VOWEL-RELATED LINGUAL ARTICULATION IN /QCVC/ SYLLABLES AS A FUNCTION OF STOP CONTRAST

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ABSTRACT

Lateral cineradiographic pellet-tracking of tongue blade and tongue body movements along with formant frequency trajectories show that articulation of the vowels /i/ and /u/ in /QCVC/ syllables vary by as much as 8-10 mm as a function of the stop consonant environment in which they are produced. The magnitude of the variation is related to the identity of the stop and vowel.

INTRODUCTION

This study represents one of a set of experiments completed or underway at Haskins Laboratories that aim to study the dynamics of vowel articulation. What distinguishes the set of studies from previous work is that the dynamics of vowel articulation is studied by examining data representing the four accessible measurement levels of speech production, namely 1) muscle activity (by hooked-wire electromyography), 2) corresponding movements of the speech structures (primarily by tracking the movements of lead pellets glued to the lips, tongue, and jaw by lateral cineradiography or x-ray microbeam), 3) representative speech acoustic signals, and 4) perceptual testing of selected auditory segments to determine whether or not the underlying articulatory movements provide relevant linguistic information. In the first experiment to use these measurement techniques, a single subject's productions of disyllables of the form /QCVC/, where V represented one of eleven vowels, were analyzed. As an example of the conclusion that can be drawn from multi-level analysis, the results showed that vowel-related tongue horizontal and vertical movements can have different time constraints in labial environments. When fronting and raising occur together they are necessarily time-locked since they are caused primarily by the same muscle, genioglossus. Backing and raising, on the other hand, can and do occur independently, since they are caused by different muscle groups. While vertical movements for all vowels and horizontal movements for front vowels always began about the moment of implosion for the initial stop, horizontal movements for back vowels began much earlier, even before the acoustic onset of the schwa. Acoustic and perceptual analysis indicated that anticipatory tongue movements were linguistically significant since listeners were able to identify the vowels when presented with only a portion of the schwa segment.

More recently, a second subject has been run following the same procedures but increasing the data base in two ways: 1) the same set of vowels were produced in labial, alveolar, and velar stop environments, and 2) more extensive tongue EMG insertions representing the complete set of lingual extrinsic and accessory muscles. Analysis of EMG data from the second subject in general supports the temporal differentiation in vertical-horizontal tongue movements in the first subject in that the muscles of the tongue appear to be distinctly organized for front versus back vowel production [2]. Biomechanical descriptions of tongue dynamics, such as the relationship between genioglossus and fronting-raising in the first subject, will be enhanced significantly by mapping the EMG data for the second subject onto his x-ray data. While the overall purpose of the combined EMG and x-ray runs is to study the dynamics of vowel articulation in a fashion similar to the initial experiment [1], the paper presented here will focus on the x-ray runs. The purpose of the paper is to give a quantitative description at the movement and acoustic levels of the variation in vowel-related tongue articulation that occur as a function of producing the vowels /i/ and /u/ in labial, alveolar, and velar stop environments.

METHODS

An adult male native speaker of American English with a New York City dialect produced two repetitions of /QCVC/ disyllables where /C/ represents /p/, /t/ or /k/ and /V/ represents one of eleven vowels. The initial and final consonants in each utterance were identical. Lateral cineradiographic films were made at a rate of 60 frames per second while the subject produced isolated syllables at a rate of about one every two seconds. Figure 1 represents a schematic diagram of the midsagittal plane of the vocal tract sketched from a single frame of the x-ray film. The figure shows the location of lead pellets glued to the tongue blade, middle and rear dorsal areas of the tongue surface at the midline, and a jaw pellet attached between the lower central incisors. Measurements of pellet movements were made on a frame-by-frame basis with the aid of

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RESULTS

The results show that for this subject the dynamics of vowel articulation for /i/ and /u/ can be altered significantly as a function of the identity of the stop in which they are produced. Assuming that the middle and rear dorsal pellets yield appropriate estimates of tongue body shape, Table 1 shows that tongue body configurations for /i/ vary by nearly 10 mm, with the velar context producing the most high and front /i/. For /u/, variation in tongue body configuration is about 6 mm, and again the velar context produces the most extreme lingual displacement. Figure 6 shows vertical displacement trajectories as a function of stop constriction location are observed. Although the center frequency of the first and second formant also showed large variation with stop context, the expected relationship between formant frequency and tongue vertical and horizontal displacement is not observed, presumably due to the stop consonant influence on pharyngeal cavity width and the movements of other structures, most likely the lips or larynx.

DISCUSSION

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TABLE 1.
Average pellet displacement in mm from origin and average first and second formant values in Hz for the vocalic segment of /scic/ and /scuc/.
See text for definition of measurement techniques.

<table>
<thead>
<tr>
<th>Vertical Displacement</th>
<th>Horizontal Displacement</th>
<th>Formant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jaw Blade</td>
<td>Middle</td>
</tr>
<tr>
<td>/spip/</td>
<td>0</td>
<td>7.2</td>
</tr>
<tr>
<td>/sitt/</td>
<td>1.6</td>
<td>8.0</td>
</tr>
<tr>
<td>/skik/</td>
<td>0.8</td>
<td>7.2</td>
</tr>
<tr>
<td>/spup/</td>
<td>0.8</td>
<td>-5.6</td>
</tr>
<tr>
<td>/sut/</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>/skuk/</td>
<td>0.8</td>
<td>-2.4</td>
</tr>
</tbody>
</table>

Tongue blade configurations also vary greatly as a function of the stop. Whereas the magnitude of fronting and raising generally covary in tongue body articulation, they do not seem to covary for tongue blade movements. The variation for tongue blade configurations is about 6 mm in the vertical dimension, the differentiation being larger in /u/ than in /i/ with the alveolar context producing the greatest displacement. In the horizontal dimension, tongue blade displacement varies by as much as 8 mm, the velar context producing the most front tongue blade displacement.

Comparisons between movement data reported here with previously published data are not straightforward since either the method used to measure tongue displacement or the design of the experiments differ significantly. For example, the patterns reported here can be compared with corresponding data taken from a cinefluorographic experiment that similarly measured the effect of the stop consonant on vowel-related vertical displacement [3]. The two experiments are in agreement in that vowels in velar context are produced with greater vertical displacement relative to labial and alveolar contexts. However, the published displays of the cinefluorographic trajectories appear to indicate that the magnitude of the variation during the vocalic segment is no greater than 5 mm. For a number of reasons, a more appropriate comparison of the magnitude of the variation can be made between experiments that employ pellet-tracking. X-ray microbeam pellet-tracking was used to estimate the variation in a large number of repetitions of the vowels /i/, /a/, and /ae/ occurring in a wide variety of consonantal environments [4,5]. Though not specified in the text, the figures indicate that the variation approximate the 8-10 mm maximum variation reported here. Finally, there are many acoustic based studies on the topic (e.g. [6,7]). The first and second formant frequency values reported here are in good agreement with these data.

REFERENCES