Acoustical Effects of Coarticulation in Speech

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Coarticulation is one of the main causes of variability in speech. The purpose of this study is to assess the relationship between the F-to-V carryover coarticulation and F2 excursion size in fricative-vowel syllables (FV). The quantification of the coarticulatory effects was done using the DAC scale. F2 excursion sizes should reflect the magnitude of the coarticulatory effects associated with the consonant. Results show that there is indeed a significant correlation between the magnitude of the coarticulatory effect and the F2 transition, indicating that F2 is related to articulatory constraints between consonant and vowel and not to the consonant's place of articulation.

INTRODUCTION

Coarticulation is one of the main causes of acoustic variability in both consonants and vowels. Although variability can be regarded as a drawback for the acoustic characterization of speech segments, it is also true that some perceptual processes can be interpreted in the light of the acoustical effects caused by coarticulation. For instance, in a previous experiment with conflicting cue stimuli formed by the combination of fricatives /f, θ, s, ʃ/ with vowels /a,e,i,o,u/, we found that the F-to-V carryover coarticulation (articulatory influence of the fricative on the vowel) could be responsible for the perceptual improvement that takes place when listeners are presented with the fricative and the following vowel, with respect to the presentation of only the fricative noise [1].

It has usually been assumed that F2 excursion size (difference between F2 at vowel onset and F2 at steady state) reflects the articulatory movements of tongue dorsum from the release of the constriction until the vowel steady state. The purpose of this study is to assess the relationship between F-to-V carryover coarticulatory effects and F2 excursion size in fricative-vowel syllables (FV).

THE DAC SCALE

The DAC scale is based on the degree of articulatory constraint imposed on the production of the phonemes, particularly by the use of the tongue body to form the necessary constriction [2].

The following values can be tentatively assigned to the phonemes involved :

- $DAC = 1$: /f/
- $DAC = 1.5$: /a/, /o/, /u/
- $DAC = 2$: /θ/
- $DAC = 2.5$: /s/, /e/
- $DAC = 3$: /ʃ/, /i/

The DAC scale proceeds from less constrained ($DAC = 1$) to more constrained phonemes ($DAC = 3$). The DAC scale considered is intimately related to the role played by tongue dorsum, and does not consider other effects like lip rounding. As a result, the proposed DAC values should bear a relation to F2 values [2].

Using the proposed DAC scale, it is possible to estimate the degree of F-to-V carryover coarticulation for a particular FV syllable. DAC values should be related to the extent to which a certain segment will influence adjacent segments, considering also that in order to evaluate the magnitude of the coarticulatory effect, we have to consider the DAC value of the contextual segment and whether the constraints involved are compatible or opposing.

We shall denote by DFV the degree of influence of the fricative on the following vowel. The DFV values can be computed as follows :

- $DFV = 0$, if $DAC(V) \geq DAC(F)$
- $DFV = DAC(F) - DAC(V)$, otherwise

The degree of F-to-V carryover coarticulation is minimal (0 valued) whenever the vowel is more constrained than the consonant, or equally constrained. The degree of coarticulation in other cases is obtained as the difference in DAC value between consonant and vowel, whenever the consonant is more constrained than the vowel. As that difference becomes bigger, it is assumed that the degree of influence of the consonant on the vowel would be bigger too.

The resulting values of DFV would be:

- $DFV = 0$: /fa/, /fe/, /fi/, /fo/, /fu/, /si/, /θi/, /ʃi/, /se/, /θe/

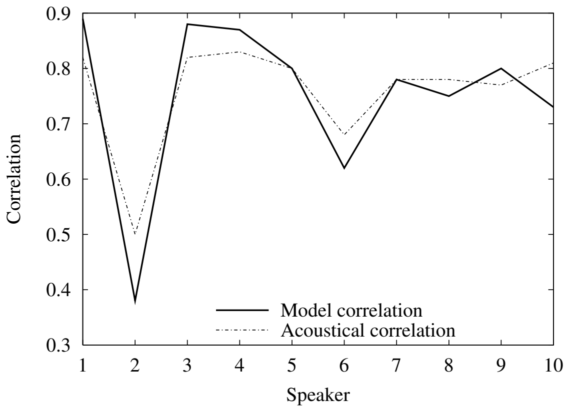

FIGURE 1: Model and acoustical correlation.

- $DFV = 0.5$: /θa/,/θo/, /θu/,/ʃe/
- $DFV = 1$: /sa/, /so/, /su/
- $DFV = 1.5$: /ʃa/, /ʃo/,/ʃu/

ACOUSTICAL MEASUREMENTS

F2 was manually measured on LPC spectra at two points within the vowel: at vowel onset and at vowel steady state. $\triangle F2$ was computed as the difference in Hz between both measurements. 5 men and 5 women with no known history of ear or throat diseases, uttered the FV syllables, formed by the combination of fricatives /f, θ, s, ʃ/ with vowels /a,e,i,o,u/. Signals were captured with a Shure BDG 3.0 microphone and sampled at 32 kHz. To obtain the formants, signals were downsampled at 5 kHz. F2 was located on the LPC spectra and stored for further calculations. The LPC order employed was 12. Whenever the second formant was difficult to find (especially in some cases at vowel onset) the FFT of a single glottal cycle was computed to help us decide its precise location.

RESULTS AND DISCUSSION

To assess the relationship between the predictions of the model and the acoustical measurements, pearson correlation was computed between $\triangle F2$ and DFV, which will be denoted as *model correlation*. To assess the consistency of the effect, for each particular FV combination, $\triangle F2$ of a given speaker was correlated with $\triangle F2$ of the other speakers, and the results were averaged in a single value, which will be denoted as *acoustical correlation*. In this way we can estimate whether the acoustical consequences of coarticulation are a general effect and can be properly represented by $\triangle F2$.

Fig. 1 shows the values of *model correlation* and *acoustical correlation* for each of the 10 speakers. All the correlations were significant at the $p < 0.01$ level, except for speaker 2. Mean correlation values are 0.75 for the *model correlation*, and 0.76 for the *acoustical correlation*. What these results show is that the degree of F-to-V coarticulation represented in the DFV values can be properly estimated using F2 excursion sizes, at least in most cases. The exceptions to this rule are represented by speaker 2, and partially by speaker 6. The personal characteristics can in some cases override the general effects of coarticulation.

As for the rest of the speakers, F2 onset and vowel values cannot be related to the place of articulation of the consonant, as some theories based on the *Locus equation concept* claim [3]. There is an interaction between the degree of articulatory constraint imposed on the consonant and on the vowel, which is responsible for the magnitude of the F2 change and location. The role of each particular vowel is not constant across fricatives, and as a result it would be very unlikely that F2 onset and vowel values, even for a particular vowel, could classify place of articulation [4]. For instance, in the /i/ context, the model based on the DAC scale predicts the same degree of coarticulation for all four places.

The *acoustical correlation* reproduces almost exactly the values of the *model correlation*. This indicates that there is a general coarticulatory effect influencing the F2 values, and that this effect is quite constant across speakers, independent of their sex, which is known to alter formant values.

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