 was used to obtain the ultrasound tongue images and the software Articulate Assistant Advanced (AAA) ultrasound module Version 2.14 (Articulate Instrument, Wrench & Scobbie, 2011) was used for the analysis with 60 frames per second. The instrument was synchronized to the audio input with a sample rate of 22,050 Hz. Hardware pulse generated a tone frequency of 1000 Hz with a beep length of 50 ms for an accurate synchronisation. Some of the parameters of Mindray Ultrasound 6600 were set as edge enhancement was set for 3, noise restriction of zero, Smooth and soften of image functions was set as 2. These default settings helped to suppress the tongue image noise. The transducer, a long-handled microconvex probe, operating at 6.5 MHz, was placed beneath the chin of the participant with the support of stabilization headset (Articulate instrument, Scobbie, Wrench & van der Linden, 2008). Each ultrasound frame was stored by AAA system as a set of raw echo-pulse with a depth of 7 mm, facilitating a standard two dimensional image. The instrument setup used is shown in Figure 1.

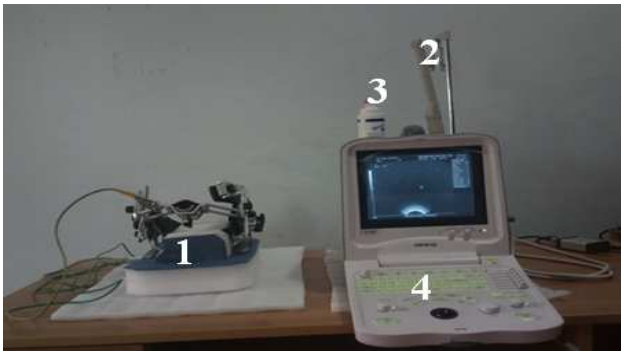

Figure 1: Shows Instrument Setup: 1. Stabilization Headset, 2. Transducer Probe, 3. Conduction Gel, and 4. Ultrasound Instrument (Note: Instrument in the Phonology Lab, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore.

The ultrasound imaging system provides three modes of recording including Amplitude (A-Mode), Motion (M-Mode) and brightness (B-Mode). Present study considered B-Mode since it has wide gray scale which helps to visualize even very small differences in echogenicity in the borders between different structures including cartilage, bone and layers of tongue tissue. Grey scale depicts the density of the tissue where the solid areas are depicted in 'white' and the fluid areas in 'black'. The interface between the tongue and the air is visible as a bright white band. Figure 2 depicts the midsagittal ultrasound image of vowel /a/. The midsagittal plane is preferentially used in ultrasound imaging as the image is most intuitive and can be compared across different speakers.

Figure 2: Midsagittal Image of Vowel /a/. The Anterior Tongue is towards the Right Side. (Note: Tongue Image in Articulate Assistant Advanced, Phonology Lab, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore).

Data Recording

Individual participants were made to sit comfortably on a high back chair. They were briefed on the test procedure before the recording and were asked to sip water before the recording to moisturize the oral cavity for better ultrasound images. The transducer probe placed beneath the chin was smeared with ultrasound transmission gel (*Aquasonic 100*) for superior tongue imaging. The probe was fastened by stabilization headset (*Articulate Assistant Advanced*) to reduce the artefacts caused by head movements. For recording the speech sample, a headphone (*iball i 333)* was used. Stimulus list was presented visually in a grapheme mode on the computer screen to one participant at a time. 10 repetitions of each prompt were recorded for further analysis. A total of 6 utterances were recorded for each participant that included ten repetitions of 6 target samples (3 vowel contexts (V1CV1) x 2 retroflex consonants including voiced and unvoiced counterparts = 6 x 10 repetitions = 60). A grand total of 1800 utterances (30 participants x 60 = 1800) were analysed for the study.

Data Analysis

For analysis, the software AAA was used with a technique ‘fan spline’ which had 42 axes or points. Figure 3 depicts 42 fan splines embedded on a tongue contour image of vowel /a/. Splines are curves defined by a mathematical function that are constrained to pass through specified points. Fan spline setups were decided for each place of articulation and used respectively. For dental and retroflex sounds, the fan spline had to be set more anteriorly, and for velars, more towards the posterior region. Semiautomatic contour plotting of midsagittal view was used in this study.

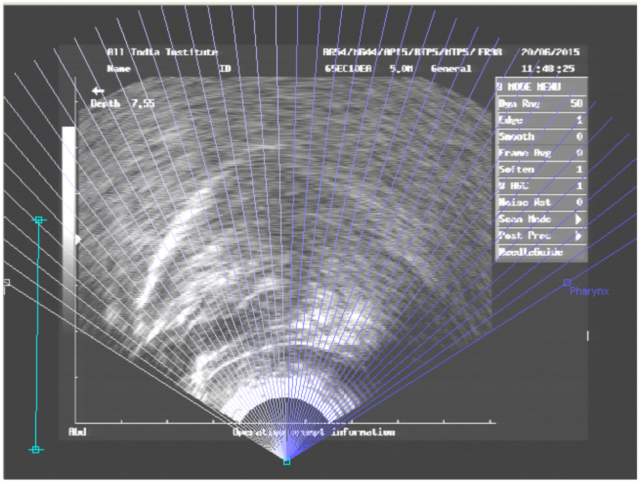

Figure 3: 42 Fan Splines (White) Embedded on a Tongue Contour Image of Vowel /a/.

Plotted contours were exported to the workspace to measure the coarticulation resistance of consonants (CRC). It is the ability of a consonant to restrict the coarticulatory effect of the preceding and/or the following vowel. CRC represents CR of consonants in relation to the surrounding vowels (Zharkova, 2008). It is measured in relation to different vowels in separate VCV sequences. For example, in order to obtain CR of the consonant /k/, we need to consider /k/ in at least two different vowel contexts such as /akka/ and /ikki/. Similarly there are two more other combinations, /akka/ -/ukku/, /ikki/- /ukku/. Hence CR of /k/ is calculated under three circumstances including (/a/-/i/), (/a/-/u/) and (/i/-/u/) as shown in Table 2. For each such combination, four RMS distances which includes preceding vowel to consonant and following vowel to consonant, needs to be calculated. Taking the example of /akka/ and /ikki/, the required RMS distances for CR of /k/ are /a_1/-/k/, /k/-/a_2/, /i_1/-/k/ and /k/-/i_2/ [Figure 4 (a & b)]. Also, the RMS distance between the mean tongue contour of /k/ in /a/ context and /k/ in /i/ context needs to be calculated [Figure 4 (c)]. Similar to /k/, three combinations each are considered for other target consonants and respective RMS distances are measured.

Table 2: Example of Tokens and Analysis Pair for Consonant /k/

Token	Analysis Pair	Analysis Pair
CRC k(a, i)	a-k; k-a	i-k; k-i
CRC k(a, u)	a-k; k-a	u-k; k-u
CRC k(i, u)	i-k; k-i	u-k; k-u

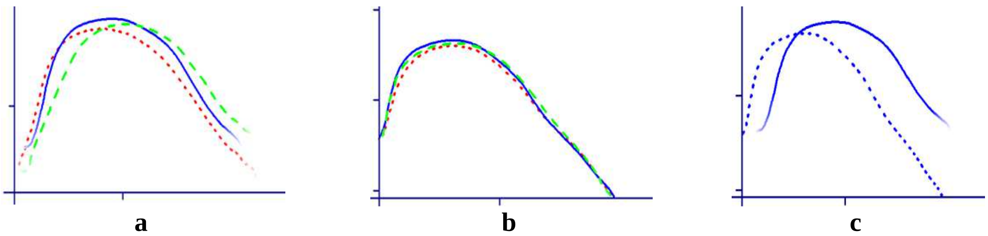

Figure 4: (a) Tongue Contours of /akka/. (b) Tongue Contours of /ikki/. Preceding Vowel Indicated as Red Dotted Line, Consonant as Blue Solid Line and Following Vowel as Green Dashed Line. (c) Tongue Contours of Consonant /k/ in Two Vowel Environments: Blue Solid Line - in the Context of /a/; Blue Dotted Line - in the Context of /i/.

The RMS distances from the consonant to its surrounding vowels (V_1-C and V_2-C) are proportionate to the degree of CR of the consonant, i.e., the degree to which C retains its identity in a VCV sequence. The V_1-C and the V_2-C RMS distances were computed for each of the tokens. CRC is calculated using the formula by Zharkova (2007) as follows:

$$\mathrm{CRC}_{C\,(V1,\,V2)} = \frac{(C-V)}{(C_{V1} - C_{V2})}$$

In the above equation, the numerator "C-V" indicates the averaged value of RMS of both contexts (as seen in Table 2.2, first row: average of a-k, k-a, i-k, k-i). The denominator ($Cv_1 - Cv_2$) was obtained as RMS distance between tongue contour of C in the context of /a/ to the tongue contour of C in the context of /i/ [example: Tongue contour of /k/ in the context of /a/ (/akka/) - Tongue contour of /k/ in the context of /i/ (/ikki/, (Figure 2.4, c)]

RESULTS

Tongue Dynamics

Tongue contour of voiced and unvoiced retroflexes in each language were analyzed separately and depicted in figures 5-7. As depicted, it varied slightly across vowel contexts in all the languages. Following vowel contour indicated in green dashed line was more towards the retroflexes than the preceding vowel implies more coarticulation of retroflex to vowel. Tongue curling was not visible in all the tokens. There was obvious similarity among the voiced and unvoiced counterparts in all three vowel contexts.

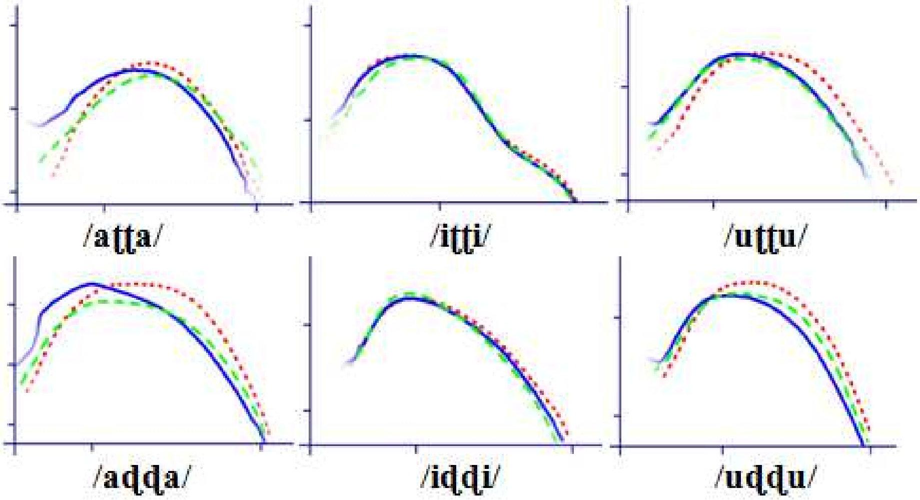

Figure 5: Averaged Tongue Contours of Voiced and Unvoiced Retroflexes in Kannada.

Figure 5 explains the tongue dynamics of retroflexes across vowel contexts in Kannada. It indicates a clear pattern of tongue fronting across contexts even when it occurred with back vowel /u/ and central vowel /a/. There was a clear disparity across voiced /ʈ/ and its unvoiced counterpart /ɖ/, when they neighboured with /a/. Raising of tongue front was common across vowels. Tongue contour of high front vowel /i/ and retroflex were mutually influenced in both preceding and following contexts.

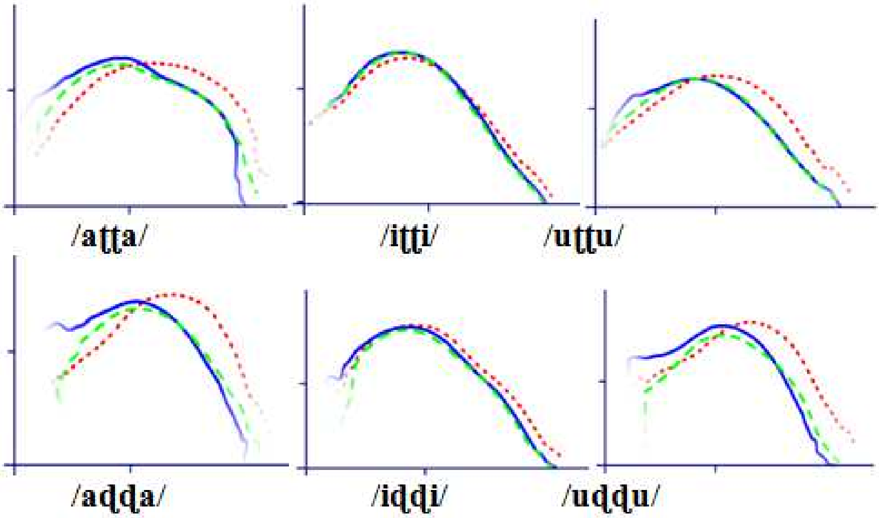

Figure 6: Averaged Tongue Contours of Voiced and Unvoiced Retroflexes in Malayalam.

As seen in Kannada, in Malyalam also retroflex behaved differently in /aCa/ context, where tongue front raising was evident in both cases (Figure 6). However, back of the tongue was more towards soft palate in unvoiced retroflex, whereas tongue front was raised with tongue tip curling in voiced retroflex. Though tongue moved towards front in vowel /u/ context, height of the tongue was relatively less. Vowels in the following context mimicked the same articulatory dynamics of retroflexes and not the preceding vowels.

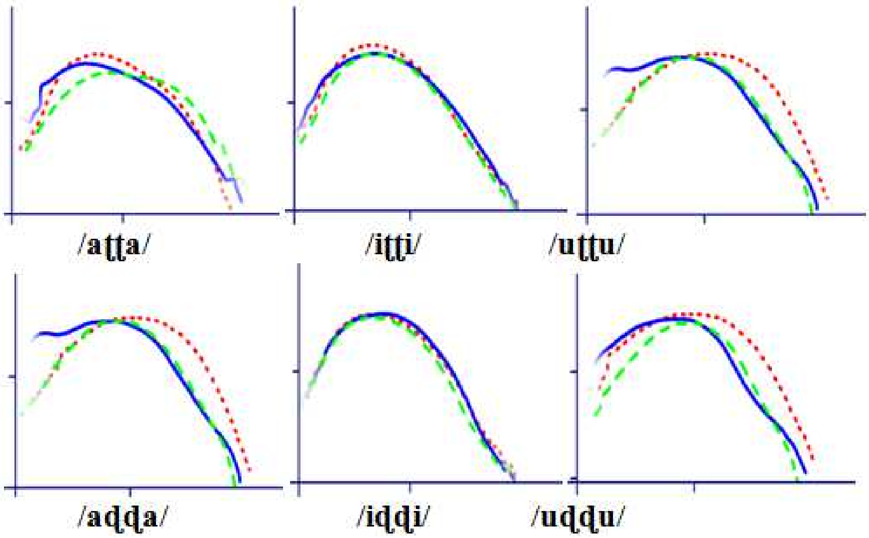

Figure 7: Averaged Tongue Contours of Voiced and Unvoiced Retroflexes in Hindi.

Hindi speakers showed clear pattern of retroflex influence in all the vowel contexts as seen in figure 7. Even the vowels in the preceding context was influenced by retroflexes especially vowel /a/. Back vowel /u/ in the preceding context deviated away from its articulatory posture and moved towards the retroflex. Tongue curling was observed for 3 out of 6 tokens in Hindi.

Coarticulation Resistance

Descriptive statistics of CRR is depicted in Table 3. CRR was high when measured in the context of /a/ and /u/; it was evident in both voiced and unvoiced retroflexes across languages. The pattern of coarticulation resistance decreased in the order (/a/, /u/) > (/i/, /u/) > (/a/, /i/). This pattern was observed in both Malayalam and Kannada speakers, whereas there was a difference between voiced and unvoiced retroflexes in Kannada. Further, statistical analysis was carried out since it was difficult to make a statement about language effect in coarticulatory resistance of retroflexes.

Table 3: Mean, Median and Standard Deviation (SD) of Coarticulation Resistance of Retroflexes (CRR)

	Kannada			Malayalam			Hindi		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
CRʈ (a, i)	21.98	21.23	9.78	22.52	19.93	11.24	26.00	21.72	16.94
CRʈ (a, u)	43.41	39.29	31.57	36.01	35.38	21.04	35.11	28.09	18.55
CRʈ (i, u)	32.16	28.68	14.88	34.33	31.04	17.34	32.46	20.88	24.72
CRɖ (a, i)	28.70	23.21	18.42	26.97	25.54	12.26	23.97	23.82	9.19
CRɖ (a, u)	53.94	41.89	39.00	41.51	41.50	13.32	35.44	27.81	34.18
CRɖ (i, u)	27.00	25.17	10.04	32.71	28.27	14.05	28.48	30.00	16.36

Note: SD-Standard Deviation

Coarticulation Resistance of Retroflex within Language

This section analyses the pattern of coarticulation resistance within each language. Kruskal wall is H test was used to obtain the effect of vowel context on CRR in each language. As seen in Table 4, CRR was significantly different across vowel context except for voiced retroflex in Hindi. Further, pair wise comparison was administered using Wilcoxon signed rank test, findings demonstrated that there was a significant difference when the phonetic contexts were (/a/, /u/) and (/a/, /i/) with obvious high coarticulation resistance in (/a/, /u/) context. Similarly, other pairs were also significantly different for unvoiced retroflex in Kannada and for voiced retroflex in Malayalam. General observation was, high CRR in the context of (/a/, /u/) followed by (/i/, /u/), and least for (/a/, /i/). This trend was noticed especially in the Dravidian languages i.e. Kannada and Malayalam.

Table 4: Coarticulation Resistance of Retroflexes Across Vowel Pair Context in each Language

				(a, u) vs (a, i)		(a, u) vs (i, u)		(a, i) vs (i, u)	
	Language	χ^2	**P**	**/Z/**	**P**	**/Z/**	**p**	**/Z/**	**p**
/ʈ/	**Kannada**	25.80	0.000***	4.638	0.000*** ↑	2.108	0.035* ↓	3.322	0.001*** ↑
	Malayalam	24.46	0.000***	4.330	0.000*** ↑	0.730	0.465	3.569	0.000*** ↑
	Hindi	8.867	0.012*	2.993	0.003** ↑	0.998	0.318	1.162	0.245
/ɖ/	**Kannada**	18.06	0.000***	4.330	0.000*** ↑	3.836	0.000***	0.257	0.797
	Malayalam	24.06	0.000***	4.021	0.000*** ↑	2.561	0.010** ↓	2.808	0.005** ↑
	Hindi	4.867	0.088	-	-	-	-	-	-

Note: *= p≤ 0.05, **= p≤ 0.01, ***= p≤ 0.001, Upward arrow (↑) shows higher mean CRC for second pair. Conversely, downward arrow (↓) shows least mean CRC for the second pair

Effect of voicing was tested using Mann Whitney U test within each language. Significant difference was observed only for Malayalam. Specifically unvoiced retroflex had higher CRC than voiced counterpart when retroflexes measured in the vowel pair context of (/a/, /i/) and (/a/, /u/). Z and p values are given in Table 5.

Table 5: Effect of Voicing within each Language

	(a, i)		(a, u)		(i, u)	
Language	**/Z/**	**P**	**/Z/**	**p**	**/Z/**	**P**
Kannada	1.738	0.082	1.162	0.245	0.895	0.371
Malayalam	2.231	0.026* ↑	2.314	0.021* ↑	0.648	0.517
Hindi	0.237	0.813	0.833	0.405	0.257	0.797

Note: *= p≤ 0.05, Upward arrow (↑) shows higher mean CRC for unvoiced retroflex.

Coarticulation Resistance of Retroflex across Languages

Friedman test results showed that there was no significant difference except for CR of /ɖ/ in the context of (a, u) [χ^2 (2) = 13.27, p =.001] across languages. Further Wilcoxon pair wise comparison showed that Hindi was significantly different from Malayalam [|Z|= 3.297, p=.001] and Kannada [|Z| = 2.98, p=.003]. This indicates that Dravidian languages exhibit higher coarticulation resistance than an Indo-Aryan language. Dravidian languages showed similar coarticulation resistance of retroflex specifically for /ɖ/ [|Z| = 0.444, p=.657].

DISCUSSION

Tongue contour of retroflexes varied slightly across vowel contexts in all the languages indicating that they were strong enough to block the influence of neighboring vowels. Moreover the articulatory posture of vowels varied marginally especially for vowel /a/ and /u/. This is in agreement with reports of Dixit (1990), Dixit and Flege (1991) Krull and Lindblom (1996) and Tabain (2009). Tongue contours indicated anterior movement of tongue tip to make constriction with lowering of tongue back. Tongue blade was high with tongue tip, but there was dip in between these two structural points. Subjectively, variations of tongue contours were evident in Hindi than the two Dravidian languages.

Tongue curling was seldom visible in all the tokens, as ultrasound is not competent enough to get all the tongue tip information (Stone, 1988). This was noticed in all the three languages. However, individual data depicted better image of tongue curling than averaged images showing variation across subjects in their production. This can be considered as motor equivalence of speech production system to compliment the output goal as perceptually acceptable retroflex production in respective languages. Though tongue contours of both preceding and following vowels was influenced by the retroflex, the effect was more on following than on the preceding vowel (Dixit, 1990). This may be because of tongue constraint posture during the production of retroflex, which continues in the same posture for the following vowel. This can be considered as a carryover effect of retroflex on the following vowel in VCV syllable.

Within language, CRR was significantly different across vowel contexts especially in Malayalam and Kannada and it was in the order (/a/, /u/) > (/i/, /u/) > (/a/, /i/). As observed, /a/ and /u/ vowels get highly influenced, hence retroflexes were able to resist them maximally and in turn influence them. Since /i/ is one of the highly coarticulation resistance vowel (Irfana & Sreedevi, 2016), it is not easy for retroflex to influence vowel /i/, rather it is more of mutually influenced by each other. Difference of CR across voiced counterparts explains as a property of articulatory dynamics as observed in Sindush et al (2014) in Malayalam. However in Kannada and Hindi, there was not much variation in the articulatory pattern among voiced and unvoiced retroflexes.

Across-language comparison proves that Dravidian languages exhibited higher coarticulation resistance than Hindi. This is in congruence with previous reports explaining the sub-apicality of retroflexes in Dravidian languages and apical production in Hindi (Švarný & Zvelebil, 1955; Ladefoged & Bhaskararao, 1983; Dart & Nihalani, 1999; Sindusha et al, 2014; Kochetov & Sreedevi, 2013). This complex articulatory constriction resists the influence of nearby phonemes and rather exerts strong influence on them. Hence, the present study emphases that retroflexes also followed Recasen's degree of articulation constrain model in ther languages such as Malayalam and Hindi along with Kannada which was explored previously by Kochetov and Sreedevi (2013).

CONCLUSIONS

This study analyzed the articulatory and coarticulatory pattern of retroflexes across three languages. Findings explained the complexity of retroflexes and coarticulation resistance across vowels. Dravidian languages were similar in their coarticulation pattern, but they were deviant from Hindi. Explanation of individual data could have provided better understanding of tongue curling and this can be studied across languages using other physiological methods like EMA along with ultrasound in future. Though the study reveals that retroflexes are strong enough to exert influence it can be further explored in a long string of consonants and vowels to understand long term coarticulatory effect.

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