MODELING VOWEL ARTICULATION / MODÉLISATION DE L'ARTICULATION DES VOYELLES

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ABSTRACT

This paper discusses a cross-linguistic articulatory model of vowels based on sagittal plane x-rays of vowels from Akan, Arabic, Chinese, and French. The model gives a mapping from a universal space of articulatory parameters to the specific vowels of each language. It contains an explicit parametrization of speaker variation, based on data from 13 speakers. We show here that the model also generalizes to certain consonants. The results suggest that the phonological description of these consonants can be changed profitably.

1. INTRODUCTION

The aim of this paper is to present an articulatory model of vowel production. Vowel articulation is simpler than consonant articulation because there is relatively little contact-related deformation in the shape of the tongue and other articulators and so measurements of tongue position in vowels do not show non-linear "ceiling effects" due to the contact of the tongue with the hard palate.

Several articulatory models have been proposed (e.g. [9], [11], [12]), but few are based on multi-speaker data, and even fewer are based on cross-linguistic data ([15] and [16] are exceptions, see [6] for a review). This model fills the gap with an articulatory model based on multi-subject, cross-linguistic data from vowels in four unrelated languages. With a cross-linguistic articulatory model, we may discuss cross-linguistic differences in vowel articulation quantitatively.

1.1 Measurement of articulators

This is a model of the mid-sagittal profile of the vocal tract during vowel production, since vowels only involve central articulations. Furthermore, there are algorithms for approximating the shape of the tongue given the mid-sagittal profile ([5], [8]). The scheme used to approximate the mid-sagittal profile of the vocal tract is described fully in [7]. 34 measures of articulator position are used: two of the epiglottis, 5 of the dorsal wall of the pharynx, 13 of the tongue, 12 of the velum and uvula, and the x- and y-coordinates of the lower incisor.

1.2 Speech Materials

The data used in this study were measured from x-rays in the literature. The data used to construct the model are from Akan (described in [10]), Arabic [1], Chinese ([13], [17]), and French [4]. The Akan vowels used are /iɩeɛaɔoɷu/ (one token of each vowel from four speakers), the Arabic vowels - pharyngealized and non-pharyngealized allophones of /i: e: a: o: u:/ (two tokens, two speakers), the Chinese vowels - /iyɵauo/ (one, three), and the French vowels - /ieɛyøœuoɔa ɛ̃ œ̃ ɔ̃ ɑ̃/ (one, four). Further details are given in [7]. Overall, the model accounts for 85% of the variance in articulator positions in these vowels.

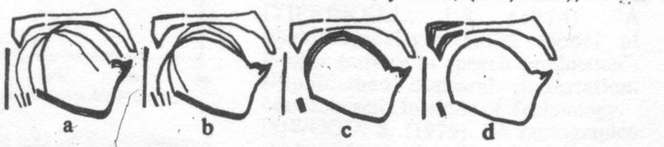

Figure 1. (a) The pattern of articulatory displacements produced by Front-Raising. (b) Back-Lowering. (c) Tongue Root Advancement. (d) Nasalization.

1.3 Parameters of the model

The articulatory model has four parameters, called Front-Raising (FR), Back-Lowering (BL), Tongue Root Advancement (TRA), and Nasalization (N). The articulatory effects of these four parameters are shown in Figure 1, in the vocal tract outline of the second Akan speaker in [10]. The mean articulatory position is plotted with a medium-weight line, the articulatory configuration given by a negative displacement is plotted with a fine line, and the articulatory configuration given by a positive displacement is in bold.

The vowels of Arabic and French are plotted in the parameter space defined by FR, BL, and TRA in Figures 2 and 3 (axes normalized to unit variance). The left-hand plots show the vowels projected into the FR/BL plane, and the right-hand plots show them in the FR/ TRA plane.

Articulatory FR is similar to traditional front/back. The pharyngealized vowels (open symbols) of Arabic and the low vowels of French tend to positive contributions from BL, whereas non-pharyngealized and high vowels have small contributions from BL. BL is thus similar to acoustic height. TRA patterns similarly to height in Arabic, but does not show a clear pattern in French. At best, it tends to separate nasalized and/or lax vowels from their oral and/or tense counterparts. In Akan, this parameter separates the [+ATR] vowels /ieou/ from the [-ATR] vowels /ɩɛaɔɷ/ (see [7]).

This model embodies various articulatory and phonological constraints which we will not discuss here. [7] shows that FR and TRA involve no velum displacement, but there is an apparently irreducible correlation between BL and velum displacement. The TRA parameter is not used in Chinese; BL and TRA are used differently in Akan and Arabic.

2.0 GENERALIZABILITY

Data from consonants is used to test the generalizability of the model. X-ray

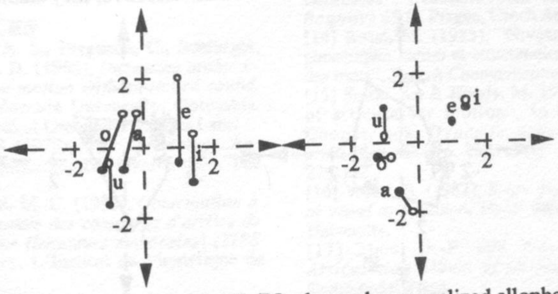

Figure 2. (left) Arabic vowels in the FR/BL plane; pharyngealized allophones in open circles, non-pharyngealized in solid. (right) Arabic vowels in the FR/TRA plane.

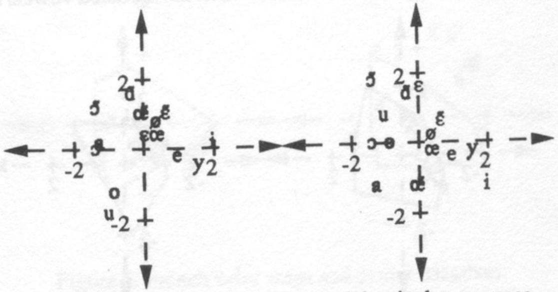

Figure 3. French vowels in the model articulatory space.

tracings of velar and uvular stops in several contexts were measured and fit to the model. Arabic uvular and velar stops from [2] & [3] in the contexts /ka ki ku qa qi qu/ (two speakers), Arabic uvular fricatives in the contexts /ʁa ʁi ʁu χa χi χu/ (one), and French velar stops and uvular fricatives in the contexts /ku ky gu gy ʁu ʁɛ/ (four) were used. Speaker normalization factors were determinedby fitting the articulatory model to the vowels /aa: ii: uu:/ for the two Arabic speakers; for the French speakers, speaker normalization was determined earlier (see [7]).

If the model generalizes well to these consonants, then it should describe them as well as it describes vowels. Quantitatively, it should account for the same proportion of variance as it accounts for in the vowels.

2.1 Arabic back consonants

When fit to the vowels from the two Arabic speakers in [2] and [3], the model accounts for 87% of the variance in articulator position. It fits 90% of the variance in the velar and uvular stops, but only about 80% in the uvular fricatives.

The parameterization of the stops is shown in Figure 4. The stops fall in the outskirts of the articulatory space occupied by vowels. The fricatives, in Figure 5, although towards the periphery, generally lie within the vowel space.

2.2 French back consonants

In French, the model accounts for 72% of the variance in the vowels. This is rather low, but on the other hand, these vowels are part of the sample which was used to construct the original model in [7]. The model also fits 72% of the variance in the velar stops, but only fits 56% of the variance in the uvular fricatives. The articulatory parameterization of these consonants is shown in Figure 6.

3.0 DISCUSSION

Uvular and velar stops are well-described by the model in both Arabic and French. Their articulation is vowel-like, but more extreme.

The uvular fricatives pattern differently. The French ones have substantial individual variation (see [4], p. 229). Since the speakers did not produce "the same" fricative, they cannot be modeled

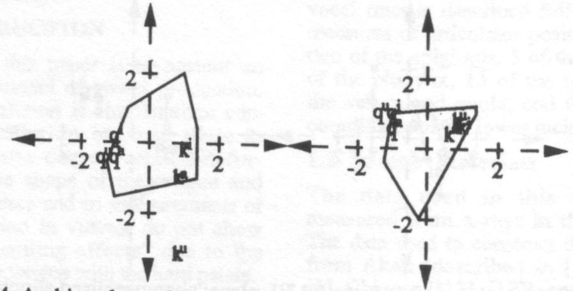

Figure 4. Arabic velar and uvular stops. Superscripts indicate vowel context. The polygons outline the area in which the modeled vowels lie.

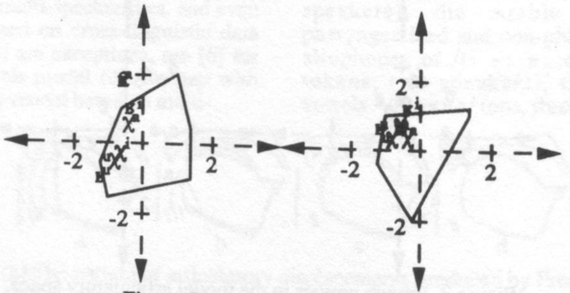

Figure 5. Arabic uvular fricatives.

uniformly by this model.

The Arabic uvular fricatives use a mode of velum displacement that is not found in the other data. In the x-rays, the velum appears to "bulge" and descend (see [3], p.100 ff.) This mode of velum displacement cannot be modeled by the N parameter of the model. If the measures of velum position are excluded, the model fits 87% of the variance in articulator position - comparable to the fit to vowels. We conclude that tongue, etc., positions in the uvular fricatives should be described with the same phonetic and phonological features as used for vowels.

Coarticulatory variation in the articulation of stops and fricatives in different vowel contexts is clearly visible in Figures 4-6. This model gives us a method for *articulatorily* quantifying contextual coarticulation, which despite its name has usually been measured acoustically.

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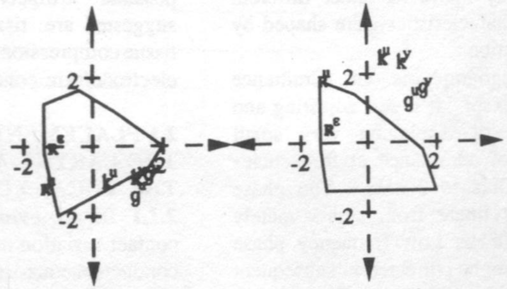

Figure 6. French velar stops and uvular fricatives.