CROSS-SECTIONAL TONGUE MOVEMENT AND TONGUE-PALATE MOVEMENT PATTERNS IN [s] AND [ʃ] SYLLABLES

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ABSTRACT

This study examines C-to-V movement patterns to determine the predictability of cross-sectional tongue movements, seen in ultra-sound images, from the movements in tongue-palate contact patterns, observed with EPG. Results indicate that tongue shapes are predictable for consonants, but not for C-to-V movement patterns, due to the confounding effects of jaw and tongue lowering.

1. INTRODUCTION

The tongue is one-third of the vocal tract and it is the major contributor to vocal tract shape. Measuring tongue movements, however, is very difficult, and real-time three-dimensional recording of such movements is not possible at present. One technique, ultrasound imaging, is able to provide two-dimensional scan sequences of tongue surface movements during speech. Scan sequences of the tongue can be imaged in multiple sagittal and coronal planes, and then temporally and geometrically aligned into a time-varying, multi-sectional composite of the tongue [1].

In addition to tongue movement, the present study examined the relationship between tongue movements and tongue-palate contact. Electropalatography provides important information about how the tongue uses the palate to create various movement patterns. The hard palate is generally ignored in vocal tract models because it does not move. However, it is, in fact, quite important in tongue dynamics. The palate provides the tongue with a solid base of contact for sensory feedback, for light support during rapid or complex movements, and for resistance. When the tongue tip pushes against the palate, various tongue shapes and movements are facilitated.

The tongue is a boneless, jointless structure, yet it can elevate, depress, widen, narrow, extend, and retract. It also can create leverage, torsion, a midsagittal groove, a midsagittal arch, and move differentially, both laterally-to-medially and left-to-right. These feats are remarkable, and are possible largely because of the tongue's exceedingly complex musculature, the support of the jaw, and the support and resistance of the palate.

Some ultrasound data already exist describing cross-sectional tongue shape [5] and movement patterns [6]. We also know quite a bit about tongue-palate contact patterns (e.g.,[2,3,4]). The present study investigates whether patterns seen in coronal tongue movements during CV syllables are reflected in tongue-palate contact patterns.

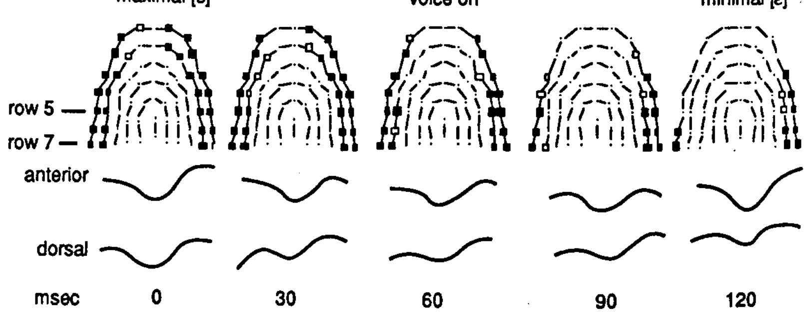

Figure 1: EPG and ultrasound sequences for the [s] to [ε] movement. The sequence begins at maximal [s] and ends at minimal [ε]. Samples are presented at every 30 ms and the two data sets are not exactly to scale, as the ultrasound images do not include the most lateral margins of the tongue. The ultrasound images show that the anterior tongue lowers as the dorsal tongue elevates. Jaw lowering (not pictured) lowers the tongue so that row 7 on the palate does not reflect dorsal tongue raising.

2. METHODS

The subject was a normal male speaker of American English (New York City dialect) in his mid-40's. The subject's palate has a noticeable but normal degree of post-alveolar asymmetry. Maximal asymmetry occurred 30 mm behind the incisors: The right side was 2.5 mm higher than the left. The phones [s ʃ ε ɑ] were embedded in [əCVCə] utterances, with the same C preceding and following the V. These phones were chosen because of their variety of tongue shapes, positions, tongue-palate contact patterns, and C-to-V movement patterns.

2.1 Ultrasound Recording/Analysis

Ultrasound images of the tongue were made in real time at the NIH, using an established recording procedure [5]. Each image was a 90° sector representing a 1.9 mm thick slice of tissue in the coronal plane. Scan sequences were produced at 30 scans per sec.

The ultrasound transducer was placed under the chin 20 mm posterior to the mental symphesis, using a specially designed holder. The beam angle was 110° posterior to the long bone of the mandible. The subject wore the electropalate, to create the same oral morphology as in the EPG recording session. The speech materials were recorded 10 times at this scan angle, and then 10 times with the transducer repositioned at 120° posterior, to provide anterior and dorsal coronal scan sequences of the tongue.

The ultrasound and audio signals were recorded on a videotape recorder, and analyzed on Macintosh IIci and Compaq 386 microcomputers, using custom software [1,7]. For each coronal scan sequence, the video fields containing the movements from maximum C to minimum V position were entered into the computer. The tongue surface profile was extracted for each field and stored as *xy* coordinates for later use in graphics and other software applications.

2.2 EPG Recording and Analysis

EPG data were collected at a later date at Haskins Labs, using a custom fitted RION artificial palate containing 63 electrodes. The sweep rate for the palate was 64 frames/sec, and the electrodes are c. 4 mm apart. The speech materials were repeated 20 times, while the EPG and audio signals were recorded on an FM tape recorder. After the EPG data had been digitized, tokens of each utterance type were identified from the audio signal, and were aligned at the onset of the stressed vowel. A software generated composite containing electrodes contacted in 80% of the repetitions was created for each utterance. The pre-stress C and the stressed V were selected on the basis of maxima or minima of palatal contact, as appropriate for each sound.

The ultrasound scan sequences and the EPG frame sequences for each C-to-V

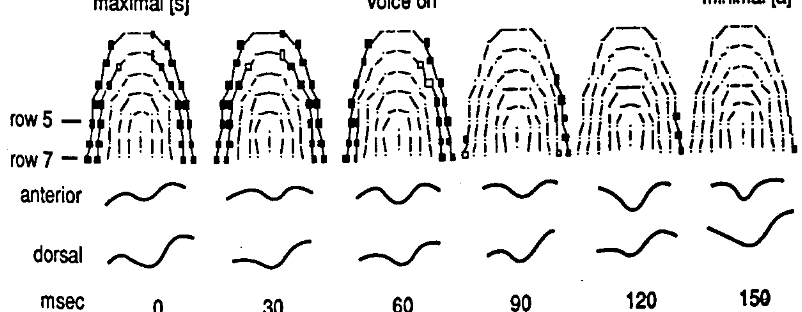

Figure 2: EPG and ultrasound sequences for the [s] to [a] movement. A small amount of anterior tongue lowering and dorsal tongue elevation can be seen. Jaw opening (not pictured) further lowers the tongue.

utterance were aligned using a time-warping algorithm that referred to the speech signals from each of the two datasets. The aligned C-to-V sequences appear in the accompanying figures.

2.3 Movement Patterns

In the ultrasound scan sequences, two patterns of C-to-V movement were observed and defined. The first, *midsagittal lowering*, was the fall of the midtongue to a greater degree than the lateral tongue, either creating a deeper groove or changing a convex (arched) tongue contour into a concave (grooved) one. The second pattern, *groove narrowing*, was the inward movement of the lateral sections of the tongue by at least one mm. Groove narrowing changes the the width of the groove without necessarily deepening it; the two patterns can co-occur.

In the EPG frame sequences, two movement patterns were also defined during the C-to-V movement. The first, *medial contact decrease*, involved the loss of medial tongue-palate contact during the C-to-V transition. The second pattern, *anterior contact decrease*, was a decrease in the number of tongue-palate contacts in the four anterior rows of the electropalate. Also of interest were changes in medial contact and symmetry at rows 5 and 7 of the electropalate, the calculated location of the anterior and dorsal ultrasound scans.

3. RESULTS

All EPG frames showed asymmetry, reflecting the subject's palatal shape. EPG patterns showed bilateral tongue-palate contact during both [s] and [ʃ] (Figs. 1-4, frame 1). At maximal [s] contact was symmetrical. At rows 5 and 7 tongue palate contact was approximately 8 mm wide on both sides. At maximal [ʃ], contact was asymmetrical. At row 5 contact was 8 mm wide on the left and 19 mm wide on the right. At row 7, contact was 13 mm wide on the left and 18 mm wide on the right. Ultrasound images showed that at maximal [s] the tongue was grooved midsagittally both anteriorly and dorsally (Figs. 1-2, frame 1, bottom). During [ʃ] (Figs. 3-4, frame 2, bottom), the tongue was arched and oblique with a higher right contour.

Movement into the following vowels was accompanied by a decrease in anterior and medial EPG contact, indicating anterior and medial tongue lowering, with retention of lateral contact. For minimal [ε] and [ɑ] (last frame) there was more asymmetry and greater medial contact following [ʃ] than [s] and more contact at row 7 than at row 5. During [s]-to-V movement, anterior-to-posterior tongue rotation was evident in the ultrasound scan sequences. Groovenarrowing and deepening appeared anteriorly during both [s]-to-V movements. During the [ʃ]-to-V movement, the tongue rotated left-to-right. Midsagittal lowering changed the arched shape into a groove during both vowels.

There is a fairly direct relationship between tongue-palate contact and cross-sectional tongue shape during the consonants for this subject (frame 1). Lateral tongue-palate contact 18 mm wide on the right accompanied the arched tongue shape seen in [ʃ]. The lesser, more lateral contact observed during [s] accompanied a lower tongue and a midsagittal

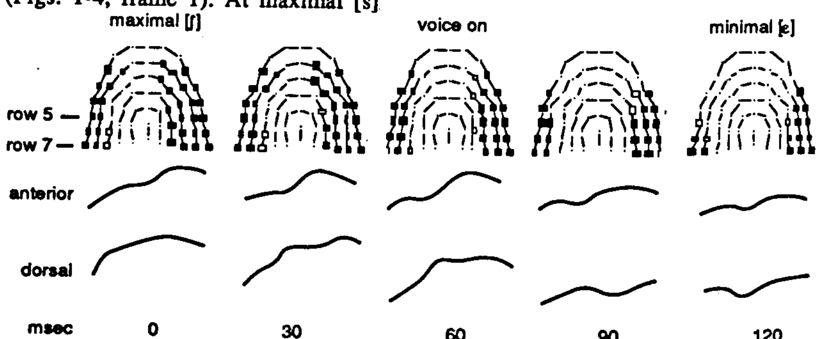

Figure 3: EPG and ultrasound sequences for the [ʃ]-to-[ε] movement. The dorsal tongue lowers to a greater extent than the anterior tongue. The tongue grooves midsagitally as it lowers.

groove. Tongue movement features like groove onset, narrowing, deepening, and increased symmetry were not visible in the EPG data. Nor was anterior-to-posterior rotation.

4. DISCUSSION

The EPG patterns predicted the ultrasound cross-sectional tongue shapes, to some extent. Beyond some degree of medial tongue-palate contact, sibilants no longer used a grooved coronal tongue shape, as during [s], but rather an arched one, as during [ʃ]. Fewer medial EPG contacts reflected a checking of the upward force of the tongue and a midsagittal groove. Palatal asymmetries were reflected in tongue shape when the tongue approximated the palate more medially. [ʃ] used a wide area of tongue palate contact at the location of the asymmetry. [s]'s narrow, lateral tongue-palate contact occurred where the palate was level.

It was proposed earlier that tongue-palate contact provides the tongue both with sensory feedback and with resistance to help it assume various shapes. The correlation between tongue shape and EPG pattern for the consonants suggests that a high tongue/jaw position allows great force in the tongue-palate contact. This would facilitate maintaining a precise sibilant airstream. During movement, however, the jaw removes the support from the base of the tongue. EPG contact then may serve more for sensory feedback than for resistance, and, as such, reflects tongue shape to a lesser degree.

In conclusion, tongue-palate contact predicted cross-sectional tongue shape during sounds that used a high jaw position. During vowels, tongue shape was not as predictable because jaw opening made tongue shape less directly a function of palatal contact. Finally, tongue-palate contact patterns did not reflect either overall tongue movement patterns like anterior-to-posterior tongue rotation or midsagittal movement patterns like groove narrowing and deepening because local tongue lowering and jaw opening removed these activities from the sphere of the palate.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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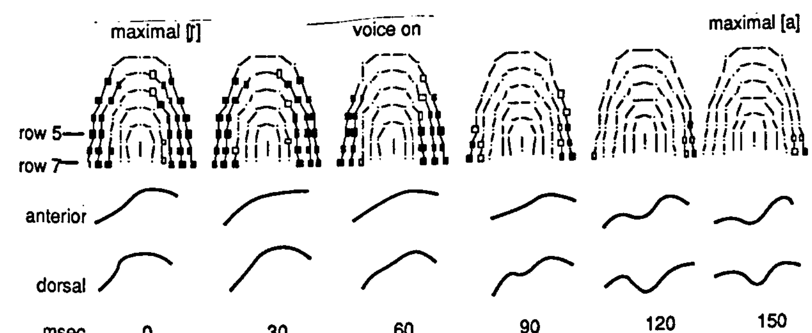

Figure 4: EPG and ultrasound sequences for the [ʃ]-to-[a] movement. In both planes, the tongue develops a midsagittal groove and lowers in height. Dorsally, it rotates left-to-right. Jaw lowering (not pictured) further lowers the tongue.