CONSTRAINTS ON THE BEHAVIOR OF THE TONGUE BODY: VOWELS AND ALVEOLAR STOP CONSONANTS

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ABSTRACT

X-ray microbeam data from two male subjects were examined in order to test the hypothesis that words with identical vowels but different places of articulation (alveolar versus bilabial) contain the same underlying tongue body activity. Statistical analyses of the microbeam data failed to support this hypothesis. Comparing tongue body activity across consonantal contexts revealed that the alveolar contexts affected different vowels differently. In order to explain this behavior, a computational model was developed, based on robotic models for arm-reaching tasks. The model generated tongue tip and tongue body behavior that was qualitatively similar to the microbeam data.

1. INTRODUCTION

Recent phonological theory has relied heavily on the distinction between the articulatory role of the tongue tip and that of the tongue body (which is often called the tongue dorsum) in the production of speech. The tongue body is considered to carry the burden of articulation for vowels, and the tongue tip is considered to be the articulator primarily responsible for the production of coronal consonants [1], [3], [8]. This phonological dichotomy between tongue tip and tongue body has been paralleled in phonetic theory, including the recently developed task-dynamic model of speech production [9].

Despite the phonological distinction between the two articulators, phonetic investigation has shown a high degree of correlation between the tongue tip and tongue body [5], [6], [7]. This result calls into question the independence of the articulators that is posited in phonology. The present study was done in order to determine the extent to which actual measurements of tongue tip and tongue body activity support the idea that these two articulators are independent of one another.

2. DATA

The data for this study were obtained at the University of Wisconsin's X-ray Microbeam facility. (I thank Dr. George Papçun of the Los Alamos National Laboratory for making these data available to me.) Two college-age male speakers of American English participated in the study. Gold pellets were placed as shown in Figure 1.

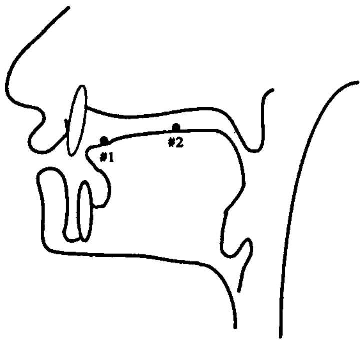

FIGURE 1. Placement of tongue pellets.

The distance from the subjects' tongue tip to pellet #1 (the tongue tip pellet) was

10 millimeters; the distance to pellet #2 (the tongue body pellet) was 35 millimeters.

Each subject was asked to produce three-syllable nonsense words of the form /CV1CəCV2C/. For a given word, all four C's were the same, taken from the set {p,t,b,d}. The two full vowels V1 and V2 were allowed to differ and were taken from the set {i,æ,a,u}. Primary stress was placed on the first syllable. This arrangement yielded words such as /bibəbib/ and /tatətit/. Words were produced in a pre-determined, random order. Visual examination of the microbeam data revealed that the vertical (Y) dimension of motion had a greater range of excursion than the horizontal (X) dimension for both the tongue tip and tongue body pellets. Therefore, only the Y dimension of these pellets' motions was considered for the study.

3. PROCEDURE, FIRST ANALYSIS

For each subject, tongue tip Y and tongue body Y values were extracted for one token of each nonsense word. Tokens were all of the same duration (approximately 1.02 seconds). The extracted tokens for thirteen alveolar consonant utterances (/'dadədad/, /'dadədid/, /'didədad/, /'didədid/, /'dudədud/, /'dædədad/, /'didədud/, /'dudədid/, /'tatətit/, /'titətat/, /'titətut/, /'tutətit/, /'tutətut/) were then strung together, making a single large data set. This data set was used as input to the BMDP 6R program for partial correlation/multivariate regression. The tongue tip Y value was used as the independent variable and the tongue body Y as the dependent variable. Thus, the residuals of the partial correlation could be considered to represent the uncorrelated, or independent, behavior of the tongue body with respect to the tongue tip. It was hypothesized that the residual would be identical to the tongue body Y for the corresponding bilabial consonant utterance, in which there was no effect of an alveolar consonant.

4. RESULTS, FIRST ANALYSIS

The results of the first analysis did not support the hypothesis of an independent vocalic component of tongue body motion in the alveolar consonant utterances. In general, the residual tongue body values were flat, indicating a constant offset of the tongue body with respect to the tongue tip. Deviations from this constant value were either much smaller than the corresponding tongue body displacement in the bilabial utterances, or did not coincide with the vocalic portion of those utterances. An example is given in Figure 2.

5. PROCEDURE, SECOND ANALYSIS

The first analysis suggested that the tongue body is strongly influenced by the tongue tip in the context of alveolar consonants. Therefore, it seemed reasonable to ask whether the alveolar consonants influence the tongue body uniformly across different vowel contexts.

To test the uniformity of the alveolar consonants' influence, it was assumed that the tongue body Y in the bilabial consonant words represented the purely vocalic behavior of the articulator. Therefore, subtracting these tongue body values from tongue body values in alveolar consonant words with the same vowel pattern would isolate the influence of the alveolar consonant. (Subtraction was used instead of a residuals technique because the first analysis suggested that the two techniques were computationally equivalent for the data examined.)

6. RESULTS, SECOND ANALYSIS

The results of the second analysis failed to support the notion that the alveolar context influences the tongue body identically across different vocalic contexts. The degree of excursion of the subtracted tongue body was much greater for low vowels than for high vowels, suggested a strong elevating effect of the alveolar context on the tongue body for low vowels. This result is illustrated in Figure 3.

7. MODELLING THE DATA

Both analyses suggested a high degree of influence of both consonants and vowels on the behavior of the tongue body. In developing a model of these influences, two distinct options presented themselves: first, a model in which the observed behavior is attributable to some unit larger than

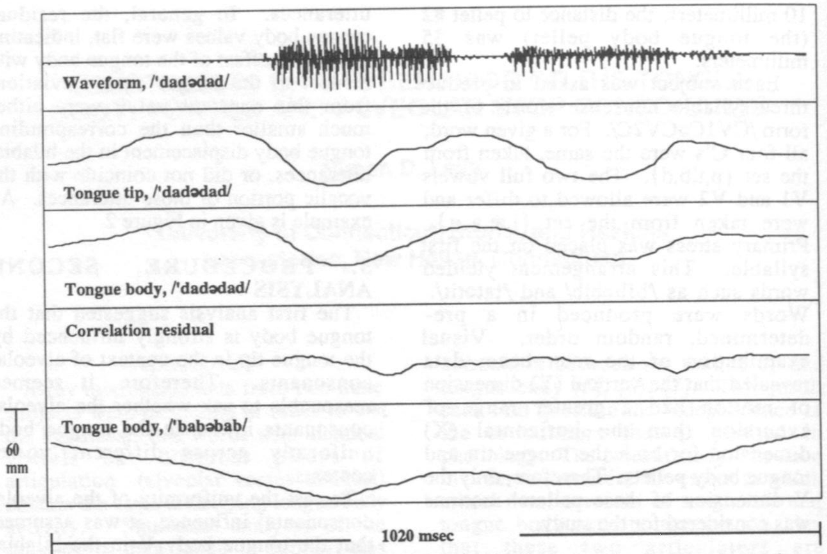

FIGURE 2. Sample results of first analysis. All articulatory channels represent vertical movement in the same scale and range.

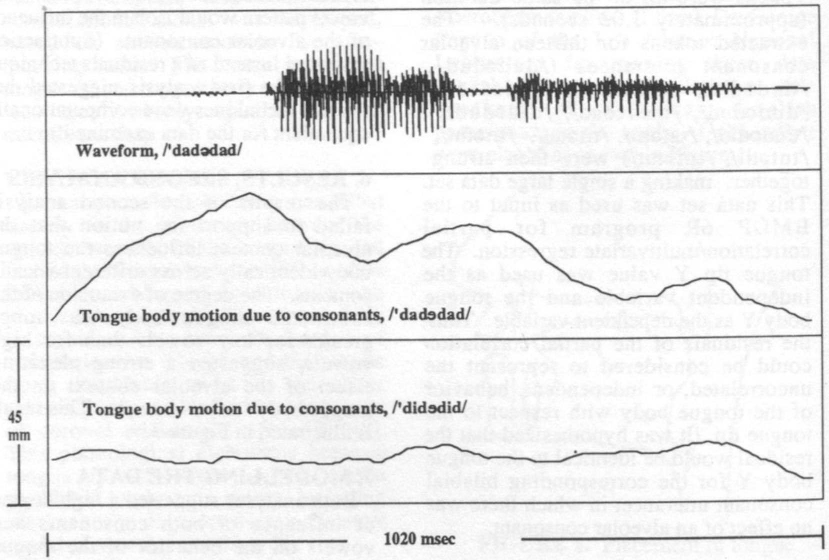

FIGURE 3. Sample results of second analysis. Both articulatory channels represent vertical movement in the same scale and range.

consonants or vowels (demisyllables, perhaps); second, a model in which the behavior results from physical constraints on the tongue's ability to achieve distinct consonantal and vocalic targets. (Öhman [7] developed a set "coarticulation functions" to generate tongue positions from separate consonantal and vocalic influences, but the physical interpretation of these functions is not clear.)

Models of this sort have been developed in the fields of robotics [4] and speech synthesis [2]. A simplified representation of the tongue based on these models is presented in Figure 4. In this model, the distance **d** between the tongue tip's current position and its target position (for an alveolar stop) is reduced iteratively by modifying the angles **a1** and **a2**.

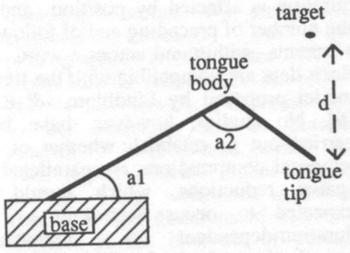

FIGURE 4. A task-based model of the tongue

Preliminary experiments with this model have revealed behavior that is qualitatively similar to certain aspects of the observed behavior of the tongue: The whole model tongue moves in order to support the achievement of alveolar closure, and the difference between the vertical position of the model tongue tip and that of the model tongue body increases as the tip nears its target.

8. CONCLUSIONS

The analyses described here suggest a high degree of interaction between the articulatory goals of the tongue tip and tongue body in the context of alveolar stop consonants. Although it is traditionally associated with the production of vowels (and dorso-velar consonants), the tongue body is strongly constrained by the articulatory requirements of alveolar stops. Nevertheless, it may be possible to maintain the distinction between the articulators by using a model that takes account of the overall behavior of the tongue in achieving different articulatory goals.

9. ACKNOWLEDGMENTS

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