AN EXAMINATION OF THE JAW'S CONTRIBUTION TO LINGUAL STABILITY

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ABSTRACT

Analysis of ultrasound, electropalatography, and jaw motion data for production of VCVCə sequences has shown the coupling among the tongue, jaw, and maxilla to be quite different for /s,ʃ/ and /l/ [6]. In the current study, two sensors are used to transduce jaw motion affording better distinction among the rotational and translational components of the movement; and a new technique for extracting tongue surface contours [5] is used to correlate loci of curvature with jaw motion and palatal contact patterns. [Supported in part by NIH grant DC-00121 to Haskins Laboratories.]

1. INTRODUCTION

In speech production, we try to make quantifiable observations of complex structures and events without trading scope for precision. The tongue is certainly the most interesting and complicated articulator structure to observe because, while difficult enough to examine alone, it continually interacts with other structures. Production of alveolar consonants, for example, entails interaction among the tongue — the whole tongue — the jaw, and the maxillary arch. Unfortunately, no single transduction method affords simultaneous observation of all the major components of this interaction. Tongue-palate contact is largely non-sagittal and often asymmetrical [2] and the jaw's motion is not a trivial rotation around a pivot [1].

In recent studies we have tried to improve our understanding of tongue behavior and its interaction with the jaw and maxilla during alveolar production by combining data from a variety of sources. Examples are the combined use of ultrasound (US) imaging and x-ray microbeam [3] or US, electropalatography (EPG), and jaw motion, [6]. Although mixing such techniques makes data analysis more elaborate, especially since the data cannot all be recorded simultaneously, it has given us insight into tongue behavior and its functional coupling with other stuctures. In what follows, we further consider these issues aided by two technical improvements: extraction of tongue surface contours from digitized ultrasound and the use of two position sensors in tracking jaw movement.

2. METHODS AND PROCEDURE

In this paper, we discuss a small sample of ultrasound (US), electropalatography (EPG), and jaw motion data taken from a much larger set of utterance types and speakers. The sample consists of one speakers's VCVCə utterances, where C is s, ʃ, or l and V is a. Each utterance type was repeated 10 times in succession at a rapid, but unprompted rate.

Ultrasound images were recorded at NIH using an ATL ultrasound unit and 30 msec sector scanner transducer. The transducer was mounted under the subject's chin so as to maintain a precise angle of tilt and to minimize transduction of jaw motion (For details, see

[4]). The ultrasound images were digitized and spatially smoothed using Wayne Rasband's IMAGE program running on a Macintosh ll equiped with a Data Translation Quick Capture Board (DT 2255). Tongue surface contours were extracted using software developed by Michael Unser [5].

Jaw movement, EPG, and acoustic data were recorded at Haskins Laboratories. Vertical and horizontal (anterior-posterior) movement of the jaw was transduced from two infrared LEDs placed 4 cm apart on a rigid splint attached to and extending midsagittally from the jaw. Tongue palate contact was transduced at 64 frames per second via a Rion flexible palate and electropalatograph. Movement data were digitized at 200 Hz, numerically smoothed at 40 Hz, corrected for head movement, and differentiated to obtain instantaneous velocity.

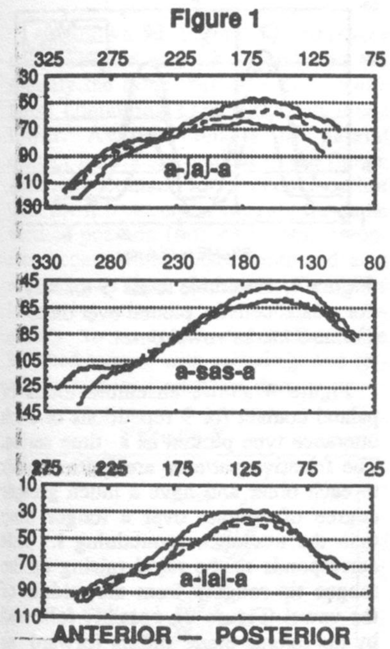

Figure 1. Extracted tongue contours taken from C1 (solid), V (dotted), and C2 (solid). Plot coordinates are rotated 35 degrees relative to the head.

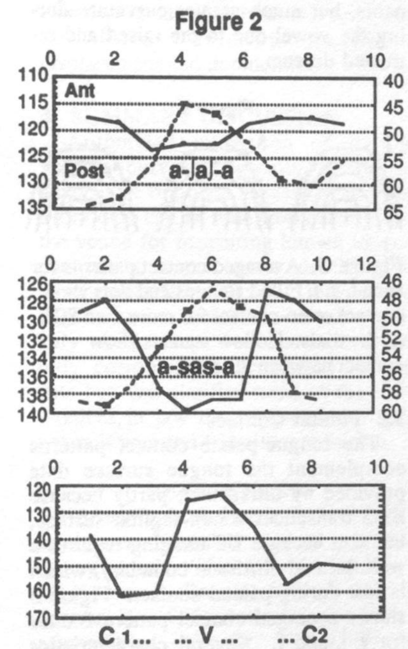

Figure 2. Top traces: overlayed time series measures for anterior blade (solid) and dorsum (dashed). Bottom: radius of circle fit to tongue surface over time.

3 RESULTS

3.1 Tongue Surface

In Figure 1, extracted tongue surface contours corresponding to maximum positions achieved during the C1, V and C2 portions of an utterance are shown for each consonant. The fricatives, s and ʃ, behave in similar fashion. Anterior blade is high and forward for C1, lowers during the C1-V transition as the dorsum raises and retracts, and then reverses the process in the V-C2 transition. Thus, the tongue surface rocks back and forth around an anterior-posterior pivot. This is also shown in the top two panels of Figure 2, where measures of blade and dorsum height, calculated by the curvature extraction program, are overlayed for the CVC time series. For l and despite the fact that the jaw is raising and lowering, the scans show little change of position for anterior blade and the extreme posterior of the tongue. Finally, tongue curvature is greater during the vowel for all 3 utterances. The bottom panel of Figure 2 shows an example of how the radius of the circle that was fit to the tongue surface decreases for the vowel. The larger radii for C1 and C2 suggest a flatter tongue surface for the consonants, but much greater curvature during the vowel due to the raised and retracted dorsum.

Figure 3

Figure 3. Averaged contact patterns for each ʃ, s, l. Filled squares and dots show contact or no-contact for more than 80% of the trials. Hollow squares show contact between 20-80%.

3.2 Palatal Contact

The tongue-palate contact patterns complement the tongue surface data provided by ultrasound; partly because EPG transduces a non-sagittal surface, but also because US imaging requires a well defined air/tissue boundary, which is lost during palatal contact. Figure 3 shows averaged contact pattern frames for s, ʃ, and l. Several characteristics are noteworthy. First, there is less contact along the sides (parasagittally) for s than ʃ. This could be due to the more grooved sagittal channel of ʃ. Second, there is more anterior, including midsagittal, contact for s than ʃ. This suggests that the tongue tip for ʃ is angled down and/or retracted more than for s. Third, contact for l is restricted to the anterior portion of the artificial palate. Although this speaker's contact pattern is more bilaterally symmetrical than many we have seen, the absence of extensive posterior bilateral contact is typical. Previously, we have suggested that the tongue tip may serve as an anchor for the lateral post-alveolar release. However, in this speaker's case, it could indicate that the tongue tip is angled upward relative to the rest of the blade. Finally, these patterns are very stable across repetitions as shown by the small number of hollow squares, indicating that a given electrode is either on or off for more than 80% of the repetitions.

Figure 4

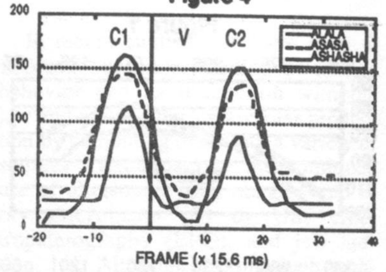

Figure 4. Ensemble totals (9 tokens) for palatal contact, plotted over time. Frame 0 marks vowel onset.

Figure 4 shows ensemble totals of palatal contact for 9 repetitions of each utterance type plotted as a time series. The fricative patterns are quite similar to each other and have a much greater degree of contact over a longer time than the utterances containing l. This corresponds to the rapid raising of the tongue tip roughly from the middle of the vowel (Figure 2), possibly followed by the tongue blade sliding forward as the jaw raises into position. Unlike contact for l which has substantially less contact for C2 than C1, the greater precision required for production of fricatives might explain why there is only slightly less contact for post-tonic C2. Finally, the relatively abrupt onset and offset of contact for l may result from articulation of the more agile tongue tip, hence the absence in l of the anterior-posterior pivoting observed for s and ʃ (Figure 2).

3.3 Jaw Motion

Figure 5

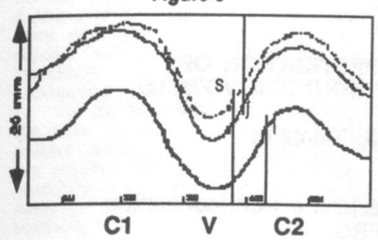

Figure 5. Averaged jaw position over time for each utterance type.

As shown in Figure 5, utterances containing s and ʃ are produced in roughly the same vertical region, while those containing l are produced much lower. Average onsets of palatal contact for C2 are marked in the figure. Although contact for s occurs earlier than for ʃ, it occurs at roughly the same vertical position (diff < .4 mm). l contact occurs 40-50 msec later and at a much lower jaw position. The jaw's lowered postion for **alala** may be necessary to accommodate the more bunched tongue with raised tip and relatively high and retracted dorsum.

Figure 6

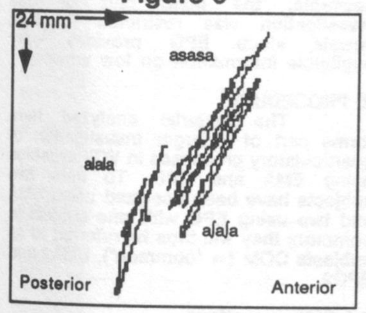

Figure 6. Lissajous plots show 2 dimensional motion of the jaw for each utterance type.

When two dimensional motion of the jaw is examined (Figure 6), we see that the jaw also is more retracted for l relative to s and ʃ, and that there is much less jaw rotation — i.e., the jaw is translated vertically. Analysis of the jaw kinematics corroborates the qualitative differences seen here. When jaw displacement measures (C1-V, V-C2) are compared for the two position sensors, the displacement difference (sensor 1 - sensor 2) was reliably less for l than the two fricatives, indicative of a greater degree of vertical translation. Furthermore, comparing the sensor displacement difference for C1-V and V-C2, there was even more vertical translation during the raising V-C2 movement for l. Finally, the jaw moved with fairly constant average velocity for the fricatives, but there was no linear relation betweeen displacement and duration for l.

4. SUMMARY DISCUSSION

Automated extraction of tongue surface curvature greatly facilitates analysis of digitized ultrasound images. More data can be analyzed quickly and the venue for measuring known tongue parameters as well as the identification of new ones is enhanced. Transduction of jaw motion which can be more reliably analyzed in two dimensions not only corroborates the tongue tongue data but also clarifies some of the differences in jaw movement control between lateral and fricative production.

REFERENCES

[1] Edwards, J., & Harris, K.S. (1990). Rotation and translation of the jaw during speech. *JSHR, 33,* 550-562.
[2] Hamlet, S., Bunnell, H.T., & Struntz, B. (1986). Articulatory asymmetries. *JASA, 79,* 1164-1169.
[3] Stone, M. (1990). A three-dimensional model of tongue movement based on ultrasound and x-ray microbeam data. *JASA, 87,* 2207-2217.
[4] Stone, M., Shawker, T., Talbot, T., & Rich, A. (1988). Cross-sectional tongue shape during vowel production. *JASA, 83,* 1586-1596.
[5] Unser, M., & Stone, M. (1990). Computerized extraction of the tongue surface from sequences of ultrasound images. *JASA, 87,* S122.
[6] Vatikiotis-Bateson, E., & Stone, M. (1989). In search of lingual stability. *JASA, 86,* S115.