Articulatory comparison of Tamil liquids and stops using Real-time Magnetic Resonance Imaging

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The Class of Liquids

Laterals & rhotics pattern together in the phonology of many languages (cluster phonotactics, allophony, assimilation, metathesis, neutralization), suggesting that they **constitute a class**. [1]

Phonetically diverse class: taps, trills, approximants, laterals. [2]

No acoustic properties common to all members of the class. [3]

Laterals & rhotics characterized by **dorsal articulatory component** in English, [4,5] Russian, [6] Squamish Salish, and Mandarin. [7]

⇒ *Are there common phonetic properties shared amongst the different types of liquid consonants which pattern together in other languages?*

Hypothesis

Production of coronal liquid consonants involves **more global coordination of lingual articulation** (tongue tip + tongue dorsum) than is required in the production of obstruents (tongue tip only). [4,6,8]

Goals of Study

Examine the articulatory characterization of laterals & rhotics in a language with a **larger, more diverse liquid inventory**:

- *how do liquids differ articulatorily from coronal obstruents?*
- *how does the dorsal articulation of liquids differ from that required in the production of retroflex consonants?*

Tamil Consonants

All varieties of Tamil contrast apical and retroflex coronal stops.

Most varieties of Tamil spoken in Madras contrast four liquid phonemes: [9]

Tamil	IPA	Gloss
கரி	/kar̪i/	*'charcoal'*
கழி	/kaɻi/	*'subtract'*
கலி	/kal̪i/	*'noise'*
களி	/kaɭi/	*'joy'*

	Lab	LD	Den	Alv	PA	Ret	Pal	Vel	
Stop	p (b)		t̪ (d̪)			ʈ (ɖ)		k (g)	
Nasal	m			n		ɳ	(ɲ)		
Affricate					tʃ (dʒ)				
Fricative				(s)					
Approximant		ʋ					j		
Rhotic				r		ɽ			
Lateral				l		ɭ			
Vowel							i,iː e,eː	a,aː	u,uː o,oː
Diphthong							aɪ		aʊ

Method: CVC Coarticulation

Exploit coarticulation inherent in speech production to investigate **intrinsic phonetic properties of consonants** (Öhman). [10]

Compare consonantal production in three maximally-contrastive intervocalic environments: [iCi] – [aCa] – [uCu].

Resistance to vocalic coarticulation: gestures intrinsic to consonant.

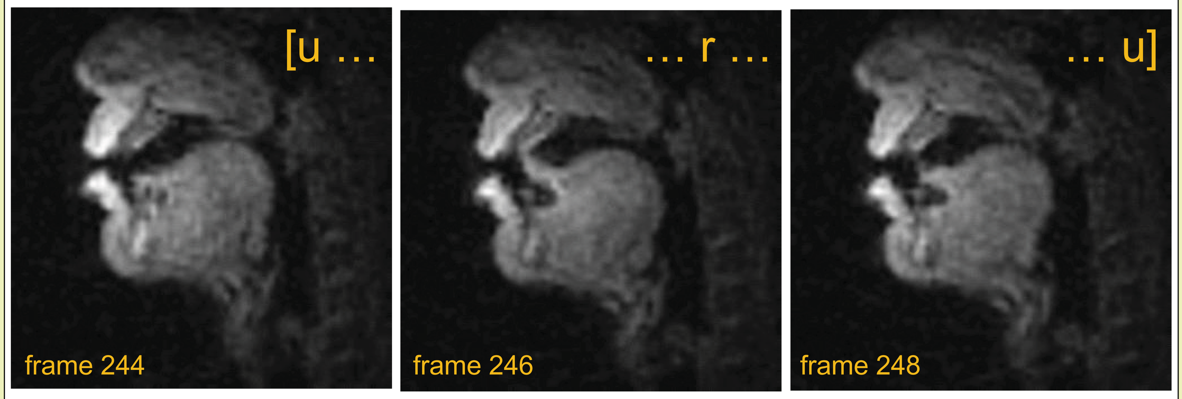
Tamil	Gloss	IPA	C	V_V	Tamil	Gloss	IPA	C	V_V
சிநேகிதி	*'girlfriend'*	[tʃineːgidi]	/d/	/i_i/	பகிடி	*'fun'*	[pagiɖi]	/ɖ/	/i_i/
பிரதிநிதி	*'envoy'*	[piradinidi]	/n/	/i_i/	திணிவு	*'mass'*	[tiɳivu]	/ɳ/	/i_i/
சிரி	*'laugh'*	[tʃiri]	/r/	/i_i/	கிழி	*'tear'*	[kiɻi]	/ɻ/	/i_i/
கிலி	*'terror'*	[kili]	/l/	/i_i/	கிளி	*'parrot'*	[kiɭi]	/ɭ/	/i_i/
கதவு	*'door'*	[kadavu]	/d/	/a_a/	கடந்த	*'late'*	[kaɖanda]	/ɖ/	/a_a/
தகநம்	*'burning'*	[taganam]	/n/	/a_a/	சணல்	*'jute'*	[tʃaɳal]	/ɳ/	/a_a/
கரடி	*'bear'*	[karaɖi]	/r/	/a_a/	கழகம்	*'society'*	[kaɻagam]	/ɻ/	/a_a/
கலன்	*'cylinder'*	[kalan̠]	/l/	/a_a/	களவு	*'burglary'*	[kaɭavu]	/ɭ/	/a_a/
முதுகு	*'back'*	[mudugu]	/d/	/u_u/	குடும்பம்	*'family'*	[kuɖumbam]	/ɖ/	/u_u/
குநு	–	[kunu]	/n/	/u_u/	முணுமுணு	*'mumble'*	[muɳu muɳu]	/ɳ/	/u_u/
குரு	*'teacher'*	[kuru]	/r/	/u_u/	குழு	*'team'*	[kuɻu]	/ɻ/	/u_u/
குலுக்கு	*'shake'*	[kulukku]	/l/	/u_u/	சுளுக்கு	*'cramp'*	[tʃuɭukku]	/ɭ/	/u_u/

Dynamic Tract Imaging: rMRI

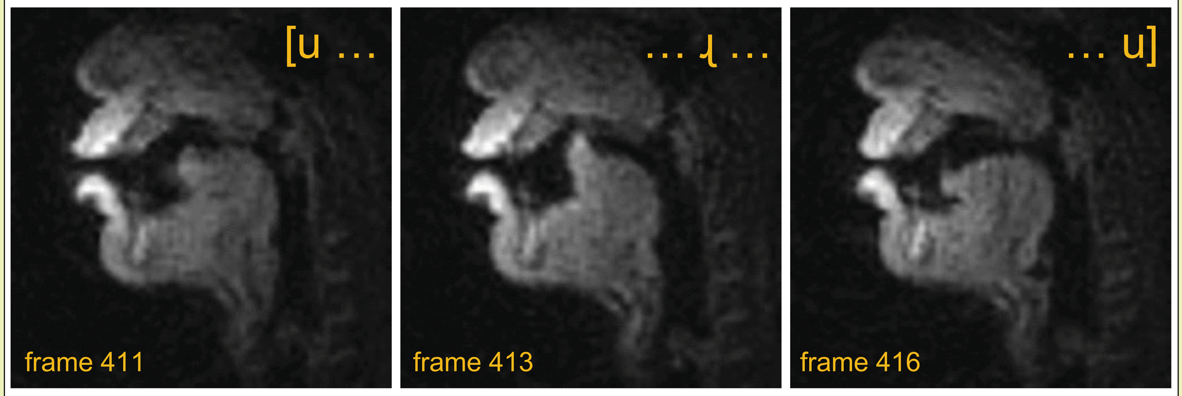
Words presented in Tamil orthography to four native speakers of Tamil from Madras (3 male: BS, SN, SR; 1 female: PR). Subjects repeated each word five times, as they lay supine in a GE Signa 1.5T scanner.

Vocal tracts dynamically imaged at 22.7Hz in the midsagittal plane using real-time magnetic resonance imaging (rMRI). [11]

Audio recorded at 20kHz using a custom optical noise-canceling microphone system; audio and video synchronized and reintegrated. [12]



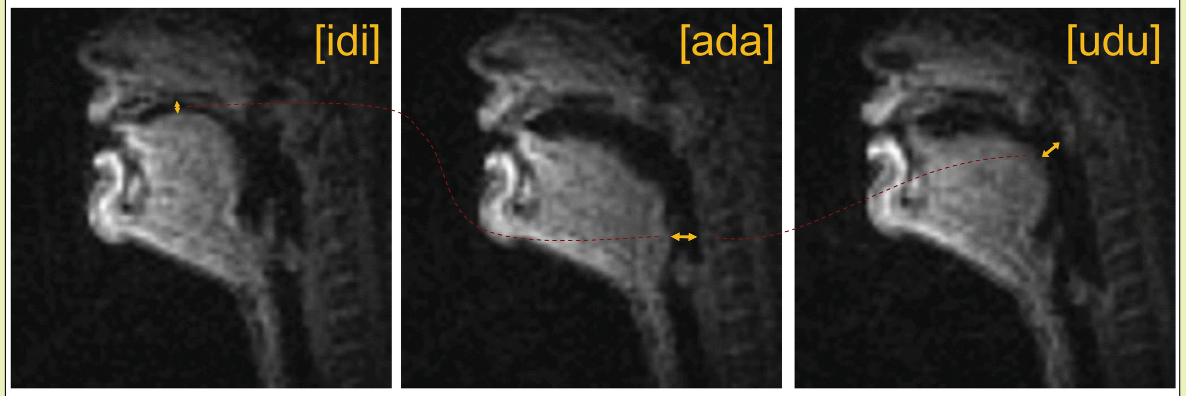
VCV sequence: dental rhotic, high back vowel context, subject SN



VCV sequence: retroflex rhotic, high back vowel context, subject SN

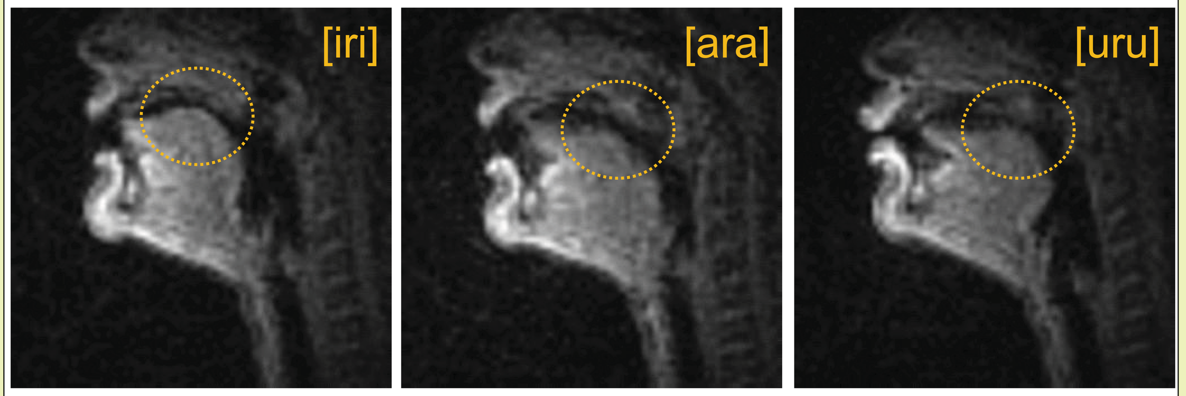
Comparison of Dorsal Articulation

Comparison of consonantal production in different vowel contexts reveals **greater degree of coarticulation in stops**, compared to liquids:



Production of dental stop (SN) in three different vowel contexts: large differences in dorsal articulation.

Production of dental lateral (SN): less difference in dorsal and pharyngeal articulation.

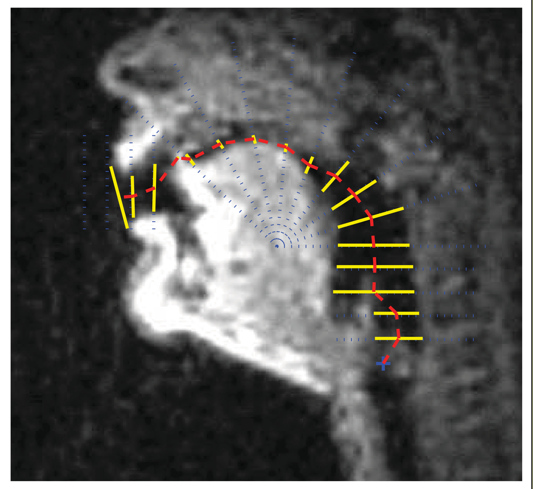


Production of dental rhotic (SN): smallest difference in dorsal articulation.

Quantifying Coarticulation

For each token in corpus:

- MRI frame corresponding to midpoint of target consonant identified, JPG exported, loaded into Matlab GUI
- anatomical landmarks selected at glottis and alveolar ridge
- analysis grid [10] constructed from landmarks, superimposed on image
- points of intersection with tract boundaries identified → vocal tract aperture function constructed

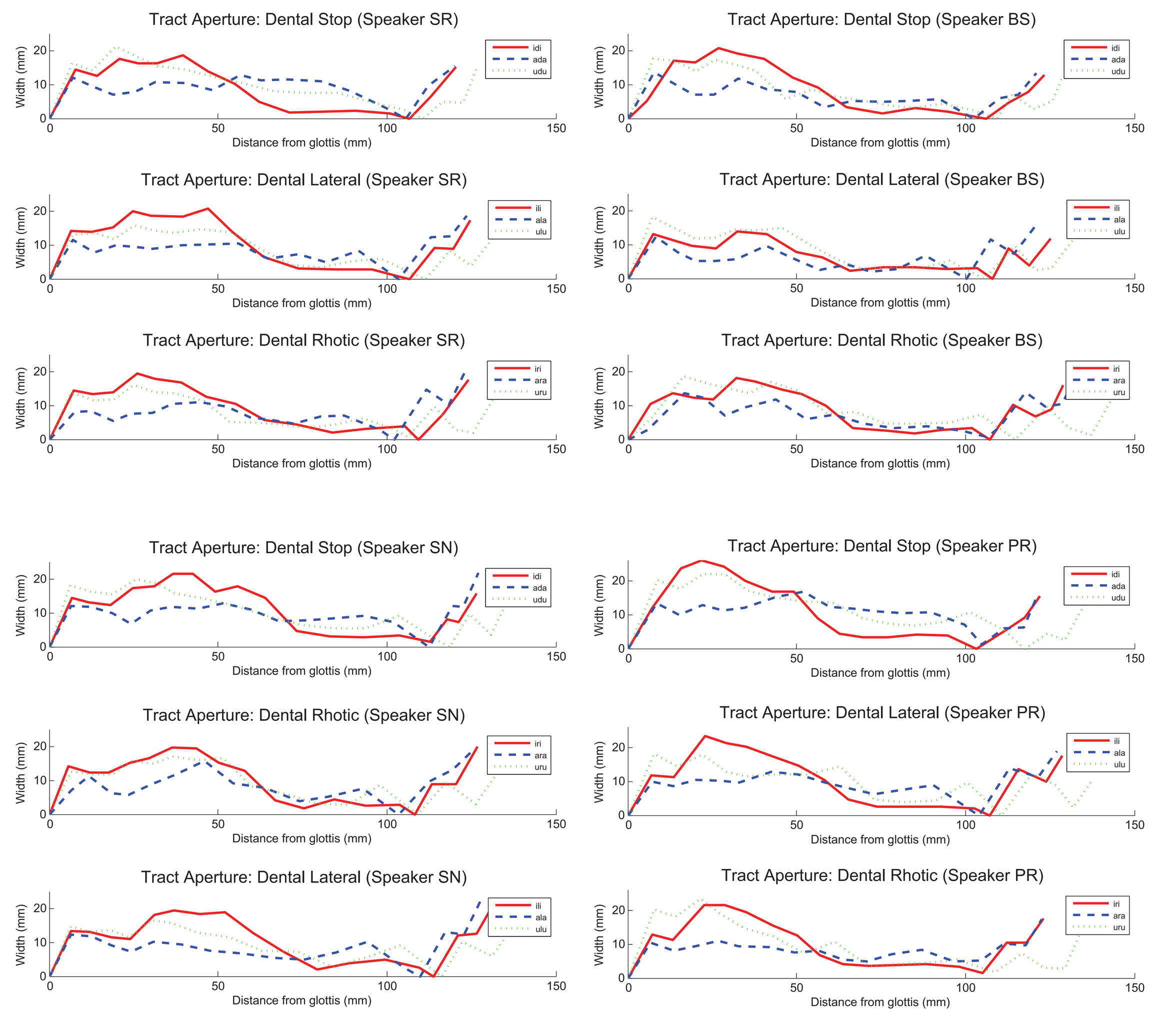


Extracting aperture function from MR Image frame: dental lateral in [kili] (subject PR)

Dorsal Articulation of Dentals

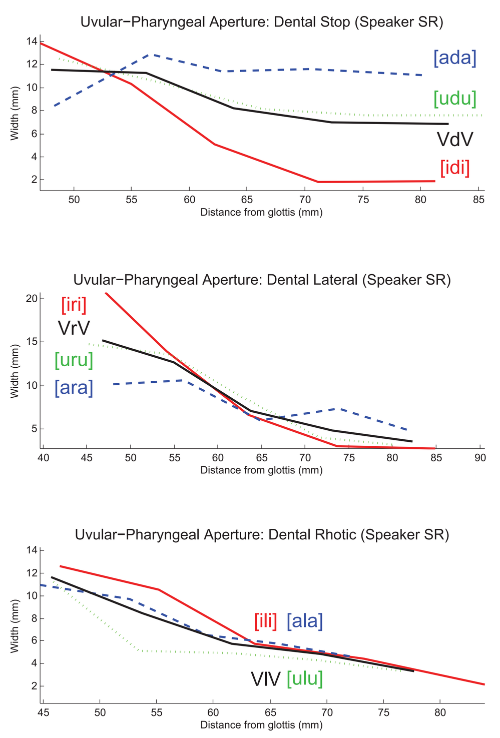
Comparison of **vocal tract aperture functions** of consonants produced in contrasting intervocalic contexts reveals:

- **higher resistance to coarticulation in liquids** cf. coronal stops
- **convergence of constrictions** for both dental rhotics and dental laterals in **upper-pharyngeal and mid-tract regions**, where dental stops show some of the greatest vocalic context effects



Convergence in production occurs in uvular-pharyngeal region (50 to 90 mm from glottis)

⇒ evidence of a **dorsal gesture** [8] inherent to liquids, absent in gestural specification of stops

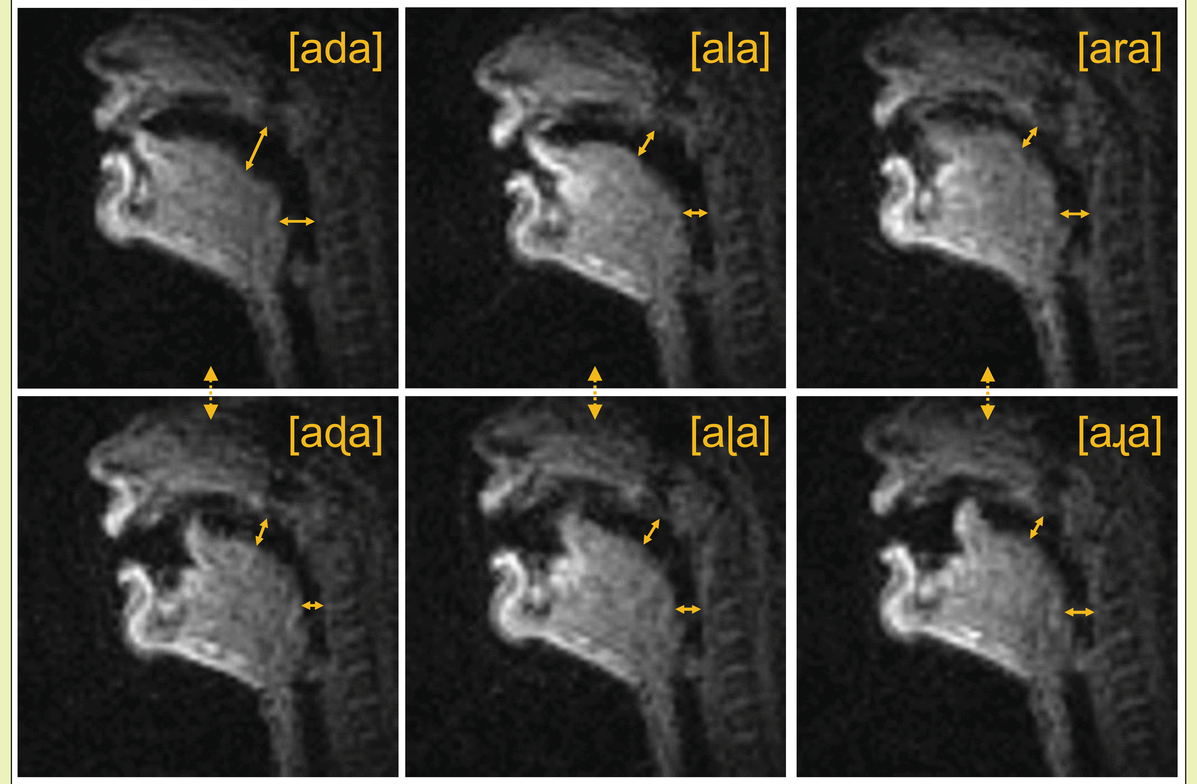


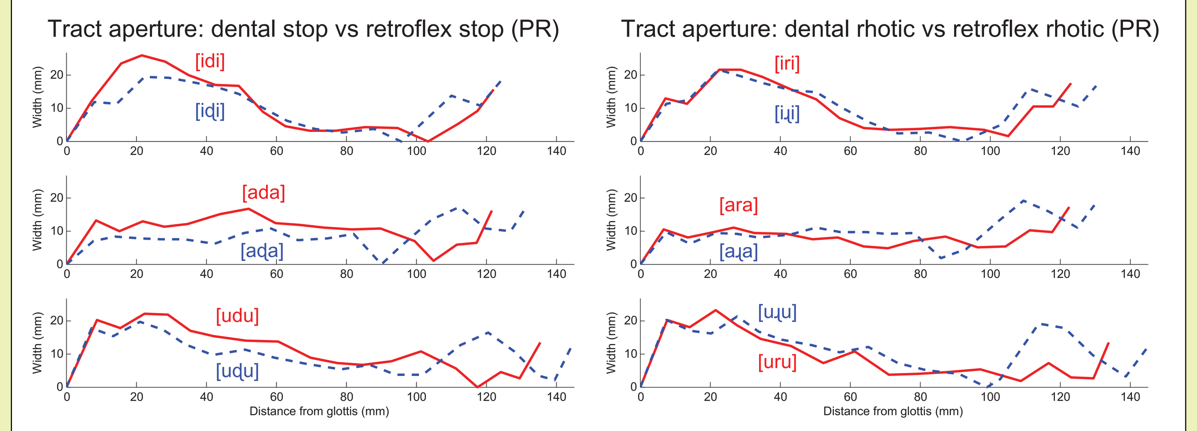
Subject	Stop	Lateral	Rhotic
PR	2.15	1.56	1.24
SN	2.53	2.15	1.84
BS	1.67	1.56	1.96
SR	2.43	1.73	0.97
Mean	2.19	1.75	1.50

Mean displacement (mm) of uvular pharyngeal region of tract (in [iCi], [aCa] and [uCu] productions) from mean articulatory configuration of dental consonants

Retroflex Liquids vs Stops

Comparison of mid-consonantal frames indicates **greater resistance to vocalic coarticulation in retroflex liquids**, compared to retroflex stops:





Larger difference in pharyngeal/uvular-pharyngeal articulation between apical and retroflex stops; smaller difference between dental and retroflex liquids

⇒ suggests dorsal/pharyngeal target inherent in liquid differs from dorsal control (bracing/ stabilization) required for retroflex production

Summary

- **greater dorsal stability** in production of liquids cf. stops
- convergent articulation in uvular-pharyngeal region in liquids, consistent with presence of dorsal gesture in uvular-pharyngeal region
- dorsal gesture appears to **differ from articulation in retroflexes**
- consistent with articulatory studies of liquids in other languages
- further analysis should **consider entire VCV sequence** (Öhman 1967)
- **phonological implications?** (clusters, word-level distribution, codas)

References

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Acknowledgements

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