LOW DENSITY ASSAMESE ALVEOLAR STOPS SHOW GREATER COARTICULATORY RESISTANCE COMPARED TO LABIALS AND VELARS

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ABSTRACT

Coarticulatory Resistance (CR) in consonants is affected by density of segments in an inventory. Sparse consonantal systems allow consonants to coarticulate freely with adjoining vowels. Assamese, an Indo-Aryan (IA) language, contains alveolar stops that result from a historical merger between the dental and retroflex stops of the IA language family. Due to the low density of contrast in the coronal place of articulation (POA), we expect Assamese alveolar stops to exhibit greater acoustic variation. Slopes from first order F2 Locus Equations suggest that alveolars in a VCV context exhibit greater CR compared to velars and labials. In fact, slopes drawn between F2 at 25% and F2 at 5% of the vowel are also found to be significantly different between alveolars, labials and velars. We argue that consonantal systems seek articulatory equilibrium by selecting CR patterns that are governed by intrinsic articulatory complexity and motor demands, not just density.

Keywords: Coarticulatory resistance, Locus Equations, Contrast, Assamese

1. LOCUS EQUATIONS, COARTICULATORY RESISTANCE AND DENSITY OF CONTRASTS

1.1. Locus Equations

Systematic acoustic variation in stop place of articulation, irrespective of the effect of contextual vowel was first observed by [1] using locus equations (LE). Formant loci were found to be invariant acoustic cues to place of articulation, especially in the case of coronal stops where F2 transition shapes do not provide cues to place of articulation unambiguously [2]. Locus equations are linear regressions of F2 frequency at the vowel midpoint and onset. It has been found that locus equations are not just an indicator of the stop place of articulation but they also predict the degree of coarticulation in VCV sequences ([3],[4],[5]. It has been employed to predict coarticulation in both linguistic and pathological variation in speech [6], [7], [8]. First-order locus equation is represented by the formula

$$(1) \quad F2_{onset} = k \times F2_{vowel} + c$$

where k is the slope and c is the y-intercept [9].

In 1 above, k, the slope of the linear equation is also known to provide a measure of coarticulatory resistance [10]. Steeper slopes correspond to lower coarticulatory resistance, while shallower slopes correspond to higher coarticulatory resistance.

1.2. Slopes of Locus Equations as a measure of Coarticulatory Resistance

Coarticulatory resistance, as measured through slopes of the First-order locus equations, provide a unified measure with which it is possible to understand how nature of contrast, size, shape and density of phonetic inventories [11, 12] affect coarticulation and by extension, variable coarticulatory resistance. Neighborhood frequencies also affect coarticulatory patterns such that higher neighborhood frequencies lead to higher degree of coarticulation [13]. Measuring coarticulation of Catalan consonants by the standard deviation of F2 values at the onset of the consonant, in relation to its following vowels has also been a useful method to quantify extent of coarticulation [14]. A low standard deviation would imply high coarticulatory resistance, because the onset would be less affected by the following vowel [14]. This relation between coarticulatory resistance and locus equation slopes has also been shown for American English consonants [15]. A steeper slope of locus equations as a result of higher degree of coarticulation was also seen in computer simulated speech [16],[9].

1.3. Density of Contrast

Coarticulatory resistance can be affected by articulatory motor constraints and by density of contrast in the language's segmental inventory. [4] observed that alveolars in a VCV context exhibit greater coarticulatory resistance compared to velars and labials in Swedish. [11][12] studied the extent of coarticulatory resistance in CV syllables between languages that differed in the density of contrast. The results showed that vowels with a higher neighborhood density of contrast had a higher resistance to anticipatory coarticulation than vowels with a low density of contrast. Coarticulatory propensity, resistance, therefore is a function of articulatory motor constraints, in terms of articulatory demands, degree of overlapping gestures, size, shape of the phonetic inventory, and density of contrasts.

2. DENSITY OF CONTRAST IN ASSAMESE

We investigate the relative effect of these factors by analyzing coarticulatory resistance in Assamese, an Indo-Aryan (IA) language spoken in India. Assamese has a low density of contrast in the coronal place of articulation when compared with other IA languages. The dental-retroflex contrast in IA languages, historically merged into an alveolar stop in Assamese[17]. Therefore, based on the results of [11][12], Assamese should exhibit lower coarticulatory resistance in the alveolar stops, as it does not have to maintain the categorical distinction between dental and retroflex stops, which is a feature in most IA languages. On the other hand, higher coarticulatory resistance in alveolar stops compared to velar and bilabials, would indicate that relative articulatory complexity and motor demands mitigate or at least are a greater determiner of coarticulatory resistance in Assamese.The effect of preceding and following vowels on syllable-initial and syllable-final /t/, /t^h/, /n/, /d/, and /d^h/ were studied by [18]. It was found that while these segments are distinctly denti-alveolar in the presence of vowels which are high and front, they were apico-alveolar when the preceding or following vowel is a back vowel. [19]'s data shows the voiceless alveolar plosive acts like the English t. Here, it is suggested that the alveolar may be due to the influence of the Bodo languages in which dental consonants are pronounced as semi-cerebrals as in English. In our study, we employ first-order locus equations in the V_1CV_2 context, where V_1 is [a] and V_2 that varies between [a, i, u]. Deriving locus equations from F2 values at 15%, 25%, and 50% we investigate the nature of the slopes at various temporal landmarks of the vowel. This is motivated by at least one study by [20] that shows that locus equation slopes as early as 25% in to the vowel are sufficient to cue place of articulation in American English. In the following section we describe the methods in greater detail.

3. METHOD

3.1. Participants and Stimuli

Speech samples from five male and five female native speakers of Assamese were analyzed for this study. The stimuli consisted of words in [...aCV_2...] context, where the C is a labial, alveolar or velar stop, while the following V_2 is one of the corner vowels /a, i, u/. The words were presented in a sentence frame of 'mɔi tat _ buli lik^{h}a dek^{h}ilu.' The word list consisted of two words from each VCV combination, making a list of 36 words (6 Consonants × 3 Vowels × 2 unique words). For instance ʤapa, ata, aka. The list was read 4 times by each participant. The first iteration was not analysed for this study.

3.2. Procedure and Analysis

Recording was conducted in a sound attenuated booth with a head mounted microphone connected to a solid state recorder. The sentences were presented to the participants on a computer screen, in a random manner and recorded at a sampling frequency of 44100 Hz. The data was manually annotated, carefully marking each phoneme boundary. A PRAAT script was used to generate the F2 frequency at 5%, 15%, 25% and 50% of the vowel. The F2 values generated were then speaker normalized using Lobanov Vowel normalization method [21]. These normalized F2 values where fitted into 1. For each individual speaker and for each place of articulation, the coefficient value of the slope was obtained by running a linear regression model. We then perform ANOVA followed by a Tukey HSD test to analyze the statistical significance of the differences in the coefficient values across place of articulation. The following ANOVA model was used for the statistical analysis:

$$(2) \quad Coefficient_{vowelpoint} \sim POA + Sex$$

In 2 above, *vowel point* is the coefficient value at either 15%, 25% or 50% of V_2.

4. RESULTS

The overall results show that velars have the steepest slope, followed by bilabial and then by alveolars. The slope of each place of articulation determines the degree of coarticulatory resistance, that is, a steeper slope indicates that there is a greater change at the beginning of the vowel for per unit change in the middle. The slopes measured at 15%, 25% and 50% are presented in section 4.1, 4.2 and 4.3 respectively.

4.1. CR at 15% of the vowel

In Figure 1, normalized F2 values at 5% of the vowel are plotted against F2 values at 15% of the vowel. We observe that velars and labials have steeper slopes compared to alveolars. The slope values of the regression models at 15% of the vowel plotted for each place of articulation in Figure 2 correspond to the observation in 1 by showing higher values for velars. The velar slope is significantly steeper compared to the alveolar ($p < 0.001$, 95% C.I. = [0.063, 0.206]). No significant difference between alveolar and bilabial slopes is found at 15% of the vowel.

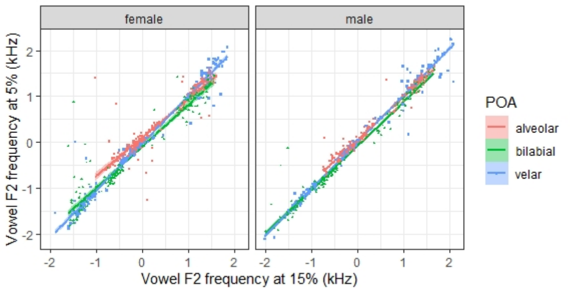

Figure 1: Linear regression of F2V and F2C at 15%

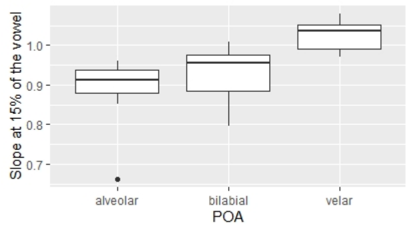

Figure 2: Coefficients at 15% of the vowel

4.2. CR at 25% of the vowel

The F2 values at 25% of the vowel plotted in Figure 3 shows similar pattern as observed at 15% of the vowel, but the difference between the regression slopes for alveolar with velar and labial increases. The coefficients of the F2 slope plotted in Figure 4 show lowest values for alveolars and highest values for velar. Statistical analysis shows a significant difference between all the three place of articulation categories - bilabial-alveolar $p < 0.05$, 95% C.I. = [0.188, 0.025]; alveolar-velar $p < 0.005$, 95% C.I. = [0.167, 0.33]; bilabial-velar, $p < 0.05$, 95% C.I. = [0.059, 0.222]. These results are similar to [20] who found similar early stability in the place of articulation determinant function of the slopes than what has been proposed in standard locus equation models in [4, 22]. The order of the slopes velar > labial > alveolar correspond to the inverse relationship that slopes have with coarticulatory resistance, namely, alveolars greater coarticulatory resistance compared to labials and velars, in that order.

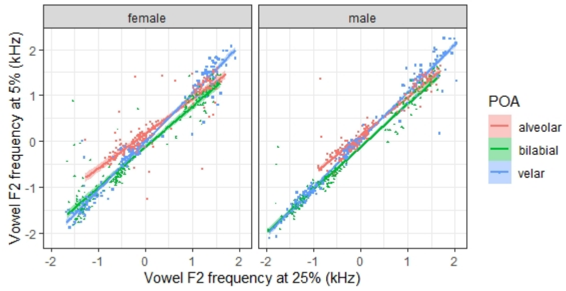

Figure 3: Linear regression of F2V and F2C at 25%

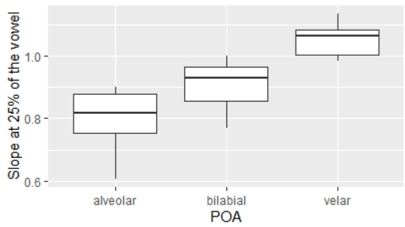

Figure 4: Coefficients at 25% of the vowel

4.3. CR at 50% of the vowel

F2 values at the vowel midpoint are plotted in Figure 5. We observe that the slope for alveolar is shallower compared to the slopes with F2 measures at 15% and 25%. The same is observed in Figure 6 where the coefficient of velar slopes are higher than both bilabials and alveolars; coefficients of bilabial slopes are higher than alveolars. Statistical analysis show significant difference between all the places of articulation (bilabial-alveolar $p < 0.001$, 95% C.I. = [0.085, 0.242]; velar-alveolar $p < 0.001$, 95% C.I. = [0.271, 0.428]; velar-bilabial $p < 0.001$, 95% C.I. = [0.106, 0.264]).

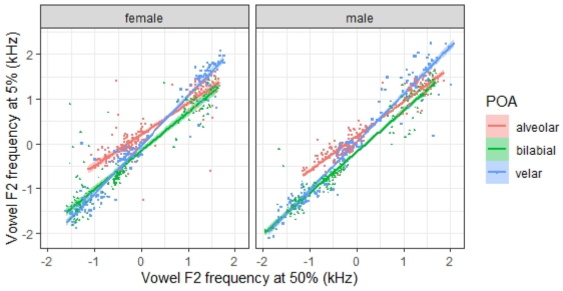

Figure 5: Linear regression of F2V and F2C at 50%

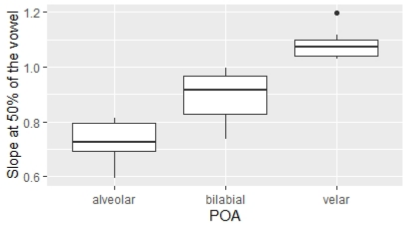

Figure 6: Coefficients at 50% of the vowel

Comparing the slopes at 15%, 25% and 50% of the vowel, we observe a gradual increase in the difference between the slopes for each place of articulation. Significant differences in F2 slopes between the three places of articulation are found between alveolar, labial and velar at 25% and 50% of the following vowel, with the alveolars showing the lowest slope values. These results suggest that the alveolars resist coarticulation to the greatest degree in Assamese, in spite of a purported merger of the Indo-Aryan dental-retroflex contrast in Assamese. While there is no reason to think that the merger would imply an articulatory variation between these two places of contrast and a subsequent articulatory stabilization of the dental-retroflex contrast into an alveolar, there is perhaps a greater likelihood that historically, the Assamese substratum mapped an already existing alveolar to the Indo-Aryan dentals and retroflexes. Alternatively, we could interpret our results to reflect the intrinsic articulatory complexity of the alveolars, compared to the velars and labials in terms of greater motor demands on the tongue tip and dorsum. The latter interpretation is conceivable even with the possible historical merger of the dental-retroflex in the inherited Indo-Aryan substrate of Assamese.

5. DISCUSSION

We examine locus equation slopes as a function of both place of articulation discrimination and coarticulatory resistance in Assamese - a modern Indo-Aryan language in which a historical merger of the Indo-Aryan dental-retroflex contrast has been reported. Our results show that the Assamese alveolars are discriminated quite well when compared to the labials and velars. The Assamese alveolars also show shallower slopes at 25% and 50% of the vowel, suggesting greater coarticulatory resistance. Our results correspond to the coarticulatory pattern seen in an earlier study on coarticulatory resistance of American English consonants, which found that bilabials and velars have lower coarticulatory resistance compared to alveolars [15]. Although coarticulatory resistance is known to be affected by the density of contrast in the segmental inventory of a language, we do not observe any correlation between coarticulatory resistance in Assamese and its sparse presence in the coronal place of constriction compared to its related languages. The possible explanation provided for the low coarticulatory resistance of the labial consonant is that the tongue gestures needed for the vowel can be overlapped substantially with the lip gestures due to the relative independence of these articulators. The low coarticulatory resistance of the velar has been been seen in a number of studies. For instance, it has been observed that the place of articulation of the velar /g/ varies in response to the frontness of the contextual vowel [23].

It has also been demonstrated that the locus equation slope for /b/ is steep, where as the slope for alveolar is flatter [24]. The order of coarticulatory resistance previously seen across place of articulation of stops is labial>velar>alveolar [14]. Another explanation suggested by [5] for a considerably steep slope for velars in some languages is due to the lack of a similar consonant with a place of articulation close to the velar leading to greater confusability [5]. This explanation doesn't quite hold for Assamese due to the presence of a voiceless velar fricative; the only Indo-Aryan language that possesses such a consonant. Given the greater coarticulatory resistance of the Assamese alveolars, we claim that the historical merger of the Indo-Aryan dental-retroflex contrast stabilized into an articulatorily complex configuration as seen in most alveolars. In that sense, the Assamese alveolars could either be conceived of as Bodo type alveolars or strictly governed by motor constraints and not determined by the density or sparsity of the coronal place of articulation. In further research, we will extend our model to include the nasals, the velar and the coronal fricatives, that are available in the inventory of Assamese in addition to fitting Bayesian regression models to tease out any subject-wise variation.

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