Interarticulator phasing and locus equations

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Abstract: A locus equation plots the frequency of the second formant at vowel onset against the target frequency of the same formant for the vowel in a consonant-vowel sequence. The slope of the equation has been assumed to reflect the degree of coarticulation between the consonant and the vowel, with higher slopes associated with more coarticulation. This study examines the articulatory basis for this assumption, using VCV sequences where the consonant is a bilabial stop /b/ and the vowels one of /i, a, u/. Articulatory movements were recorded using a magnetometer system. One articulatory measure was the temporal phasing between the onset of the lip closing movement and the onset of the tongue body movement from the first to the second vowel. Another was the magnitude of the tongue movement between the onset of the second vowel and the tongue position for the vowel, averaged across four receivers placed on the tongue. When compared with the corresponding locus equation slopes, neither measure showed support for the assumption that the slope serves as an index of the degree of coarticulation between the consonant and the vowel.

INTRODUCTION

A locus equation is based on the frequency of the second formant at vowel onset and the target frequency of the same formant for the vowel in a consonant-vowel sequence. When these two values are plotted against each other for productions of the same consonant in different vowel contexts, a linear regression equation is obtained (e.g., 4). It has generally been assumed that the slope of the locus equation is related to the degree of coarticulation between the consonant and the vowel. However, most, if not all, of the evidence in support of this notion is indirect. Therefore, the purpose of the present work was to examine the relationship between the locus equation slope and articulatory measures of degree of coarticulation.

Recently, Chennoukh, Carré, and Lindblom (1) used an articulatory model to examine the relationship between speech articulation and locus equations. With the model (3), they could vary the amount of articulatory overlap between a stop consonant and a vowel to see if the amount of overlap changed the slope of the locus equation. In one condition, the movements for the vowel and the consonant started at the same time. In a second condition, the vowel movement did not start until the closure for the consonant had occurred. In the third condition, the vowel movement started at the release of the consonant. The slope of the locus equation decreased from condition 1 to condition 3. That is, the slope increased with increasing articulatory overlap between the consonant and the vowel. One measure of articulatory overlap used in the present study was adapted from the study by Chennoukh et al. (1). It consisted of the interval between the onset of the tongue movement from the first to the second vowel in a VCV sequence and the onset of the lip closing movement for a medial bilabial stop consonant in the same sequence. When using real speech, the temporal overlap between the consonant and the vowel can only be examined with a labial consonant. For consonants produced with the tongue, it is not possible to separately identify the movements for the vowel and the consonant. A second measure was the amount of tongue movement during the vowel following the consonant. As a first approximation, a large change in vocal tract shape during the production of a consonant-vowel sequence would lead to a large acoustic difference, while a smaller articulatory change would lead to a smaller acoustic change. Here, we immediately have to acknowledge a limiting factor for making direct comparisons between articulation and acoustics. Although there is a lawful relation between articulation (vocal tract shape) and the acoustic signal, it is not linear.

METHOD

Two female (LK, DR) and two male subjects (VG, AL) participated. The linguistic material consisted of VCV sequences where the consonant was /b/ and the vowels one of /i, a, u/. Ten repetitions of sequences with asymmetrical vowel contexts were analyzed. Articulatory movements were recorded using a magnetometer system, with receivers placed on the lips, the jaw, and on four points of the tongue. All the data were corrected for head movements and rotated to bring the occlusal plane into coincidence with the x-axis.

One articulatory measure was the interval between the onset of tongue movement from the first to the second vowel and the onset of the lip closing movement for the consonant. The tongue movement onset and offset were identified in the tangential velocity signal of a receiver placed on the tongue body. For the lips, the movement onset was identified in the second derivative of a lip aperture signal, derived as the vertical difference between the receivers on the upper and lower lips. A second articulatory measure was the magnitude of the tongue movement during the second vowel, averaged across the four receivers on the tongue, and measured as the Euclidean distance. The vowel onset was defined in the acoustic signal. Formant frequencies were measured from DFT and LPC spectra.
RESULTS

We will focus on sequences where the first and second vowel differ. The slopes of the locus equations were .769, .736, .842, and .862 for subjects LK, DR, VG, and AL. The corresponding correlation coefficients were .98, .97, .99, and .99. In order to make comparisons between the articulatory and acoustic measures, a single average for each articulatory measure was calculated for each subject. Thus, comparisons will be made across speakers. Within speaker comparisons would require that locus equations be calculated for different vowel contexts separately, which would make the estimates less reliable.

![Graph 1](image1.png)

**FIGURE 1.** Plot of locus equation slope and tongue-lip phasing.

![Graph 2](image2.png)

**FIGURE 2.** Plot of locus equation slope and tongue movement.

Figure 1 plots the slope of the locus equation for each subject against the measure of lip-tongue phasing. According to the hypothesis that a higher slope is related to a higher degree of articulatory overlap, we would expect the slope to increase as the tongue leads the lips. The results do not show this, however. Figure 2 plots the slope against the magnitude of the tongue movement during the vowel following the stop. Again, a smaller tongue movement is not necessarily related to an increase in the slope.

DISCUSSION

The present results do not show much support for the idea that the slope of the locus equation is related to the amount of articulatory overlap between a consonant and a vowel, at least not when compared across speakers. One reason why the present results do not appear to agree with those obtained by Chennoukh et al. (1) in their simulations is most likely that they used constant amplitude, velocity and duration for their movements. Human subjects can change all of them; the present results do not show any high correlation between the lip-tongue phasing measure and the tongue movement during the second vowel. More importantly, the variation in the amount of overlap between their three simulated conditions is quite extreme. A recent study (2) has shown that the onset of the tongue movement from the first to the second vowel in a sequence of a vowel, a bilabial stop, and a vowel almost always occurs before the oral closure for the consonant.

ACKNOWLEDGMENTS

This work was supported by NIH Grants DC-00865 and DC-02717.

REFERENCES