An investigation of lingual coarticulation resistance using ultrasound

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Introduction

This paper uses ultrasound data in order to explore the extent to which lingual coarticulatory resistance for front lingual consonants and vowels in VCV sequences increases with the place and manner of articulation requirements involved in their production. Coarticulatory resistance for a given consonant or vowel is a measure of its degree of articulatory variability as a function of phonetic context such that the less the target segment adapts to the articulatory configuration for the flanking segments, the more coarticulation resistant it may be assumed to be. In principle, ultrasound should be more appropriate than EPG and EMA for studying coarticulatory resistance since it allows us to measure phonetic contextual effects not only at the alveolar and palatal zones but at the velar zone and at the pharynx as well.

In the present investigation coarticulatory resistance will be evaluated for the Catalan consonants /t, d, n, l, s, ɾ, r, ʎ, ɲ, ʃ/ and vowels /i, e, a, o, u/ embedded in symmetrical VCV sequences. In present-day Catalan, those consonants may be characterized as follows: /t, d/ are dentoalveolar and /d/ is realized as an approximant intervocalically ([ð]); among the alveolar consonants /n, l, s, ɾ, r/, /ɾ/ is a tap, /r/ is a trill and /l/ is clear rather than dark (as for the Catalan speakers who took part in the present study, F2 for /l/ amounts to 1400 Hz next to /i, e/ in the case of males and to 2500 Hz next to /i/ and 1700 Hz next to /e/ in the case of females); /ʃ/ is palatoalveolar and /ʎ, ɲ/ are alveolopalatal.

Within the framework of the degree of articulatory constraint (DAC) model of coarticulation and in line with kinematic data reported elsewhere (Recasens & Espinosa, 2009), we hypothesized that the degree of coarticulatory resistance for the phonetic sounds under investigation ought to conform to specific trends. On the one hand, palatal consonants and palatal vowels were expected to be most resistant since their production involves the entire tongue body. On the other hand, coarticulatory resistance for dentoalveolar consonants should depend on manner of articulation and thus, be highest for /s/ and the trill /r/, lowest for the approximant [ð], and intermediate for /t, n, ɾ/ and clear /l/. As for vowels, differences in tongue constriction location and lip rounding should render /a/ less variable than /o, u/. In sum, our initial hypothesis was that coarticulatory resistance ought to decrease in the progression /ʎ, ɲ, ʃ/ > /t, n, ɾ, l/ > /s, r/ > /d/ for consonants and /i, e/ > /a/ > /o, u/ for vowels.

Method

The speech materials, i.e., symmetrical VCV sequences with /t, d, n, l, s, ɾ, r, ʎ, ɲ, ʃ/ and /i, e, a, o, u/, were recorded by five native speakers of Catalan, three females and two males, wearing a stabilization headset. Tongue contours were tracked automatically and adjusted manually every 17.5 ms with the Articulate Assistant Advanced program. The resulting 83 data point splines were then exported as X-Y coordinates, converted from Cartesian into polar coordinates, and submitted to a smoothing SSANOVA computation procedure (Davidson 2006, Mielke, 2015). Based on EPG data on constriction location for specific Catalan consonants (Recasens, 2014) and on vocal tract morphology data available in the literature (Fitch & Giedd, 1999), the splines in question were subdivided into four portions which correspond to the alveolar, palatal, velar and pharyngeal articulatory zones (see Figure 1). As revealed by the graph, the articulatory zones differed in size in the progression pharygeal > velar, palatal > alveolar for all speakers.

Coarticulatory resistance was measured at each articulatory zone for consonants at C midpoint using the mean splines across tokens for the five contextual vowels /i, e, a, o, u/, and for vowels at the V1 and V2 midpoints using the mean splines across tokens for the ten contextual consonants /t, d, n, l, s, ɾ, r, ʎ, ɲ, ʃ/. It was taken to equal the area of the polygon embracing all contextual splines as determined by the maximal and minimal Y values at all points along the X axis (Figure 1 shows the polygon for /l/ at the palatal zone for exemplification). In all cases, the smaller the area of the polygon, the higher the degree of coarticulatory resistance. In order to draw interspeaker comparisons the area values of the polygons computed with Gauss’ formula were submitted to a normalization procedure separately at each articulatory zone by subtracting the mean area value across all consonants or vowels from the area value for each individual consonant or vowel and dividing the outcome by the standard deviation of the mean.

The resulting normalized area values were submitted to an ANOVA analysis with ‘consonant’ or ‘vowel’ and ‘zone’ as fixed factors and ‘subject’ as a random factor. The statistical results will be interpreted with reference to the ‘consonant’ or ‘vowel’ main effect and the ‘consonant’/‘vowel’ x ‘zone’ interaction but not to the ‘zone’ main effect since the normalization procedure happened to level out the differences in area size among the polygons located at differents zones (see above).

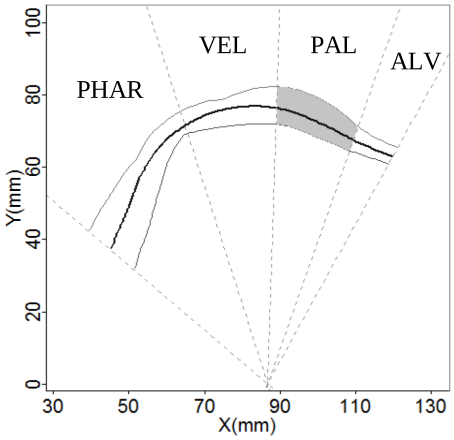

Figure 1. Subdivision of the lingual spline field for /l/ into the four articulatory zones ALV (alveolar), PAL (palatal), VEL (velar) and PHAR (pharyngeal). The spline field encompasses the splines for /ili, ele, ala, olo, ulu/. The polygon for the palatal zone is highlighted for exemplification.

Results

The statistical results for the consonant data yielded a main effect of ‘consonant’ (F(9, 160)=80.39, p< 0.001) and a ‘consonant’ x ‘zone’ interaction (F(27, 160)=3.09, p< 0.001). As shown in Figure 2, a Tukey post-hoc test revealed that the area size across zones varies in the progression /d/ ([ð]) > /l, ɾ, t, n/ > /s, r/ > /ʎ, ɲ, ʃ/ and simple effects tests that these consonant-dependent differences hold at all four zones except for /s/ (and to a much lesser extent for /r/) which turned out to be more variable at the pharynx than at the velar and palatal zones. On the other hand, the statistical results for the vowel data yielded a main effect of ‘vowel’ (F(4, 195)=83.89, p< 0.001) but no ‘vowel’ x ‘zone’ interaction meaning that, as shown in Figure 3, differences in area size for /u/ > /o/ > /a/ > /i, e/ apply equally to all four articulatory zones.

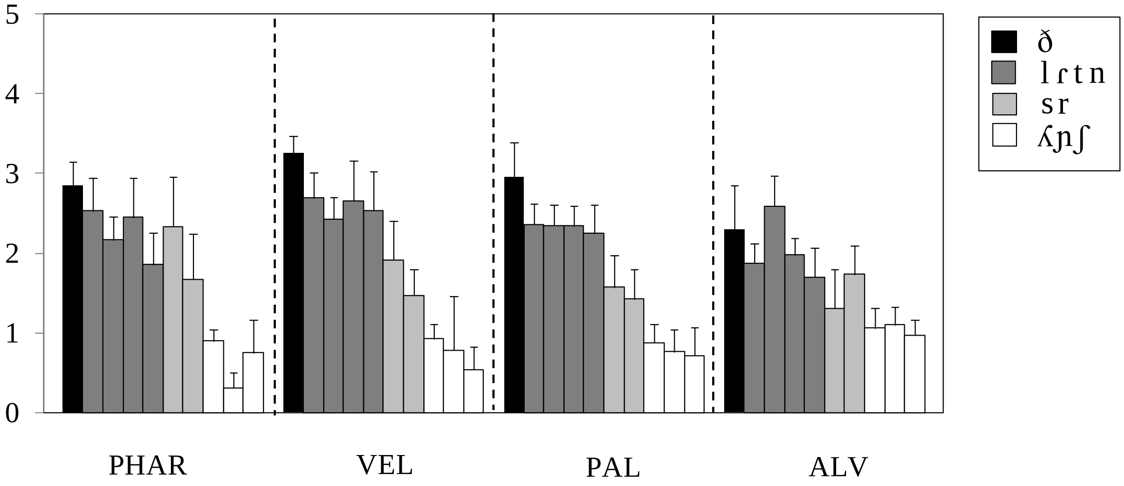

Figure 2. Cross-speaker normalized area values for consonants at the four articulatory zones ALV (alveolar), PAL (palatal), VEL (velar) and PHAR (pharyngeal). Error bars correspond to +/-1 standard deviation.

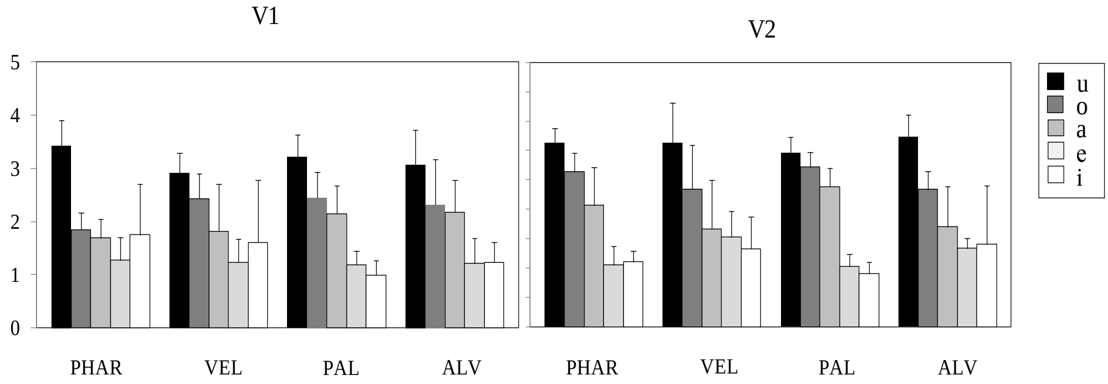

Figure 3. Cross-speaker normalized area values for vowels at the four articulatory zones ALV (alveolar), PAL (palatal), VEL (velar) and PHAR (pharyngeal). Error bars correspond to +/-1 standard deviation.

Discussion

Data reported in this study agree to a large extent with our initial hypothesis that coarticulatory resistance should vary in the progression /ʎ, ɲ, ʃ > /s, r/> /t, n, ɾ, l/ > /d/ ([ð]) for consonants and /i, e/ > /a/ > /o, u/ for vowels. Moreover, generally speaking, this hierarchy holds at the palatal, velar and pharyngeal zones where the tongue body is located and not just at the palatal zone, as reported by earlier EPG and EMA studies. Little contextual variability for palatal consonants and vowels (also for the trill /r/) at the three zones suggests that the entire tongue body is highly controlled during the production of these segmental units. Larger degrees of coarticulation were found to hold for the less constrained dentoalveolars /t, n, ɾ, l/ and for non-palatal vowels also at the palatal, velar and pharyngeal zones simultaneously. As for the highly constrained fricative /s/, there appears to be somewhat less coarticulatory variability at about constriction location than at the back of the vocal tract. These results accord with formant frequency data on coarticulatory resistance for the same consonants and vowels reported in the literature. They are also in support of the degree of articulatory constraint (DAC) model of coarticulation in that the extent to which a portion of the tongue body is more or less resistant to coarticulation depends both on its involvement in the formation of a closure or constriction and on the severity of the manner of articulation requirements.

Acknowledgments

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