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Differences in coarticulation resistance between vowels and consonants: an ultrasound study

Sound segments show considerable influence from neighbouring segments, which is described as being the result of coarticulation. No published reports on coarticulation in vowel-consonant-vowel (VCV) sequences have used ultrasound. One advantage of ultrasound is that it provides information about the shape of most of the midsagittal tongue contour. In the experiment reported here, ultrasound was employed for studying symmetrical VCV sequences. The work was situated within the Coarticulation Resistance (CR) theoretical framework, which interprets coarticulatory properties of speech sounds based on how resistant these sounds are to the contextual influence. Resistance can be defined as degree of similarity of the same speech sound across contexts. The Degree of Articulatory Constraint (DAC) model of lingual coarticulation has developed coefficients of CR, thus including quantification in a theory of coarticulation (e.g., Recasens et al. 1997; Recasens 2004). The DAC model is largely based on electropalatographic and acoustic data. This study proposes a method for measuring coarticulation, based on midsagittal ultrasound data.

Ultrasound and acoustic data were collected using the Queen Margaret University ultrasound system (see Hewlett & Beck, 2006). The programme “Articulate Assistant Advanced” was used for data recording and analysis; Matlab and SPSS were used for statistical analysis. The data were English /ɑkɑ/, /ɑtɑ/ and /iti/ sequences, occurring in meaningful sentences, repeated 15 times. The subjects were three native speakers of Southern British English. Three time points were identified in the acoustic signal: mid-V1, mid-C, and mid-V2. Then three curves corresponding to the tongue contour were captured. Tongue curve comparison was based on nearest neighbour calculations. For each two curves, nearest neighbour distances were calculated from each point on one curve to the other curve, and the mean of all nearest neighbour distances was used as a measure of the average distance between the two curves.

Comparison of the ultrasound curves for /t/, in the context of two vowels, /i/ and /ɑ/, provided a measure of vowel-on-consonant (V-on-C) coarticulatory effect. Comparison of the ultrasound curves for /ɑ/, in the context of two consonants, /t/ and /k/, provided a measure of consonant-on-vowel effect. C-on-V1 and C-on-V2 effects were measured by comparing tongue contours for the vowel /a/ separately for the first and the second vowel of the VCV sequence.

For comparing two sets of curves for significant differences, across-context distances (between each of the 15 curves in one set and all of the 15 curves in the other set) were compared with within-context distances (each of the 15 curves in a set and all the other 14 curves in the same set). A one-way Univariate ANOVA was conducted for comparing three sets of values: one set of across-context distances and two sets of within-context distances. For an effect to be deemed significant, at 0.05 level, a significant difference was required in the Post Hoc test between across-context distance and each of within-context distances.

All three effects were significant. The V-on-C effect was significantly greater than C-on-V1 and C-on-V2 effects. This finding is in agreement with the results presented in Keating et al. (1994): they analysed vertical jaw displacement in VCV sequences, and found a significant effect of vowels on consonants, but only a trend towards significance with regard to an effect of consonants on vowels. This experiment demonstrates that consonants have a greater potential for lingual coarticulation than vowels; in other words, vowels are more resistant to consonantal coarticulatory effects than consonants are to vocalic effects. For the vowel production, the constraint on tongue posture tends to be rather global, in order to create a resonance required for the correct vowel perception by the listener. For producing consonants, however, a local constriction is often required, while the rest of the tongue can vary considerably according to the context, the listener still being able to identify the intended consonant phoneme. A number of other speech production theories incorporate a radical distinction between consonants and vowels (e.g., Öhman 1967; Perkell 1969; Fowler 1980).

The CR classification in the DAC model is based on the degree of constraint on tongue dorsum during the sound production. The model assumes that /ɑ/ and /t/ have a similar CR value, because tongue dorsum is only indirectly involved in the production of both of these sounds: for producing /t/, the tongue is constrained by coupling effects with the tongue blade, resulting in raising, and for producing /ɑ/, the tongue root retraction gesture induces some concomitant tongue dorsum lowering (Recasens et al. 1997). The results of this experiment contradict the DAC model assumption: the resistance of /ɑ/ was shown to be significantly greater than the resistance of /t/. In the discussion, it is suggested how the actual distance measures could be used as a basis for improving the DAC classification, allowing for a unified description and theoretical interpretation of lingual coarticulatory properties of consonants and vowels interacting in speech.

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