Coordination of tongue tip and body in place differences among English coronal obstruents

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Abstract

Using electromagnetometry tracking of the tongue, Best et al. (2010, 2014) have demonstrated that Wubuy, an Australian language with four coronal stop places, shows significant differences in tongue tip vs. tongue body motion range and motion coordination contrasting apicals and laminals. Here we continue this line of inquiry with three coronal obstruents in English, the apical alveolar stop /d/ and alveo-palatal affricate /d͡ʒ/ vs. the laminal dental fricative /ð/. The results show support for tongue tip/body motion range differences between /d/ and /ð/ across vowel contexts. They also showed a tongue tip/body motion coordination distinction between the apical /d/ and laminal /ð/, which was significant for /i/ and /u/ but not /a/ contexts. Results are consistent with the Wubuy findings (Best et al, 2010, 2014) despite the differences in the coronal obstruent contrasts of the two languages, suggesting an apical/laminal distinction in tongue tip/body coordination.

Keywords: articulatory phonology, coronal obstruents, apical-laminal distinction, tongue tip/body coordination

1. Introduction

Of all the speech articulators, the tongue tip is the most flexible and versatile for production of obstruent consonants, that is, stops, affricates and fricatives. This flexibility is evidenced by the huge variety of tongue-tip, or *coronal*, consonants that exist cross-linguistically. Importantly, however, languages also vary widely in which coronal obstruents they use contrastively, as well as in the phonetic realizations of those coronals, which can vary notably even within a language (e.g., among regional accents or specific talkers or contexts). A fundamental issue, then, is the interplay between the universal and language-specific forces that underlie the way coronals are produced. One well-accepted characteristic of coronal obstruents that would lend itself to examining universal vs. language-specific properties is the distinction between apicals, with tongue tip constriction, and laminals, with anterior tongue blade constriction (Butcher & Tabain, 2004; Flemming, 2003). It has also been proposed that the apicals are distinguished from the laminals by tongue tip orientation – up for apicals, and down for laminals (Browman & Goldstein 1989). Both analyses focus on tongue tip only.

But despite the versatility of the tongue tip, its spatial and temporal motion is necessarily constrained by the positioning of the tongue body because the tip (including the blade just behind the tip) is of course attached to the body, and thus its motion is at least partially determined by the posture and motion of the tongue body. Therefore, an important and possibly universal characteristic of coronal consonants should be the dynamic coordination between tongue tip and tongue body movements.

Here we examine possible universal vs. language-specific characteristics of the time-varying coordination between the tongue tip and the tongue body during coronal obstruent production. At one extreme are languages such as Wubuy (Nunggubuyu), an Australian language that uses a very rare four-way coronal place distinction within the stop manner class: two apicals (alveolar [t], retroflex [ʈ]), and two laminals (dental [t̪], postalveolar [c]). In an electromagnetic articulometry (EMA) study of Wubuy coronal stop production, which tracked mid-sagittal flesh-points on tongue tip and tongue body, Best et al. (2009; 2010; 2014) found that tongue tip/tongue body motions are more tightly coupled for laminals than for apicals, which use a more stabilized TB to support lever-like actions by the TT.

1.1. The Present Study

But few languages constrain coronal production *within a single manner class* in such a crowded place of articulation space. Therefore we decided to test whether this pattern holds for English, which has only a three-way (voiced) coronal obstruent contrast, as represented by the alveo-palatal affricate /d͡ʒ/, alveolar stop /d/, and dental fricative /ð/. (see Figure 1).

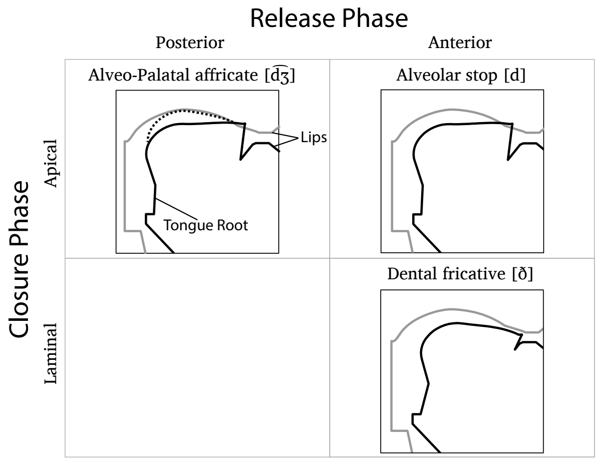

Figure 1: *English coronal obstruents in a 2 x 2 matrix contrasting apical vs. laminal closure by anterior vs. posterior release. NOTE: we schematize the alveo-palatal affricate as having apical anterior closure (solid line) but laminal posterior release (dashed); closure and release are congruent for [d] and [t] (solid line only. Figures based on those in the Proctor et al. (2010) modeling study of Wubuy coronal stops.*

English has many other coronal obstruents: /t/ and /s/ are anterior apicals like /d/; /θ/ is an anterior laminal like /ð/; /ʃ/, [ʒ] are posterior laminals; and /t͡ʃ/ has apical anterior closure with laminal posterior release like /d͡ʒ/. However, none of them display the posterior apical or laminal closure+release of of the Wubuy retroflex [ʈ] and post-alveolar [c], respectively...

More importantly, the place of articulation differences among the three English coronal consonants are confounded with manner of articulation differences, specifically, apical is confounded with stop manner[1] and laminal with fricative manner[2] Thus, the same type or degree of apical/laminal organization of tongue tip and tongue body might not be as clear in English as it seems to be in Wubuy because of the added production/perceptual cues that result from these different manners of production. Therefore, we ask whether anything like the tongue tip/body coordination that appears to define the apical vs. laminal distinctions observed in Wubuy is also seen in production of these English coronals.

1.1.1. Hypothesis 1

If the apical/laminal difference in tongue tip-tongue body coordination is universal, then it should differentiate English apical /d/ and possibly /d͡ʒ/ from laminal /ð/, analogous to Wubuy apical versus laminal coronal stops.

1.1.2. Hypothesis 2

But if contrastive tongue tip-tongue body coordination is language-specific (e.g., distinguishing coronal places *within* a manner class), then it may not reliably differentiate among English /d/-/d͡ʒ/-/ð/.

2. Methods

Nine native English speakers participated, aged between 20 to 61 years old. There were 4 females and 5 males. There were 4 American and 5 Australian English speakers.

Participants were tested at the speech production lab of the University of Western Sydney's MARCS Institute. They were seated in a non-metallic chair sitting beside the NDI WAVE articulometer, where wired magnetic sensor coils were taped over their left and right mastoids and nasion. Sensors were glued along the mid-sagittal line to their tongue body about 2 cm away from the circumvallate papillae (to avoid the gag reflex), about 1 cm from their tongue tip, and in between the two at the tongue blade. Sensors were also glued to the gum below their lower incisors, and on the border at the centers of their upper and lower lips.

Participants read aloud 10 blocks of sentences, presented on a computer screen via DMDX. Each block contained /d/, /d͡ʒ/ and /ð/ in /aCa/, /iCi/ and /uCu/ contexts (Table 1), in the carrier phrase "Now I want a _____ around her." The target items and carrier were designed to be phonetically comparable to the Wubuy target items (Best et al, 2010; 2014). Occlusal plane and palate traces were then collected.

Table 1: Tokens examined

Dental Fricative	*Alveo-palatal Affricate*	*Alveolar Stop*
maða	*mad͡ʒa*	*mada*
miði	*mid͡ʒi*	*midi*
muðu	*mud͡ʒu*	*mudu*

2.1. Data analysis

We corrected for head motion using the data from the nasion and mastoid reference censors, and rotated the dataset to the occlusal plane so that the heads all faced the same direction (right).

To test our hypotheses, we performed the same two measures on the EMA data for tongue tip and body gestures as had been developed for the Wubuy study (Best et al., 2014): i) a short term velocity correlation (Velocity correlation) between tongue tip and tongue body motion during the tongue tip gesture; and ii) a range of motion comparison (Quad Ratio) between tongue tip and tongue body during the period of the tongue tip gesture. In Wubuy, apicals have a lower Velocity correlation and higher Quad Ratios than laminals. Both these measures are based on gesture measurements.

2.1.1. Locating Tongue Tip Gestures

For both measures, we located the tongue tip gestures for the coronal consonant of each token, using MVIEW's find gesture routine (Tiede, 2005, 2010, Matlab, 2012). The onset of the consonant constriction gesture is identified by a critical threshold of increase in velocity (GONS), which is defined conventionally as 20% of the maximum or peak velocity (PVEL1) prior to constriction. The articulator slows down as the constriction target is achieved. The onset of the consonant closure is arbitrarily defined as 20% of the maximum velocity, named the nucleus onset (NONS) of the consonant closure period. The offset of the closure period, or nucleus offset (NOFF), is reached when the articulator reaches 20% of its maximum velocity during the release of the constriction (PVEL2). The velocity of the articulator then slows down again, with the gesture offset (GOFF) defined as a decline to 20% of PVEL2. The center point of the NONS to NOFF closure period is Mid-C (see Figure 2).

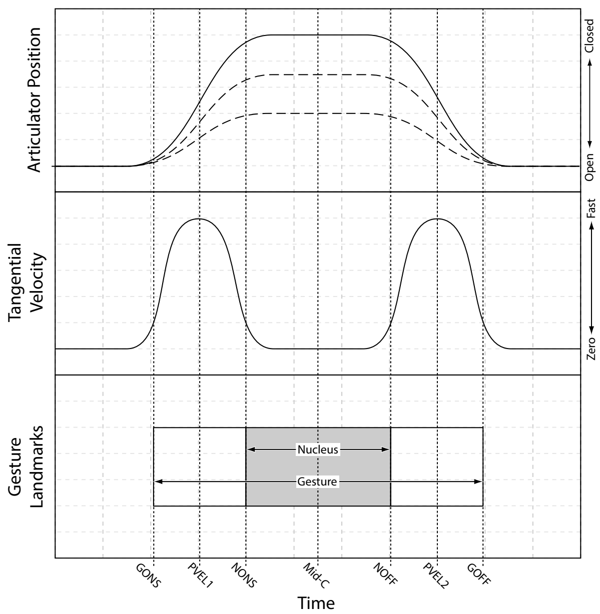

Figure 2: *Path of an articulator constriction gesture as defined in the FindGest routine in MVIEW (Tiede, 2005, 2010).*

2.1.2. Short-term velocity correlation

Once the tongue tip gestures were located, the tangential velocity was computed for each sample of the tongue tip and tongue body sensors' motion trajectories using Euclidean distances between samples and the central difference method. A rectangular sliding window of 7 samples (+- 30 milliseconds) was shifted sample-wise over the tongue tip and tongue body velocity signals, beginning at the tongue tip gesture's GONS and ending at GOFF.

[1] We treat the alveo-palatal affricates as stops here, reflecting the fact that the closure phase is stoplike

[2] While we included only the dental [ð], the other English coronal fricatives are also laminals.

The static, or near-zero velocity sections in both the tongue tip and tongue body trajectories can result in high correlations. However these correlations are spurious since the hypotheses concern simultaneous vs. not simultaneous movements. To avoid these false correlations, each value was multiplied by the average tongue tip and tongue body velocity within the sliding window.

The procedure results in a series of correlation values over time for each target consonant, themselves based on the average (mean) velocities within their window. The series of correlation values are then averaged again for a single mean velocity correlation value per token.

The correlation values were not rectified, so values before averaging can be positive or negative. For our purpose this is preferable since a negative correlation means that either the tongue tip or tongue body is accelerating while the other is decelerating. This outcome strongly hints at phase differences and so should have an opposite influence to positive correlations, indicating in-phase movements (see Figure 3).

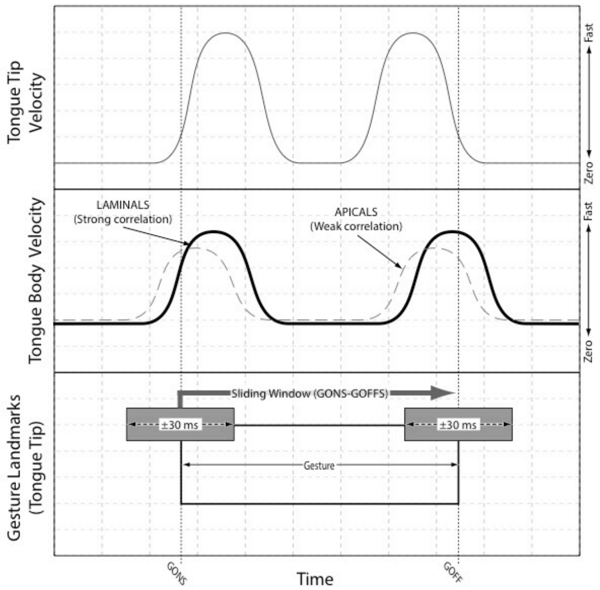

Figure 3: *Schematic of the Short-term Velocity Correlation Measurement.*

The prediction is that laminals should have higher values (more synchronous movements of tongue tip and tongue body) than apicals.

2.1.3. Quad ratio

In addition, the spatial 2D (midsagittal) position of the tongue tip and tongue body sensors were taken at the time points of GONS (1), GOFF (2), NONS (3), and NOFF (4). The area of the resulting quadrilateral was then computed for the tongue tip gesture. Similar measures were taken for the tongue body gesture based on the above four tongue tip gesture times. This resulted in a single value representing the area of motion transcribed by the tongue tip gesture and a second value for the area transcribed by the tongue body for the same points in time. A schematic of this technique can be seen in Figure 4:

According to the hypothesis that for laminals the tongue tip and body move in tandem, while for apical the tongue body is relatively more stabilized during tongue tip motion, the tongue body gesture area should be significantly larger for laminals than for apicals, while the tongue tip gesture area should be the similar for both. However, given that speaker variability due to different palate and tongue shapes and sizes, the self-normalising ratio of tongue tip gesture area divided by tongue body gesture area was chosen for analysis. To make results easier to handle numerically and to generate a statistically normal distribution, a logarithmic transformation was applied to these ratios. The result is that positive values indicate that the tongue tip gesture area is larger than the tongue body gesture area. A negative value indicates the opposite. The prediction follows that the normalized tongue tip/body area ratio should be higher for apicals than it is for laminals, even for English coronal obstruents, if the universal hypothesis about tongue tip and body coordination for coronals is correct.

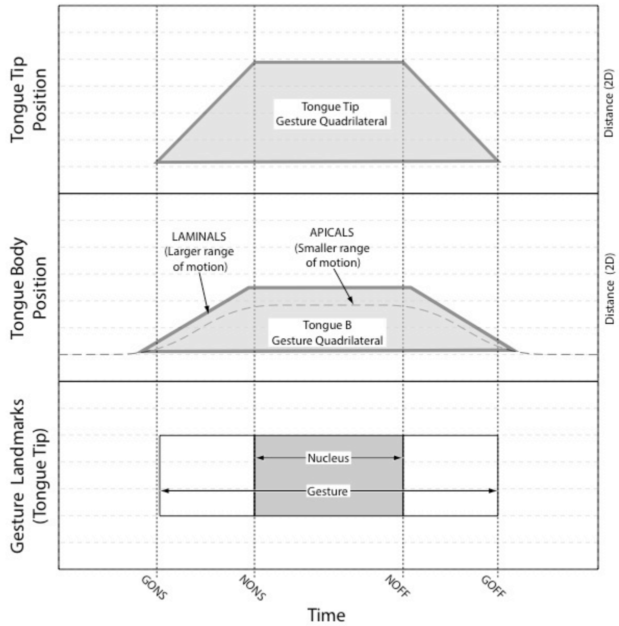

Figure 4: Schematic of the QuadRatio measurement.

2.1.4. Statistics

Tokens where gestures could not be found or where gestures did not line up appropriately with the consonant (270 of 641 observations, or 42.1% of the tokens) were excluded in order to avoid conflating vocalic gestures with the intended consonantal gestures. The numbers were this high due to the difficulty participants experienced in repetitively producing coronals with a pellet glued to the tongue tip. To compensate for this, statistical analysis was conducted on the two measures using generalized linear mixed effects models in R (R Core Team, 2013) as they are extremely robust against imbalances in datasets. For both *QuadRatio* and *Velocity Correlation*, the first test checked for interactions between the consonants and their vocalic contexts. Assuming no interactions, a second test compared the results of the measure against the consonants alone.

3. Results

3.1.1. Short-term velocity correlation

For the short-term velocity correlation, there was a significant main effect of vowel context such that the correlation was lower for /u/ and /i/ than for /a/, and a significant pain effect such that the correlation was lower for /ð/ than /d/, as seen in Table 2.

Table 2: *GLMM of short-term velocity correlation interactions with consonant and vocalic environment. * = Significant. (GLMM does not provide p values.)*

Variable	Estimate	Std. Err.	T value
(Intercept)	0.463	0.085	* 5.460
ð vs. d͡ʒ	0.088	0.078	1.129
ð vs. d	0.135	0.062	* 2.169
a vs. u	-0.235	0.089	* -2.637
a vs. i	-0.350	0.069	* -5.092
ð vs. d͡ʒ: a vs. u	-0.266	0.078	* -3.397
ð vs. d: a vs. u	-0.364	0.085	* -4.261
ð vs. d͡ʒ: a vs. i	-0.168	0.097	-1.732
ð vs. d: a vs. i	-0.232	0.099	* -2.355

There was also an interaction between consonant and vocalic context such that the short-term velocity correlation was significantly higher for /ð/ than /d/ in the /uCu/ and /iCi/ context, and significantly higher for /ð/ than /d͡ʒ/ in the /uCu/ context, as seen in Table 2 and Figure 6.

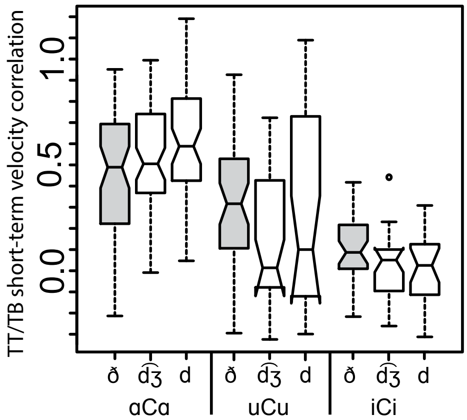

Figure 6: *Boxplots of Velocity correlation separated by vowels x consonants.*

3.1.2. Quad ratio

There were no significant quad ratio interactions between consonants and vocalic context. Examining quad ratio by consonant alone showed that the quad ratio was significantly smaller for /ð/ than /d/ ($t = 2.246$), and smaller for /ð/ than /d͡ʒ/ ($t = 2.496$), as seen in Figure 7.

4. Discussion and conclusion

Both the quad ratio and velocity correlation results show a distinction between the laminal /ð/ and the apicals /d/ and /d͡ʒ/. The quad ratio result is consistent with that seen in Wubuy. The short-term velocity correlation's consistency varied significantly by vocalic context: laminal /ð/ showed a higher velocity correlation than the apicals /d/ and /d͡ʒ/ in the /uCu/ context, and a higher correlation than /d/ in the /iCi/ context. However, in the /aCa/ context this result vanished for English.

The alveo-palatal affricate /d͡ʒ/ trended with apical /d/, indicating that the apical vs. laminal distinction appears based on onset, and anterior vs. posterior appears based on release.

Thus, we found robust support for Hypothesis 1, i.e., that tongue tip/tongue body coordination differences between apicals and laminals are universal. However, the specific nature of tongue tip/tongue body coordination in apicals vs. laminals is partially language-specific as vocalic context strongly influenced velocity correlation.

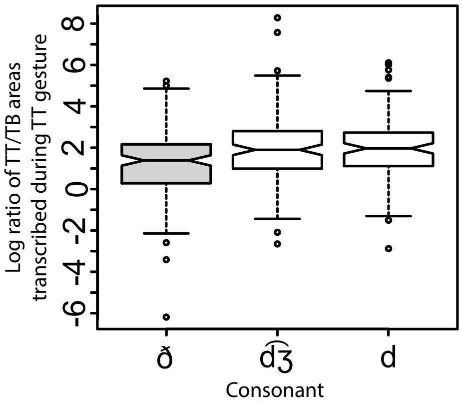

Figure 7: *Boxplots of Quad Ratio results by consonant.*

5. Acknowledgements

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