

An Ultrasound Study of Coarticulatory Resistance and Coarticulatory Aggression

¹ **Irfana, M** (Corresponding author)

Junior Research Fellow

Department of Speech Language Sciences

All India Institute of Speech and Hearing

Manasagangothri, Mysore -570006, India.

² **Sreedevi, N**

Reader in Speech Sciences

Department of Clinical Services

All India Institute of Speech and Hearing

Manasagangothri, Mysore -570006, India.

Type of Review: Peer Review

DOI: <http://dx.doi.org/10.21013/jmss.v4.n2.p2>

How to cite this paper:

Irfana, M., & Sreedevi, N. (2016). An Ultrasound Study of Coarticulatory Resistance and Coarticulatory Aggression. *IRA-International Journal of Management & Social Sciences* (ISSN 2455-2267), 4(2), 314-323. doi:<http://dx.doi.org/10.21013/jmss.v4.n2.p2>

© Institute of Research Advances



This work is licensed under a [Creative Commons Attribution-Non Commercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/) subject to proper citation to the publication source of the work.

Disclaimer: The scholarly papers as reviewed and published by the Institute of Research Advances (IRA) are the views and opinions of their respective authors and are not the views or opinions of the IRA. The IRA disclaims of any harm or loss caused due to the published content to any party.

ABSTRACT

The term 'coarticulatory resistance' refers to the degree to which a given segment, a consonant or a vowel, resists potential interference of neighbouring segments. The phoneme with coarticulatory resistance exert stronger influence on neighbouring phoneme and exhibit less contextual variation, this characteristic termed as 'coarticulatory aggression'. The present study aimed to analyse the coarticulatory resistance and coarticulatory aggression based on ultrasound imaging technique . Thirty adult Malayalam speakers participated as subjects . The stimuli consisted of VCV sequences , with C corresponding to voiced/voiceless counterparts of dental stops (/t̪, /d̪/) or retroflex stops (/ɻ, /ɻ/) or velar stops (/k/, /g/), in the context of vowels /a, i, u/. Measurements of coarticulation resistance of consonants, preceding vowels and following vowels were carried out based on Root Mean Square (RMS) distance between the tongue contours of vowels and consonants. Results showed that coarticulatory resistance of consonants were decreased in the order from retroflex followed by velars and dentals. High front vowel /i/ resisted coarticulation of preceding consonant more than other vowels considered. It highlights the trend of Degree of Articulatory Constraint (DAC) model for both consonant and vowel system.

Key words: *Coarticulatory resistance, Coarticulatory aggression, Ultrasound, Malayalam, Stops.*

1. Introduction

Coarticulation in a broad manner refers to the fact that a phonological segment is not realized identically in all environments, but often apparently varies to become more like an adjacent or nearby segment (Kuhnert & Nolan, 2000). Lingual coarticulation is important since the tongue is a complex, mobile organ which plays a major role in the production of all vowels and majority of the consonants. The term coarticulatory resistance refers to the degree to which a given segment resists the potential interference of neighbouring segments. The sounds with coarticulatory resistance also exert strong influence on their neighbouring vowels; they exhibit the least contextual variation and induce the greatest. In VCV syllable, if coarticulatory resistance of the consonant is higher, it indicates that the consonant has higher resistance against the influence of preceding and following vowel.

Coarticulation varies as a property of tongue dynamics of each phoneme in a particular language. Previous studies especially Recasens (1984a, 1984b, 1985, 1989, 1993) suggested that variation of coarticulatory resistance is consequence of gestures of phonemes place on the tongue dorsum. He had studied different consonants including palatal consonant /j/, alveopalatals /ɲ/ and /ʎ/, alveolar /n/ in VCV syllable context. Their extended studies revealed that constraint of the tongue dorsum is the major factor for lack of invariance in the coarticulatory resistance. In subsequent studies, Recasens, Pallarès and Fontdevila (1997) proposed a “Degree of Articulatory Constraint (DAC) model” to explain this property of speech production. According to this model coarticulatory resistance should increase with the degree of articulatory constraint, i.e., with the mechano-inertial properties of the articulators and their involvement in the formation of a closure or constriction. Fowler and Brancazio (2000) explored this trend using locus equation and suggested that magnitude of resistance is determined by the mutual incompatibility of their gestures with those of sequentially adjacent or nearby segments.

The phoneme having higher coarticulatory resistance exert stronger influence on their neighbouring vowels, but, exhibit the least contextual variation. This characteristic has been termed, coarticulatory aggression (Fowler & Saltzman, 1993). It is the characteristic of a phoneme or segment with high coarticulatory resistance to exert high influence on the adjacent phonetic segments. When the segment is aggressive, the influence extends well beyond the boundary. It also indirectly indicates how the phoneme resists the influence of neighbouring segment and exhibits its own identity. Based on DAC model, coarticulatory aggression is more related to the tongue dorsum constraint and it can be dependent on the phonetic characteristics of the sound segment. According to this model,

coarticulatory sensitivity of the consonants in VCV sequences (V-to-C effect) varies inversely with the strength of the consonantal effects (C-to-V effects) and with the degree of articulatory constraint of the intervocalic consonant. Recasens and Espinosa (2009) revealed that coarticulatory aggressiveness scale decreases in the progression from lingual fricatives, alveolopalatals, velars, labials, /n/, to a lesser extent, /l/ for consonants, high /i, u/ > low /a/ for vowels in Catalan. Based on tongue height, high vowels are more aggressive than low vowels (Recasens, 2012).

The present study intend to explore the coarticulatory resistance and aggression in Malayalam, a less explored language, across three places of articulation specifically voiced and unvoiced counterparts of dentals, retroflexes and velars with three cardinal vowels. Malayalam is one of the major Dravidian languages that is spoken in the south Indian state of Kerala. Like other languages of the sub-continent, it has complex set of place contrasts involving labials, alveolar, velars, dentals, palatals, and retroflexes (Asher & Kumari, 1997).

Articulatory dynamics are different across these consonants and vowels. Production of retroflex consonant got particular interest because of its articulatory complexity and rarity across languages (Ladefoged & Maddieson, 1996). It produces with higher articulatory constraint with sub-apical contact than other Dravidian language retroflexes (Sindusha, Irfana & Sreedevi, 2014). The contact for the dental consonant is made with the moderately raised blade of the tongue, presumably at the alveolar ridge and the upper teeth. The shape of the tongue is overall lowered, and flat, with the posterior tongue body somewhat backed. The point of contact for the velar stop is presumably at the velum and the tongue body is strongly convex (Kochetov, Sreedevi, Kasim & Manjula, 2014). The present study considered phonemes with different articulatory placement including phonemes more towards front i.e /i/ and dentals, back vowel (/u/) and velars and phonemes more central position including vowel /a/ and retroflexes with the intention to explore the relation of coarticulation resistance and aggression with articulatory dynamics.

2. Method

Thirty native adult speakers of Malayalam served as subjects for this study. All of them were considered after oro motor examination and were excluded if identified with speech, language, hearing, or any cognitive deficits. The test material consisted of non-meaningful V1CV2 sequences with C corresponding to voiced and unvoiced counterparts of dental stops (/t̪, /t̪̥ /) or retroflex stops (/ɖ, /ɖ̥/) or velar stops (/k, /g/) in the context of vowel V1 and V2, these were high front vowel /i/ or low central vowel /a/ or high back vowel /u/. Table 2.1 shows the test items. VCV were sequences embedded in a short carrier phrase (Now I will say CVCV).

Table 2.1: Stimuli list of V1CV2 sequences with consonant in 3 places of articulation in the context of vowel V1 and V2 (/a, i, u/).

Vowels	Places of articulation					
	Dental		Retroflex		Velar	
	Voiced	Unvoiced	Voiced	Unvoiced	Voiced	Unvoiced
Low central	/aɖɖa/	/aɖ̥ɖa/	/aɖɖa/	/aɖ̥ɖa/	/aɖɖa/	/aɖ̥ɖa/
High front	/iɖ̪ɖ̪i/	/iɖ̪̥ɖ̪i/	/iɖ̪ɖ̪i/	/iɖ̪̥ɖ̪i/	/iɖ̪ɖ̪i/	/iɖ̪̥ɖ̪i/
High back	/uɖɖu/	/uɖ̥ɖu/	/uɖɖu/	/uɖ̥ɖu/	/uɖɖu/	/uɖ̥ɖu/

In the present study, articulatory movement data were obtained using the instrument Mindray ultrasound 6600. This system was connected to a PC installed with the software Articulate Assistant Advanced (AAA) ultrasound module Version 2.14 (Articulate Instrument, Wrench & Scobbie, 2011) for the analysis with 60 frames per second. It was synchronized to the audio input with a sample rate of 22050 Hz. Hardware pulse generated a tone frequency of 1000 Hz with beep length of 50 millisecond to accurate the synchronization. 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

stored by AAA system as a set of raw echo-pulse with a depth of 7mm from which a standard two dimensional image was created. Figure 2.1 depicts the midsagittal ultrasound image of vowel /a/.



Figure 2.1. 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).

2.1. Data collection: Participants were made to sit comfortably in a high back chair and the transducer probe was placed beneath the chin smeared with ultrasound transmission gel (*Aquasonic 100*) for better tongue imaging. The probe was fastened by stabilization headset (*Articulate Assistant Advanced*) to reduce the artifacts because of head movements. A headphone *iball i 333* was used for recording the audio speech sample. Stimulus list was presented visually in grapheme mode to individual participant and 10 repetitions of each prompt were considered for further analysis. A total of 270 utterances were recorded from each participant including 10 repetitions of 9 target samples (3 same vowel contexts (V1CV1) * 9 consonants including both voiced and unvoiced counterparts= 27*10 repetitions=270). A grand total of 810 utterances (30*270=8100) were recorded for the study.

2.2. Data Analysis: For analysis, semiautomatic contour plotting was considered in this study. Individual token splines for each consonant and vowel were used to create mean splines, based on means at 42 fan lines. Plotted contours were exported to workspace to find following parameters.

2.2.1. Coarticulation resistance

In VCV syllable, it is possible to find coarticulation resistance of consonants (CRC) and coarticulatory resistance of vowel (CRV). CRC is the ability of consonant to restrict the coarticulatory effect of preceding and/or following vowel. CRV is the vowel capacity to maintain its own characteristics. The formula used in the study was adapted from Zharkova (2007) to find the coarticulatory resistance.

2.2.1.a) Coarticulation resistance of consonants (CRC)

CRC was calculated in relation to both vowels from a VCV sequence where the calculations can also be performed in relation to V1 and V2 separately. CRC was found by using the formula:

$$CRC_{C(V1-V2)} = \frac{(C-V)}{(C_{V1}-C_{V2})} \times 10$$

In the above equation, the numerator “C-V” indicates the averaged value of RMS of both V1 and V2 contexts. The denominator ($C_{V1} - C_{V2}$) was obtained as RMS distance between tongue contours of C in different vowel contexts.

2.2.1.b) Coarticulation resistance of preceding vowel (CRPV)

CRPV was calculated in relation to different consonants from preceding vowel in VCV sequence. The RMS distances from the vowel to neighbouring consonant (V1-C and V2-C) are proportionate to the degree of CR of the vowel, i.e., the degree to which V retains its identity in a VCV sequence. The V1-C and the V2-C, RMS distances were computed within token, separately for each of the tokens and for each of the 10 repetitions also. CRPV was found by using the formula:

$$CRPV_{V(C1-C2)} = \frac{(V-C)}{(V_{C1}-V_{C2})} \times 10$$

The numerator of the above equation, “V-C” indicates the averaged value of RMS of both contexts. The denominator ($V_{C1}-V_{C2}$) was obtained as RMS distance between the mean tongue contours of V in different consonant contexts.

2.2.1.c) Coarticulation resistance of following vowel (CRFV)

CRFV was calculated in relation to different consonants from following vowel in VCV sequence. The analysis was similar as above described format. In this section following vowel was considered instead of preceding vowel to find the CRFV.

3. Results

3.1. Tongue dynamics across places of articulation

Figure 3.1-3.3 shows the average tongue contours of 30 subjects for each phoneme in VCV syllable. There was difference across tongue contours though the vowels were same in preceding and following context. General trend of fronting was observed when consonants neighboured with front vowel /i/. Both voiced and unvoiced counterparts of each place of articulation are discussed together since there is much variation across them in the tongue dynamics as seen from the images.

As seen figure 3.1, dental consonants were vulnerable and changed based on the vowels occurred with. It was evident that backing of posterior tongue body when they nearby with back vowel /u/ and centralization of anterior tongue body when occurred with vowel /a/.

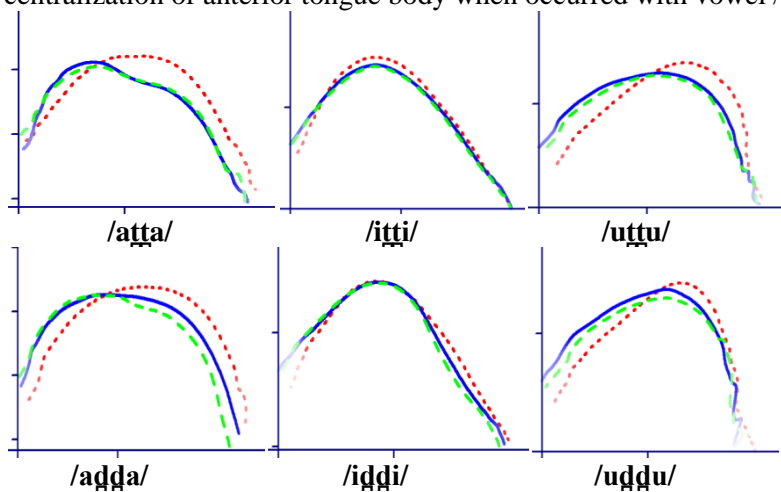


Figure 3.1. Average tongue contours of 30 subjects- preceding vowel (red dotted line), consonant (blue solid line) and following vowel (green dashed line) for voiced and unvoiced counterparts of dental consonants across three vowel contexts.

Contrast to dentals, retroflexes were influenced the vowels and changed the articulatory dynamics as observed in figure 3.2. Though there is some information loss of tongue tip curling, overall tongue shape of vowels were more as retroflexes especially back vowel /u/ and low central vowel /a/.

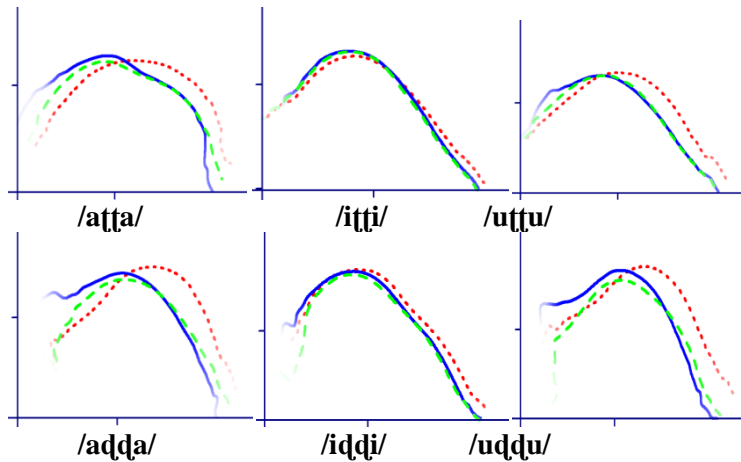


Figure 3.2. Average tongue contours of 30 subjects- preceding vowel (red dotted line), consonant (blue filled line) and following vowel (green dashed line) for voiced and unvoiced counterparts of retroflex consonants across three vowel contexts.

There were slight variations in articulatory position of vowels and velars. Velars were not always raise towards posterior with posterior tongue body. It was more of in between the articulatory position of velars and vowels. Especially when it occurred with front vowel /i/, there the tongue contour of velar consonant moved towards anterior position.

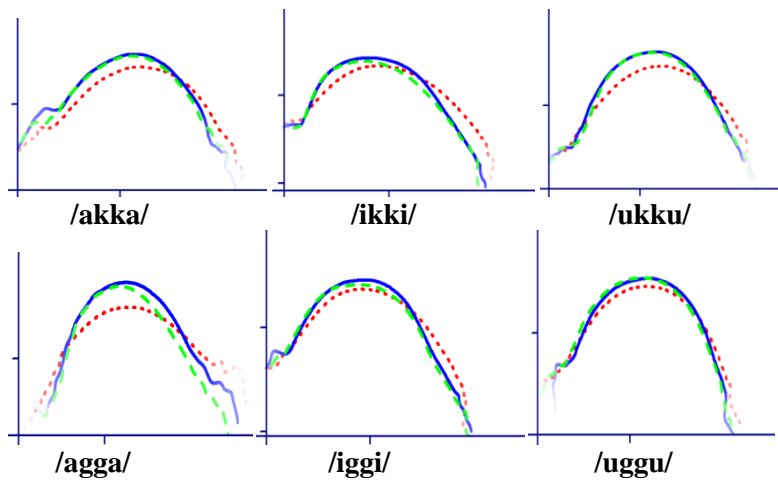


Figure 3.3. Average tongue contours of 30 subjects- preceding vowel (red dotted line), consonant (blue filled line) and following vowel (green dashed line) for voiced and unvoiced counterparts of velar consonants across three vowel contexts.

3.2. Coarticulatory resistance of consonants

Based on the equation, CRC calculated for each subject and mean and standard deviation of 30 subject depicted in Table 3.2. It is evident that the coarticulatory resistance is relatively higher when sequentially adjacent to vowels /a/ and /u/ than other contexts. Interestingly, all the places of articulation including dental, retroflex, and velar stop consonants followed the same trend.

Friedman non-parametric tests were administered across consonants to analyse the coarticulatory resistance in each vowel context. Results showed that there was significant difference between the coarticulatory resistances of consonants in all the three vowel contexts ($\chi^2(5) = 15.80, p < .001$).

Table 3.2: Mean and standard deviation of coarticulatory resistance of consonants of 30 subjects

CRC	Mean	SD	CRC	Mean	SD	CRC	Mean	SD
CRC _t (a, i)	12.27	4.88	CRC _t (a, i)	22.52	11.24	CRC _k (a, i)	15.42	5.85
CRC _t (a, u)	21.78	8.60	CRC _t (a, u)	36.01	21.04	CRC _k (a, u)	45.20	24.57
CRC _t (i, u)	15.68	7.56	CRC _t (i, u)	34.33	17.34	CRC _k (i, u)	14.78	7.78
CRC _d (a, i)	14.02	6.15	CRC _d (a, i)	26.97	12.26	CRC _g (a, i)	17.48	7.73
CRC _d (a, u)	24.72	10.70	CRC _d (a, u)	41.51	13.32	CRC _g (a, u)	44.74	20.4
CRC _d (i, u)	18.67	13.78	CRC _d (i, u)	32.71	14.05	CRC _g (i, u)	17.06	12.00

Further, Wilcoxon Sign Rank test revealed similar pattern of coarticulatory resistance when the consonant was near to vowels /a/ and /i/ ($|Z|=4.271$, $p=.010$); /u/ and /i/ ($|Z|=2.098$, $p=.036$). Here, dental and velar consonants were significantly more influenced by adjacent vowels than retroflex consonants which were not different for both voiced and unvoiced counterparts. Particularly retroflex consonants set strong constraints on the tongue dorsum that limit the variation exerted by both preceding and following vowels, whereas, other consonants were influenced by adjacent segments.

Dental consonants were weak to exert coarticulation even when the vowels were /a/ and /u/, while velars and retroflexes showed significantly higher magnitude of resistance ($p\leq 0.001$). Also, dentals permitted influence of all the three vowels when they preceded and followed in VCV segment, whereas, retroflex opposed the influence and maintained their own identity. Velars were flexible purely based on the context of vowel that were mutually compatible.

3.3. Coarticulatory resistance of preceding vowel

Table 3.2 depicts that the mean of coarticulatory resistance of preceding vowel was more for vowels /i/ and /u/ followed by /a/. Variability noticed was high for /a/ and relatively less for vowel /i/ indicating robust articulatory gesture.

Table 3.3: Mean and standard deviation of coarticulatory resistance of preceding vowel

Tokens	t & d		t & d		k & g	
	Mean	SD	Mean	SD	Mean	SD
CRPV	23.67	39.37	30.54	81.60	35.09	56.68
CRPV	49.17	18.63	79.74	21.48	69.59	23.62
CRPV	41.29	48.55	60.19	35.43	37.93	23.15

Coarticulatory resistance by preceding vowels was analysed using Friedman test. Results showed significant difference of coarticulation resistance only in dental consonant contexts ($\chi^2(2) = 20.89$, $p=.001$). Wilcoxon Sign Rank test revealed that vowel /a/ was having significantly less coarticulation resistance than /i/ and /u/ ($|Z|=2.887$, $p=.004$). This indicates that vowel /i/ and /u/ resisted the influence of voiced and voiceless counterparts of dentals moreover similarly, whereas, vowel /a/ could not influence neighbouring consonants.

3.4. Coarticulatory resistance of the following vowel

Coarticulation resistance of following vowel /i/ was higher than /a/ and /u/ vowels. This was common across all the stop consonants considered in this study. Table 3.3 illustrates the mean and standard deviation of coarticulatory resistance of /a/, /i/, and /u/ in the following context.

Table 3.4: Mean and standard deviation of coarticulatory resistance of following vowel

Tokens	t & d		t & d		k & g	
	Mean	SD	Mean	SD	Mean	SD
CRPV	9.16	6.97	15.05	12.89	14.79	13.54
CRPV	13.87	4.67	19.05	8.47	17.16	10.07
CRPV	15.86	9.45	19.19	10.00	14.69	7.66

The ability to retain the characteristics of following vowel was analysed using Friedman’s test. There was significant effect in consonant context including dental ($\chi^2 (2) = 15.23, p = .009$) retroflex, and velar ($\chi^2 (2) = 27.78, p = .000$). Wilcoxon Sign Rank test was used to do pair wise comparison and the results showed the presence of stronger coarticulatory resistance of /i/ than /a/ ($|Z| = 2.859, p = .004$) across three different places of articulation.

4. Discussion

The present study results revealed that the retroflex consonants /d/ and /t/ resisted coarticulatory effect significantly than other consonants especially in the context of /aCa/, /iCi/, and /uCu/ respectively. Similar result was reported in another Dravidian language, Kannada study (Kochetov & Sreedevi, 2013). A previous experiment (Sindusha, Irfana & Sreedevi, 2013), reports that Malayalam retroflexes have more complicated tongue movement. Also, the angle between the slope of the surface of the anterior tongue body and the tongue blade is reduced indicating a greater degree of the tongue curling typical of a sub-apical post alveolar retroflex articulation.

Similarly, velar consonants highly resisted the influence when occurred in /a-a/ and /u-u/ contexts. This can be attributed to the presence of wider tongue dorsum contact area during the production of velars than dentals. Tongue dorsum constriction is very minimal in dental consonants where the tip of tongue touches the teeth to make obstruction rather than entire tongue body constriction.

To correlate, DAC model explains that the degree of coarticulation should vary with the constraints exerted upon the kinematics of different tongue constrictions. Thus, for instance, concluded that the place categories especially, retroflex consonants impose restrictions upon tongue activity to almost prevent V-to-V coarticulation from occurring. From this study, it is evident that coarticulatory resistance decreases progressively from retroflex > velar > dental. Though the production of retroflexes occurs as apical constriction rather than tongue dorsum constriction discussed in DAC model, the degree of constriction is more influential and this tongue tip constriction is more precise to make accurate angle of retroflexion. Hence, this specific articulatory dynamics oppose the influence of other adjacent segments. Similarly, better coarticulatory resistance of velars than dentals provides reason to believe the notion of tongue dorsum constriction against palate. This suggests that the coarticulatory resistance scale is a valid criterion for consonant classification and also provides valuable information on spatio-temporal planning mechanisms underlying speaker’s speech production.

Furthermore, results showed that there is significant difference in the coarticulatory resistance of vowels in preceding (V1) and following vowel (V2) contexts. Resistance declined progressively from high front vowel /i/ to high back vowel /u/ followed by low central vowel /a/. For coarticulatory resistance of preceding vowel, this pattern was seen only in the context of dental consonants. This might be because of the property of high coarticulatory resistance of the retroflex and velar consonants. However, resistance of vowel /i/ was obvious in all the three considered places of articulation than /u/ and /a/ in the following vowel context. This exemplifies that the high front vowel /i/ has the capacity to resist the influence of consonant in both preceding and following contexts. These results are in agreement with some of the previous studies where the vowel /i/ showed maximum coarticulatory resistance in English (Stevens & House, 1963), Dutch (Pols, 1977), and Catalan (Recasens, 1985).

Since the vowels behaved differently in preceding and following context, it is possible to deem the importance of phonetic place of a phoneme in a segment (Fowler & Brancazio, 2000). Also, the present study indicated strong coarticulatory effect for high back vowel /u/ than low central vowel /a/. This is incongruent with previous studies (Perkell & Nelson, 1985; Recasens & Espinosa, 2009). This can be explained based on the property of vowel production, where both /a, u/ are considered as back vowels in English, whereas, in Malayalam /a/ is low central vowel and possibility of variance is more compared to high back vowel /u/.

Coarticulatory aggressiveness is directly related to the resistance of the phoneme. Hence, it follows the same trend as explained in DAC model. Phonemes have raised tongue dorsum position and more constriction that show sheer antagonism against influence. Results reveal that the retroflexes in consonants and high front /i/ in vowel category spectacted maximum aggressiveness. Tongue dynamics of vowels were customized based on the neighbouring consonant. This was more evident when retroflexes were adjacent to vowels /a/ and /u/ (/aʈʈa/, /aɖɖa/, /uʈʈu/, /uɖɖu/). Retroflexes neighboured to other higher aggressive phoneme /i/ was interesting aspect of the study. Though direct parametric comparison is not applicable here, tongue contour of vowel /i/ was modified when it occurred in both preceding and following contexts. Tongue tip curling with wide angle of retroflexion was observed during the production of /i/. Hence, the statement of opinion is that, coarticulatory aggressiveness is more for lingual consonants than vowels. Perhaps, tongue body constriction explains the same.

Articulatory dynamic properties of speech production categorise phonemes differently. Hence, it is not always possible to conclude coarticulation as language independent aspect. It is better to explain as combination of articulatory and language property. More crosslinguistic studies are required along this line to validate this notion.

Acknowledgements

We extend our sincere gratitude to Prof. S.R. Savithri, Director, All India Institute of Speech and Hearing for permitting us to carry out this study. We also thank all the participants of our study for their kind cooperation.

References

- Articulate instrument, Scobbie, Wrench & van der Linden, 2008
- Articulate Instrument, Wrench A.A. & Scobbie, J.M. (2011)
- Bladon, R. A., W. & Nolan, F. J. (1977). A videofluorographic investigation of tip and blade alveolars in English. *Journal of Phonetics*, 5, 185-193.
- Farnetani, A., & Recasens, D. (2010). Differences in base of articulation for consonants among Catalan dialects, *Phonetica*, 67, 201-218.
- Fowler, C. A. & Saltzman, E. (1993). Coordination and coarticulation in speech production, *Language and Speech*, 36 (3), 171-195.
- Hoole, P., Gfroerer, S., & Tillmann, H. G. (1990) Electromagnetic articulography as a tool in the study of coarticulation, *Forschungsberichte des Instituts für Phonetik, Munich*, 28, 107 – 122.
- Irfana, M. & Sreedevi, N. (2016). Coarticulatory aggression and direction of coarticulation: an ultrasound study, *International journal of innovative research and development*, 5(5), 24-29.
- Kochetov, A. & Sreedevi, N. (2013). Vowel coarticulatory effect on Kannada retroflex stops. Proceedings of 10th International Seminar on Speech Production cologue, Germany.
- Kouznetsov, V.B., & Ott, A. (1987). Spectral properties of Russian stressed vowels in the context of palatalized and nonpalatalized consonants. *XIth International Congress of Phonetic Sciences*, 3, 117-120.
- Kühnert, B. & Nolan, F. (1999). The origin of coarticulation. In *Coarticulation: Theory, Data and Techniques*. W. J. Hardcastle and N. Newlett. Cambridge: Cambridge University

- Press, 7-30.
- Pols, L C. W. (1977). Spectral analysis and identification of Dutch rowels in monosyllabic words. Soesterberg: Institute for Perception.
- Recasens, D. (1985). Coarticulatory patterns and degrees of coarticulatory resistance in Catalan CV sequences. *Language and Speech*, 28, 97-114.
- Recasens, D. (1999). "Lingual coarticulation," Coarticulation, edited by W. J. Hardcastle and N. Hewlett Cambridge University Press, Cambridge, pp. 80–104.
- Sindusha, C., Irfana, M., & Sreedevi, N. (2014). Crosslinguistic comparison of angle of retroflexion and area of retroflexion using ultrasound imaging. *Proceedings of Frontiers in Research of Speech and Music*, Mysore.
- Stevens, K. N., & House, A. S. (1963). Perturbation of vowel articulations by consonantal context: An acoustical study. *Journal of Speech and Hearing Research*, 6, 111-128.
- Yeou, M. (1995). Trading relations between cues for the pharyngealized/ non-pharyngealized contrast. *13th International Conference of Physical Science*. 464-467.
- Zharkova, N. (2008). An Investigation of Coarticulation Resistance in Speech Production Using Ultrasound. PhD thesis, Queen Margaret University, Edinburgh.