Articulatory Modelling of Coronal Stop Contrasts in Wubuy

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Abstract

Like many Australian languages, Wubuy (aka Nunggubuyu) uses four contrastive coronal stops. The phonological basis of this contrast is not well understood, as it is not known to what extent phonological primitives are grounded in the phonetic domain. We introduce a preliminary gestural computational model of Wubuy phonology being developed as an extension of the Task Dynamics Application (TaDA: [1, 2]). Coronal stops are modeled as recurrent dynamic structures of coordinative tongue tip and tongue body gestures, contrasting in constriction degree and location. Articulatory kinematics produced by gestural models are qualitatively compared with EMA data obtained from a Wubuy speaker producing the same segments. The implications of these experiments for theories of phonological representation are discussed.

Index Terms: Wubuy, Nunggubuyu, coronal, stop consonant, apical, laminal, gesture, articulatory phonology

1. Introduction

Describing the distribution and behaviour of the stop consonants found in Australian languages has proven to be problematic for phonological theory. While lingual stops are traditionally defined in terms of their primary place of articulation [3], Australian coronal stops – which exploit multiple contrastive lingual postures articulated within a small region of the anterior part of the oral cavity – appear to be better categorized as *apical* or *laminal*. Some languages contrast a single apical with a single laminal (Dyirbal, Yidiny), others contrast two apicals (Western Desert, Warlpiri), or two laminals (Guugu Yimidhirr, Wik-Munkan), while still other languages use a four-way contrast between two different apical and two different laminal stops (Pitta-Pitta, Kaititj) [4].

		Apical		Laminal		
	Lab	Alv	Retr	Dent	PAlv	Vel
Stop	b	d	rd	dh	dy	g
Nasal	m	n	rn	nh	ny	ng
Lateral		l	rl	lh		
Approx	w		r		y	
Trill		rr				

Table 1: **Phonologically contrastive consonants of Wubuy**.

Wubuy (a Gunwingguan language of east Arnhem Land) is of particular interest in that it retains a four-way coronal contrast in word-initial position, as well as intervocalically [5]. The consonant inventory of Wubuy is given in standard orthography [4] in Table 1. The phonetic realization of the stop series d-rd-dh-dy has been described as /t/-/ʈ/-/t̪/-/c/, based on observations of speakers [6, 5], acoustic analysis [7], and analogy with other Australian languages [4, 8]. The first articulatory studies of Wubuy, as far as we are aware, were reported in [9, 10, 11].

1.1. Capturing Coronal Contrasts

A variety of features have been proposed to capture the four-way distinction among coronal stops, including [±DISTRIBUTED], [±PERIPHERAL], [±ANTERIOR], [±INTERDENTAL], [±LAMINAL] and [±RETROFLEX] [4, 8], yet phonological descriptions based on these primitives have not been able to offer a unified account of the range of processes which these consonants participate in, such as neutralization in certain phonological environments [12, 13]. Furthermore, it is not clear that a given feature set can be applied universally to all languages which exploit similar coronal contrasts, or whether the hypothesised features would have the same phonetic manifestations across languages.

Butcher [14] has characterized the phonetic basis of coronal contrasts in 14 Australian languages, and Tabain [15] and Henderson [16] have examined these contrasts in further detail amongst speakers of Arrernte. The picture which emerges from these studies is that Australian coronal contrasts cannot be adequately described using purely static phonological primatives. Baker and Harvey [13] propose that phonological models of retroflex segments should distinguish between transition and release phases, and Harvey and Baker [17] argue that characterisations of coronals in terms of tongue shaping are more cross-linguistically robust than representations which make reference to passive articulators or anteriority.

1.2. Gestural Modelling of Coronal Contrasts

The hypothesis being examined in our work is that Australian coronal consonants are better characterized as epiphenomenal segments produced through the coordination of tongue-tip (TT) and tongue-body (TB) gestures. In the framework of Articulatory Phonology [18], lexical items are represented as constellations of coordinated gestures. Under this model, coronal contrasts result not from abstract distinctive features, but from the articulation of coordinated *dynamic* structures of coronal and dorsal gestures with different constriction specifications.

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[10] found support for a gestural model of syllable structure in Wubuy, in a study of prosodic context effects on acoustic differentiation of coronals. [9, 11] found that global tongue action differentiated the production of laminals (forward thrust of TT+TB) from apicals (TB stabilization + TT extension), while within-class contrasts resulted from additional differences in tongue-tip kinematics. Representing such intrinsically dynamic phonological contrasts in terms of static geometries of distinctive features is problematic, but warrants further investigation within a gestural framework. In the work described here, hypotheses about phonological representations are tested by comparing the results of TaDA simulations against articulatory phonetic data acquired from Wubuy speakers producing the same utterances.

2. Modeling Phonological Representations using TaDA

The Task Dynamics Application (TaDA: [1, 2]) is an integrated software suite consisting of three interconnected components: (i) a syllable-based gestural coupling model, (ii) a coupled oscillator model of inter-gestural coordination, and (iii) a Task Dynamic model of inter-articulator coordination. Because TaDA was originally developed as a model of English phonology, an extension of the software suite was developed to experiment with articulatory representations of Wubuy words, input using standard Australian language orthography [4].

In the TaDA model, an input utterance is decomposed into a hypothesized set of gestures, represented as an intergestural coupling graph that specifies the coupling relations among the gestures' timing oscillators. From the coupling graph, a gestural score is generated, specifying activation intervals in time for each gesture. The motions of the vocal tract constriction variables are then calculated from the gestural score, and an acoustic representation of the modelled utterance is synthesized from the simulated vocal tract parameters [19].

2.1. Gestural Specification

Gestures are defined in TaDA using a polar coordinate system. For each tract variable, a constriction degree (CD) is specified as the target aperture (mm) to be attained at a given constriction location (CL), specified in degrees, where 40° represents a dental constriction, and 180° a pharyngeal constriction (Fig. 1).

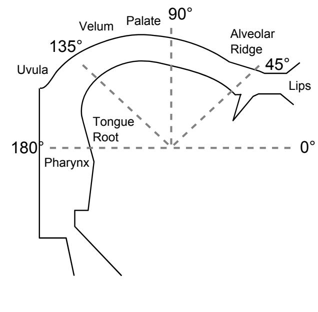

Figure 1: **Coordinate system used for specification of gestural parameters in TADA simulations of Wubuy coronals**.

2.2. Simulation of Wubuy Coronal Articulation

Articulatory data were obtained from a three-dimensional EMA study of three female speakers of Wubuy [9, 10]. Lingual articulation during production of coronal consonants in a low vowel context (aCa sequences) was examined. Hypothesised gestural specifications were proposed for each of the Wubuy coronal stops, and tested by calculating the articulatory trajectories produced by these models in TaDA simulations of VCV sequences, comparing the results of the simulations with the EMA data.

Coronal models were refined by iteratively adjusting gestural specifications to minimise the observed differences between the simulated and measured mid-sagittal lingual trajectories.[1] Two criteria were used to assess the validity of the model simulations:

i. *global lingual configuration during mid-consonantal production*: does the tongue shape at the point of maximum constriction resemble that observed in the articulatory data?

ii. *dynamic lingual trajectories*: do the tongue body and tongue tip approach and release from the consonantal constriction in the same directions and with the same pattern observed in the articulatory data?

A preliminary set of gestural parameters for the Wubuy oral stop series is proposed in Table 2. In these models, it is hypothesised that Wubuy stops are differentiated by (i) location of the tongue tip constriction, (ii) aperture of the accompanying tongue body gesture, and (iii) the spatial coordination of the tongue tip and tongue body gestures. All gestures intrinsic to the stop were specified to be synchronous (0° phasing). Onset consonants were phased 0° with homosyllabic vowel gestures, and 180° with the nucleus gesture of the preceding syllable.

SEGMENT	TONGUE TIP		TONGUE BODY	
	TTCL	TTCD	TBCL	TBCD
d	56	-2	100	10
rd	60	-2	95	15
dh	35	-2	80	10
dy	40	-2	95	10

Table 2: **Hypothesised Tongue Tip (TT) and Tongue Body (TB) gestural specifications: Wubuy coronal stops**.

3. Results

3.1. Apicals

Lingual trajectories for TaDA models of Wubuy sequences ada and arda are shown in Figs. 2 and 3 respectively, where they are compared with EMA data showing productions of the same tokens by speaker W3.[2] The model simulations capture the common mid-consonantal articulatory configuration of the apical stops – the presentation of a restricted region of the tongue tip to the roof of the mouth – as well as the difference in place of articulation which distinguishes the two segments in the class. The mid-consonantal lingual configuration of the simulated intervocalic retroflex also exhibits a lowered tongue body in the palatal region, which matches that observed in the EMA data

[1] Various methods of automatic model optimization – iteratively refining gestural specifications so as to minimze the error between simulated and observed lingual trajectories – were explored; however, these approaches were unfruitful because of problems with quantifying error and accounting for differences in palate shape.

[2] Subject W3, although missing some upper dentition, had lived in Numbulwar since birth, had no tongue-sensor tracking problems, and most consistently produced articulatorily contrastive tokens of the four stops, which were therefore used as prototypes for this experiment [11].

obtained from speakers W2 and W3 [11].[3]

The TaDA simulations also capture another important characteristic of Wubuy apical retroflex production: asymmetries between constriction formation and release [11]. While the tongue tip and tongue blade follow a trajectory which is largely perpendicular to the passive articulators during the production of the laminal stops, EMA data reveal that retroflex apical production involves different tongue tip kinematics for approximation and release, and that this movement is sometimes transverse to the alveolar ridge.[4] The TaDA simulations of intervocalic consonant production based on the hypothesised gestural models captures the same broad patterns of tongue tip motion as that observed in the EMA studies (Fig. 3).

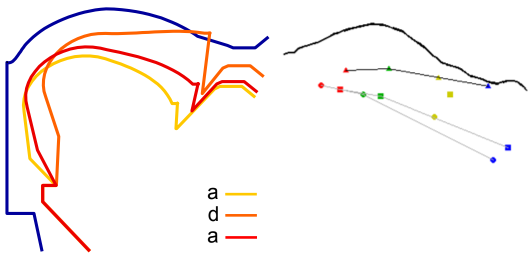

Figure 2: **Simulated and measured lingual trajectories for Wubuy alveolar apical in a low vowel context: *ada*.** *Left*: simulated midsagittal articulation at three points in time: (i) pre-consonantal vowel, (ii) mid-consonant, (iii) post-consonantal vowel. *Right*: Splines fit through mean midsagittal EMA pellet positions at equivalent time points (Speaker W3).

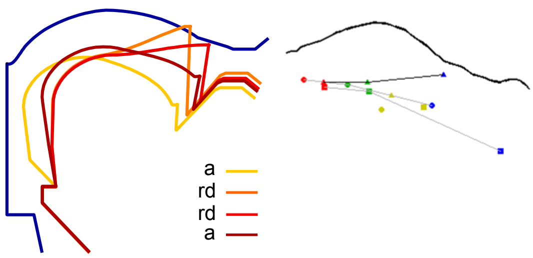

Figure 3: **Simulated and measured lingual trajectories for Wubuy retroflex apical in a low vowel context: *arda*.** *Left*: simulated midsagittal articulation at four points in time: (i) pre-consonantal vowel, (ii) VC transition, (iii) consonantal release, (iv) post-consonantal vowel. *Right*: Splines fit through mean midsagittal EMA pellet positions at equivalent time points (Speaker W3).

3.2. Laminals

Lingual trajectories for TaDA models of Wubuy sequences adha and adya are shown in Figs. 4 and 5 respectively, where they are compared with EMA data showing productions of the same tokens by speaker W3. The simulations capture the broad lingual configurations at the point of maximum lingual constriction, and the basic dynamics of formation and release. The distributed palatal constriction which characterises *dy*, and the more anterior place of constriction of *dh* have been modelled.[5]

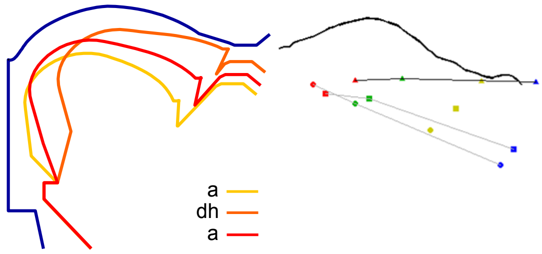

Figure 4: **Simulated and measured lingual trajectories for Wubuy dental laminal in a low vowel context: *adha*.** *Left*: simulated midsagittal articulation at three points in time: (i) pre-consonantal vowel, (ii) mid-consonant, (iii) post-consonantal vowel. *Right*: Splines fit through mean midsagittal EMA pellet positions at equivalent time points (Speaker W3).

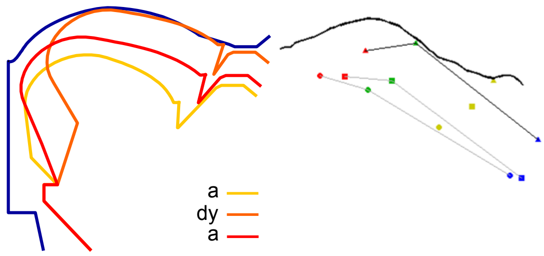

Figure 5: **Simulated and measured lingual trajectories for Wubuy postalveolar laminal in a low vowel context: *adya*.** *Left*: simulated midsagittal articulation at three points in time: (i) pre-consonantal vowel, (ii) mid-consonant, (iii) post-consonantal vowel. *Right*: Splines fit through mean midsagittal EMA pellet positions at equivalent time points (Speaker W3).

4. Discussion

The results of these preliminary experiments are consistent with the hypothesis that the Wubuy coronal stop series can be modelled as a set of recurrent dynamic structures of lingual gestures in which phonological contrast results from differences in the aperture, location and coordination of tongue body and tongue tip constrictions.

4.1. Specifying Phonological Contrasts

These experiments raise some important questions about the relationship between phonological contrasts and their phonetic manifestations, and the ways in which these contrasts are described. New techniques of phonetic investigation are beginning to reveal greater detail about the variety of vocal tract configurations employed during the articulation of coronal consonants across languages [20]. The retroflex stop used in Tamil (Fig. 6), for example, differs considerably from that of Wubuy,

[3] Although two of the three Wubuy speakers produced clearly differentiated apical stops, no consistent constrast was observed among the stops produced by Wubuy speaker W1, whose apicals appear to have neutralised in most phonological environments [11].

[4] A small difference in tongue tip kinematics of this nature could also be observed for speaker W1.

[5] It is a limitation of the semi-polar reference system that a more anterior constriction cannot be specified for the (inter)-dental laminal; however, it must be noted that the highly fronted production shown for speaker W3 might partly result from her missing front teeth [11].

in terms of timing and place of articulation, lingual posture, degree of retroflection, and acoustic characteristics [21], yet these two consonants are typically described with the same segmental label /ʈ/, or the same set of distinctive features, e.g. [−PERIPHERAL], [−LAMINAL], [+RETROFLEX] [4], or [−ANTERIOR], [−DISTRIBUTED] [22]. In the Task Dynamic framework, Tamil and Wubuy retroflexes would be specified using different sets of language-specific parameters: categorical phonological contrasts, described in terms of gestural primitives whose interactions are lawfully determined by articulatory dynamics, reflecting those observed in real world data.

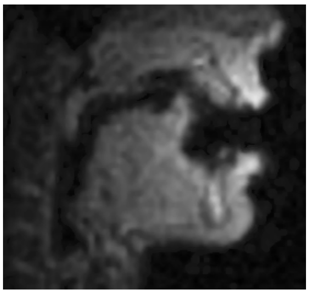

Figure 6: **Tamil retroflex coronal stop** produced in a low vowel context /aʈa/ by an adult male speaker of Standard Madras Tamil. (Data courtesy of USC SPAN group).

4.2. Future Directions

This work is primarily intended as a proof of concept that phonological contrasts in Australian languages can be represented using gestural primitives. The models presented here represent merely a first step towards the development of an empirically grounded account of coronal contrasts in Wubuy and other languages which use similar phonological contrasts.

An important step in the development of a complete phonological model will be to consider the ways in which the laterals differ from the stops in Wubuy, and how these contrasts might be represented in gestural terms. It may well be the case that it is not possible to capture the salient distinctions between such a rich set of laterals and coronal stops using the current set of tract variables, which are restricted to the midsagittal plane.

Goldstein et al. (1989) have proposed the use of a Tongue Tip Constriction Orientation (TTCO) tract variable, which might serve as an additional parameter of tongue shaping that could be used to differentiate between the wide variety of lingual configurations observed amongst retroflex consonants in Wubuy, Tamil, Mandarin, Swedish and Hindi, for example.[6] Another tract variable specifying degree of lingual lateralization in the coronal plane might be required to describe the full set of phonological contrasts used in Wubuy and other languages with rich lateral inventories.

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[6] Although it remains to be seen if all of these contrasts might be described using only tongue tip and tongue body gestural specifications, as in the examples described in these experiments.

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