A Comparative Ultrasound Study of Coronal Consonants in Arrernte and Kannada: Manner Contrasts

Marija Tabain[1], Alexei Kochetov[2], Richard Beare[3,4] & N. Sreedevi[5]

[1]La Trobe University, Australia
[2]University of Toronto, Canada
[3]Monash University, Australia
[4]Murdoch Children's Research Institute, Australia
[5]All India Institute of Speech and Hearing, India

m.tabain@latrobe.edu.au, al.kochetov@utoronto.ca, richard.beare@monash.edu, nsreedevi@aiishmysore.in

Abstract

We present ultrasound data from four speakers of the Australian language Arrernte, and ten speakers of the Dravidian language Kannada. Our focus is on the coronal consonants of these languages, and in particular on the manner contrasts (stop, nasal and lateral) for the various places of articulation. The places of articulation are dental, alveolar, retroflex and palatal for Arrernte; and dental/alveolar and retroflex for Kannada. We show that the tongue back is consistently more back for the lateral manner of articulation, and almost always more forward for the nasal manner. We discuss the possible reasons for these results.

Index Terms: ultrasound, coronal consonants, manner contrasts, Australian languages, Dravidian languages

1. Introduction

The languages of Aboriginal Australia and the Dravidian languages of India are remarkably similar in terms of phonemic structure, yet very little work has compared these two groups of languages directly. In this study we present a comparison of the relative tongue back positions for the coronal consonants of two languages, Arrernte (Australian) and Kannada (Dravidian), with a particular focus on the manner contrasts – stop, nasal and lateral – at each place of articulation. Arrernte is a language of Central Australia, spoken by about 2000 people in and around the administrative township of Alice Springs (*Mparntwe*). It has four coronal places of articulation: dental, alveolar, retroflex and alveo-palatal. The dental and palatal sounds are classified as laminal consonants, and the alveolar and retroflex sounds are classified as apical consonants [1,2].

Kannada is a Dravidian language spoken mainly in the South Indian state of Karnataka by over 35 million people [3]. The main difference within Kannada coronals is between retroflexes /ʈ ɖ ɳ ɭ/ and non-retroflexes, with non-retroflexes being either laminal dental (for stops /t̪ d̪/) or apico-laminal alveolar (for nasals and laterals /n l/) [4,5]. The set also includes alveolopalatal affricates (/ʧ ʤ/, not examined here). All these consonants occur as singletons and geminates.

In this paper, we consider ultrasound data for the stop, nasal and lateral coronal consonants in these languages. Preliminary examination of our data suggested that the differences resided primarily in the posterior half of the tongue as imaged by ultrasound, and this is therefore the portion of the tongue that we focus on in this study. However, since the Kannada non-retroflex consonants have different places of articulation according to manner – dental for the stops, and alveolar for the nasals and laterals – we do not directly compare the Kannada non-retroflex stop with the Kannada non-retroflex lateral and nasal.

2. Method

2.1. Speakers and Recordings

2.1.1. Arrernte

Seven female speakers of Arrernte were recorded to ultrasound using the Telemed Echo Blaster 128 CEXT-1Z, the Articulate Instruments stabilization helmet [6, 7], the Articulate Instruments pulse-stretch unit, and the AAA software version 2.16.07 [8]. In addition we used an MBox2 Mini soundcard, a Sony lapel microphone (electret condenser ECM-44B), and an Articulate Instruments Medical Isolation Transformer. The ultrasound machine, sync pulse, sound card and a software dongle were connected via USB to a Dell Latitude E6420 laptop running Windows software. Typical frame rate was 87 f.p.s., using a 5-8 MHz convex probe set to 7 MHz, a depth of 70 mm and a field of view of 107.7 degrees (70%). An eighth potential speaker was not recorded because we were unable to see a clear outline of her tongue.

Recordings took place either in a hotel room in Alice Springs (five speakers) or in the staff-room of the Santa Teresa school, 85 km south-east of Alice Springs (two speakers).

Speakers read a list of 92 Arrernte words designed to present the four coronal places of articulation for the oral stop, nasal and lateral consonant series. Some of these words illustrated homorganic nasal+stop, stop+nasals or lateral+stop clusters. Wherever possible, surrounding vowels were the central vowels /a/ or /ə/, which are the most common vowels in Arrernte (Arrernte has three phonemic vowels, /a ə i/, and a fourth vowel [u] which occurs as a result of rounding on a consonant – rounded consonants were avoided in the list, though were not entirely absent). Where possible, the target consonants were illustrated both in stressed and in unstressed word position (note that schwa can be stressed in Arrernte).

The words were displayed on the laptop screen. Speakers were asked to say each word three times, or as often as possible within the 5-second recording window set by the Articulate Assistant software. Some speakers were able to produce four or five repetitions in each 5-second window. Each speaker read the list through at least once, and four speakers read through the list a second time. Some speakers

chose not to produce a particular taboo word which was accidentally included on the list, and some speakers weren't sure of some words. Note also that the ultrasound machine does not begin recording until about 150 ms into the 5-second audio recording window – as a result, some repetitions were discarded because they were cut off by these limitations.

In the present study, we are only presenting data from four speakers – these particular speakers were chosen for these initial analyses because their tongue images were relatively clear for a large set of the target consonants. Note that two speakers presented in the current study were not literate in Arrernte, and were prompted by another (literate) speaker who was present in the room, and/or by the author MT providing an English gloss of the target word. One of these speakers read through the list once, and the other speaker read through the list twice.

A total of 3653 tokens were analyzed for this study. Three of the speakers had about 1000 tokens, while the fourth speaker had about 600 tokens.

2.1.2. Kannada

Ten Kannada speakers (5 females and 5 males, 21-26 years old) from Karnataka, India were recorded using a PI 7.5 MHz SeeMore probe by Interson Corporation (http://www.interson.com/) with a 90 degree field view and a depth of 10 cm at the frame rate of 15 f.p.s. The ultrasound image was displayed using the SeeMore software (version 1.3.02) on a Lenovo ThinkPad Edge E220 s laptop and synchronized with the audio (using a Sony DVDirect MC6 multi-function DVD recorder via a PC-to-TV converter) at 29.97 frames per second (the NTSC standard rate). The audio signal was captured at 48 kHz using an AT831b lavalier microphone and a Sound Devices USBPre2 pre-amp. The ultrasound probe was stabilized using Articulate Instruments stabilization helmet [6, 7].

The data were collected in a quiet room in the Speech Sciences Department at the All India Institute of Speech and Hearing, Mysore.

The materials consisted of Kannada VC:V words (where C: is geminate) with consonants of various places and manners of articulation. The current study examines manner differences in dentals/alveolars and retroflexes in the [a_a] context, involving 6 meaningful words [a̪t̪:a] 'that side', [an:a] 'cooked rice', [al:a] 'not', [aʈ:a] 'garret', [haɭ:a] 'small stream', and [aɳ:a] 'elder brother' (henceforth referred to as atta, anna, alla, aTTa, aLLa, and aNNa). The first vowel was typically pronounced as reduced in duration and raised to [ʌ]; the second vowel was a low central [a].

The words were written in the Kannada orthography and presented on a laptop screen 10 times each, with an inter-stimuli interval of 1 second. Words with geminates were selected to ensure that consonant closures were adequately captured by the ultrasound system despite the relatively slow frame rate.

A total of 591 tokens of the 6 target words (or on average 59 per speaker) were recorded, with 9 tokens skipped by some of the speakers.

2.2. Data processing

2.2.1. Arrernte

Acoustic data were labelled using the EMU speech software package [9] version 2.3, and tongue contours were tracked semi-automatically using the AAA software. Tracked tongue data were exported as text files with 42 x and y coordinates plus confidence levels (note that all confidence levels were accepted for the present study, given that much manual correction was involved in the tracking). Data were subsequently converted to Simple Signal File Format (SSFF) for compatibility with EMU. Analyses were conducted using EMU/R version 4.4, interfaced with the R statistical package version 3.1.2 [10].

2.2.2. Kannada

Individual frames were extracted from videos and the frames corresponding to consonant constrictions were identified by visual inspection with reference to the acoustic signal. Tongue contours were traced semi-automatically using EdgeTrak [11] and exported as text files with 100 x and y coordinates (with no confidence intervals).

2.2.3. Analyses

Tongue spline data were sampled at the acoustic offset of the consonant for Arrernte. For Kannada, tongue spline data were sampled at the frame with maximum consonant constriction – this tended to be the last frame of the acoustic consonant duration.

For both Arrernte and Kannada, smoothing spline ANOVAs (SS-ANOVAs) were calculated using the *gss* package in R [12]. Figures were created using the *ggplot2* package [13].

It will be recalled that all of the Kannada stimuli were inter-vocalic, whereas the Arrernte stimuli were mostly intervocalic, but also contained word-initial and -final tokens, as well as homorganic clusters. However, we chose to include all of the vocalic and prosodic contexts for the Arrernte analysis, since including only the intervocalic context for Arrernte would have left us with no data for the palatal nasal (the sequence /aˈɲə/ is a taboo word in Arrernte). We did examine the intervocalic-only data for Arrernte, and can confirm that the patterns presented below are quite similar for intervocalic context and for all contexts.

In addition, it should be noted that no attempt was made to separate the apicals (alveolar or retroflex) according to prosodic context in the Arrernte data: the apical contrast is in principle neutralized in word-initial position, and the retroflex is more prototypically retroflex when it is in unstressed position [14, 15].

Based on [16], we examined the posterior half of the tongue spline. The splines were considered significantly different if there was no overlap for over 2/3 of this portion – labelled '$>$' in the table below. A trend was defined if there was no overlap for over 1/2 of this portion of the tongue – labelled '$\geq$' in the table below). SS-ANOVA figures were examined by both the first and the second author of this paper.

3. Results

Figure 1 gives an example of tongue splines for one speaker of Arrernte, and Figure 2 gives an example of tongue splines for one speaker of Kannada. It can be seen that the rear-most 50% of the tongue for the lateral (red line) is more posterior than for the stop (blue line) and the nasal (green line) in all of these plots. In addition, for this Kannada speaker's data, it can be seen that the rear-most 50% of the tongue is more anterior for the nasal (green line) than for the stop or for the lateral, for both the alveolar and the retroflex places of articulation. However, this is not the case for the Arrernte speaker – it can

be seen that the nasal is more forward only for the dental data for this speaker, and not for the other three places of articulation.

It should also be remarked that the dental stop for the Kannada speaker in Figure 2 (and also for the other Kannada speakers not shown here) has a much flatter tongue body than the alveolar nasal and lateral – recall that the dental stop and the alveolar lateral and nasal are classified as non-retroflexes. This flatter tongue body for the Kannada dental is consistent with the flatter tongue body for the stop, nasal and lateral dentals for the Arrernte speakers (the three other speakers are not shown here). This flatter tongue body is often accompanied by a more posterior tongue back position: this is why, as we noted in the Introduction, we do not directly compare the Kannada non-retroflex stop with the Kannada non-retroflex lateral and nasal.

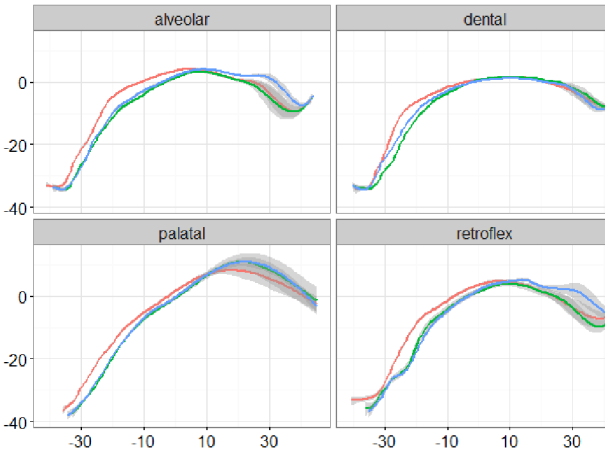
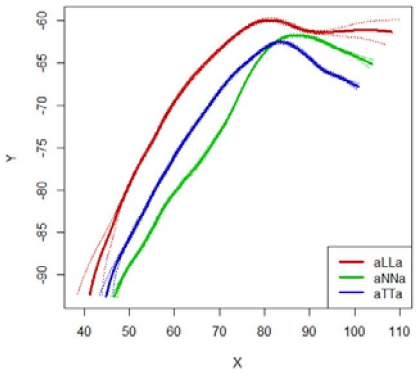


Figure 1: *Tongue contours for Arrernte speaker AF2, sampled at the offset of the consonant. The red line denotes a lateral consonant, the green line denotes a nasal, and the blue line denotes a stop. The grey shadows surrounding each contour represent the confidence intervals generated by the SSANOVA.*



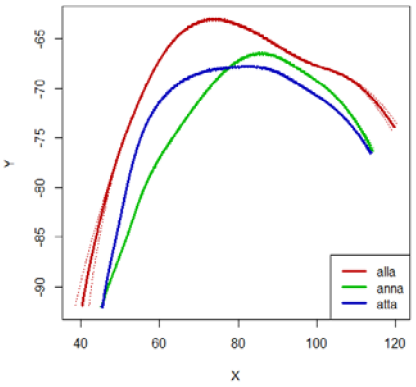


Figure 2: *Tongue contours for Kannada speaker KF2, sampled at the offset of the consonant. Top panel: dental/alveolars. Bottom panel: retroflexes. The red line denotes a lateral consonant, the green line denotes a nasal, and the blue line denotes a stop. The dotted lines surrounding each contour represent the confidence intervals generated by the SSANOVA.*

Table 1. *Classification of tongue posterior spline location for four speakers of Arrernte and ten speakers of Kannada. '>' denotes that the tongue position is more back through at least 2/3 of the rear-most 50% of the spline. '≥' denotes that the tongue position is more back through at least half (but less than 2/3) of the last 50% of the spline. '=' denotes no difference in tongue position for at least half of the rear-most 50% of the spline. 'L' denotes lateral, 'S' denotes stop, and 'N' denotes nasal. Cells in red denote a pattern that does not fit in with the dominant pattern.*

Arrernte	**Dental**	**Alveolar**	**Retroflex**	**Palatal**
AF1	L > S = N	L > S = N	L > S = N	L > S = N
AF2	L > S > N	L > S = N	L > S = N	L > S = N
AF3	L = S > N	L > S = N	L > S = N	L = S = N
AF4	L > S = N	L > S = N	L > S = N	L > S > N
Kannada		**Alveolar**	**Retroflex**	
KF1		L > N	S > L > N	
KF2		L > N	S > L > N	
KF3		L > N	N > L = S	
KF4		L > N	L > S > N	
KF5		L > N	S = N ≥ L	
KM1		L > N	L > S > N	
KM2		L > N	L > S > N	
KM3		L > N	L = S > N	
KM4		L > N	L > S = N	
KM5		L > N	L = S = N	

Table 1 provides a list of the relative placement of the tongue back for the stop, nasal and lateral positions for each place of articulation, for each speaker. It can be seen that for Arrernte, the lateral manner is more posterior than the nasal manner (L > N) for 14 out of the 16 comparisons, and more posterior than the stop manner (L > S) for 15 out of the 16 comparisons. By contrast, the stop manner is more posterior than the nasal manner for only three of the 16 comparisons (S

> N) – in all other cases, there is no difference between the stop and the nasal (S = N).

For the Kannada comparisons, it can be seen that the lateral is posterior to the nasal for all ten of the alveolar comparisons (L > N). The same is true for seven out of the ten retroflex comparisons (the three exceptions are marked in red, with one exception showing no difference between lateral and nasal, and the other two exceptions showing the reverse pattern). By contrast, the relative placement of the stops in this tongue back placement hierarchy varies greatly from speaker to speaker – nevertheless, it can be remarked that the stop is posterior to the nasal (S > N) in six out of ten cases. However, lateral is posterior to stop (L > S) for only four out of ten cases, with three cases showing no difference between the two (L = S). In three cases, stop is posterior to lateral (S > L).

4. Conclusion

There is a strong preference for the tongue back to be further forward for the nasal than for the lateral consonants, for all places of articulation. This may be due to the need to avoid contact between the tongue back and the velum, which has been lowered in order to allow airflow through the nasal cavity. As pointed out by Fant [17], it is possible for the back of the tongue to contact the centre of the uvula during nasal consonant production, with air flowing along the sides of this connecting point — this may occur, for example, with a high tongue position and a fully lowered velum. Such a configuration may set up a different set of oral and nasal resonances, which may not be desirable in the case of a place-rich consonant system [18]. By contrast, the hydrostatic nature of the tongue may mean that as the tongue sides are lowered for lateral production, the back of the tongue is pushed further back to compensate for this – or perhaps, lateral production involves active elongation of the tongue by dorsal retraction [19].

What is not clear in our study is the relative placement of the stop manner of articulation in the hierarchy of tongue back placements. Whilst in Arrernte there is a tendency for the stops to pattern with the nasals, this is not quite so clearly the case for Kannada. Whether these differences are genuine differences in the languages, or whether they are an artefact of the different methodologies that we used for data collection in the two languages, is a question for future studies.

5. Acknowledgements

We would like to thank our Arrernte and Kannada speakers for their interest in language work; Gavan Breen and Midula Kasim for assistance with participant recruitment and data collection, and Casey Tait for (Arrernte) data annotation. This research was supported by an Australian Research Council Future Fellowship to Marija Tabain, an All-India Institute of Speech Hearing (AIISH) Research Fund to Dr. N. Sreedevi and Alexei Kochetov, and a Social Sciences and Humanities Research Council of Canada Standard grant to Alexei Kochetov. Ethical approval for this research was granted at La Trobe University, at AIISH, and at the University of Toronto.

6. References

[1] G. Breen and V. Dobson. "Central Arrernte," *Journal of the International Phonetic Association,* vol. 35, pages 249-254, 2005.

[2] J. Henderson, *Topics in Eastern and Central Arrernte grammar*. Lincom Europa: Germany, 2013.

[3] M. Lewis. (ed.). *Ethnologue: Languages of the world*, 16th edition. Dallas, TX: SIL International. Online version: http://www.ethnologue.com/. 2009.

[4] H. Schiffman, H. *A reference grammar of spoken Kannada*. Seattle: University of Washington Press. 1983.

[5] U. P. Upadhyaya, *Kannada phonetic reader*. Central Institute of Indian Languages, Mysore. 1972.

[6] Articulate Instruments Ltd., *Ultrasound Stabilisation Headset Users' Manual: Revision 1.4*. Edinburgh, UK: Articulate Instruments Ltd., 2008.

[7] J. Scobbie, A. Wrench, A., and M. van der Linden. "Head-probe stabilization in ultrasound tongue imaging using a headset to permit natural head movement," *Proceedings of the 8th International Seminar on Speech Production*, pp. 373-376. 2008.

[8] Articulate Instruments Ltd., *Articulate Assistant Advanced User Guide: Version 2.14*. Edinburgh, UK: Articulate Instruments Ltd., 2012.

[9] J. Harrington, *The Phonetic Analysis of Speech Corpora*. Blackwell, 2010.

[10] R Core Team "R: A language and environment for statistical computing. R Foundation for Statistical Computing," Vienna, Austria. URL http://www.R-project.org/, 2014.

[11] M. Li, C. Kambhamettu and M. Stone. "Automatic contour tracking in ultrasound images," *Clinical Linguistics and Phonetics, 19*, 545–554. 2005.

[12] C. Gu, "Smoothing Spline ANOVA Models: R Package gss," *Journal of Statistical Software*, vol. 58(5), pages 1-25. URL http://www.jstatsoft.org/v58/i05/, 2014.

[13] H. Wickham. *ggplot2: Elegant Graphics for Data Analysis.* Springer-Verlag New York, 2009.

[14] M**.** Tabain and R. Beare. "An EPG and EMA study of apicals in stressed and unstressed position in Arrernte," *18th International Congress of the Phonetic Sciences.* Glasgow: Scotland, 2015.

[15] M. Tabain. **"**An EPG study of the alveolar vs. retroflex apical contrast in Central Arrernte," *Journal of Phonetics,* vol. **37,** pages 486-501, 2009.

[16] A. Kochetov, N. Sreedevi, M. Kasim and R. Manjula. "Spatial and dynamic aspects of retroflex production: an ultrasound and EMA study of Kannada geminate stops," *Journal of Phonetic, 46,* 168-184. 2014.

[17] G. Fant, *Acoustic Theory of Speech Production,* 2nd ed. (Mouton, The Hague), 1970.

[18] M. Tabain, A. Butcher, G. Breen and R. Beare, "An acoustic study of nasal consonants in three Central Australian languages," *Journal of the Acoustical Society of America, 139,* 890-903, 2016.

[19] P. Ladefoged & I. Maddieson, *The Sounds of the World's Languages.* (Blackwell: Oxford, UK ; Cambridge, Mass.), 1996.