RECONSTRUCTING THREE-DIMENSIONAL TONGUE TRAJECTORIES USING MULTIPLANAR PACED SONOGRAPHY

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1. INTRODUCTION

The tongue has been characterized as a non-rigid three-dimensional hydrostat (Smith & Kier, 1989). However, investigations of tongue movement in speech are usually limited to the midsagittal plane (electromagnetic articulography, videofluoroscopy, B-mode ultrasound). This is unsatisfactory because tongue movement in speech is a three-dimensional process, and the position of the lateral free margins of the tongue cannot be automatically inferred from the midsagittal plane. The goal of our research is to develop a feasible method of 3D ultrasound imaging of surface tongue movement for qualitative and quantitative analysis. Previous 3D research in ultrasound imaging of the tongue has focused on the reconstruction of sustained sounds (Watkin & Rubin, 1999; Bressmann et al., 2005; Stone & Lundberg, 1996). Recently, Yang & Stone (2002) demonstrated a method of reconstructing 3D tongue movement during sentence-level speech from multiple two-dimensional B-mode scans. However, the authors found considerable temporal variability between tokens even when their speaker tried to repeat every sentence with exactly the same speed and intonation. Therefore, they used a dynamic programming algorithm to time-stretch and compress their tokens before reconstructing smooth three-dimensional tongue surface movement. The purpose of our exploratory study was to build on the research by Yang & Stone (2002) and to develop a more practical method of reconstructing three-dimensional tongue movement in speech. We investigated biomechanical aspects of tongue movement such as its surface velocity and functional segmentation.

2. METHOD

The participants were seven normal adults (two males and five females, 22 to 34 years of age). They sat in an office chair with their foreheads resting against the Comfortable Head Anchor for Sonographic Examinations (CHASE). The apparatus stabilized the participant's head and held the ultrasound transducer in a constant position under the subject's chin. A lever system allowed the examiner to move the transducer to different preset view angles. For the present study, the ultrasound transducer was angled at -20º, -10º, 0º and 10º (see Figure 1). The data was collected using a General Electric Logiq Alpha 100 MP ultrasound machine with a 6.5 MHz micro convex curved array scanner with a 114 degree view (Model E72, General Electric Medical Systems, PO Box 414, Milwaukee, Wisconsin 53201). The ultrasound video and acoustic signal were simultaneously recorded to digital video.

Fig. 1. CHASE II set-up with four coronal scan angles

The participants recited the last stanza from William Wordsworth's poem "I wandered lonely as a cloud" (1815), which was chosen for its regular iambic foot. The participants read the stanza double-time to a digital metronome set at 108 beats per minute. Subjects recited the passage with a neutral intonation on a single breath stream. Four repetitions were recorded, one at each coronal plane.

Ultra-CATS, a software tool developed by our lab for semi-automatic tongue contour tracings, was used to analyze the data. Data from the four coronal planes were assembled into a 3D surface graph to create a moving image (see Figure 2). The seven speakers' results were compiled to analyze tongue velocity and functional segments. We calculated total surface velocity at 28 points in meters per second and used a principal component analysis with Varimax rotation to identify functional segments on the tongue surface.

Fig. 2. Sample frames from moving tongue reconstructions. The anterior tongue is toward the lower left side of each frame

3. RESULTS

3.1 Velocity

Figure 3 shows a topographical map of the tongue indicating the average speed at the 28 surface points. The centre of the tongue moved with greater velocity than the sides, and the front with greater velocity than the back.

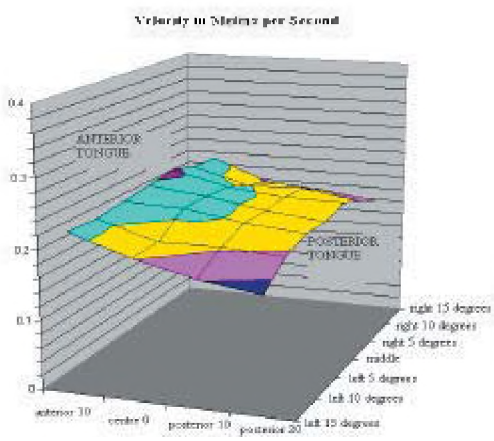

Fig. 3. Velocity map of the tongue surface

3.2 Functional Segments

A principal component analysis was used to identify functional segments in tongue movement. Three functional segments were identified. Component 1 included all 14 data points in the posterior tongue (-10º and -20º), accounting for 87% of the variance. Component 2 included all seven data points in the anterior plane (10º), as well as the four most extreme lateral points on the coupling plane (0º). This component accounted for an additional 5 % of the data. Finally, a third component included the three remaining central points of the tongue blade (0º), accounting for 3% of the variance. The three components combined accounted for 95% of the variance.

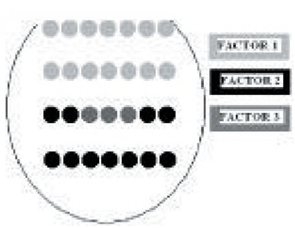

Fig. 4. Functional segments in the moving tongue

4. DISCUSSION

By simply using a digital metronome to pace the participants' speech and the CHASE lever system to control transducer position, we reconstructed visually and phonetically plausible three-dimensional tongue surface movement from seven speakers. The length of the speech sample and the number of participants make our data set the largest and most extensive yet reported. Important parameters of tongue function in speech were identified for further investigation. We found a consistent pattern in the velocity of different parts of the tongue. We posit that the anterior tongue moved most rapidly because the tongue blade has more degrees of freedom than the posterior tongue, which is anchored to the pharynx. The greater speed in the centre of the tongue compared to the sides can be explained by the activity of the midline genioglossus furrow. The principal component analysis revealed a certain degree of independence in the anterior and posterior parts of the tongue, which confirmed findings from our previous research (Bressmann et al., 2005).

The results reported here are the first steps toward a more comprehensive investigation of complex three-dimensional tongue movement tongue in speech. In future research, we will expand our data collection and develop quantitative functional indicators for the mathematical description of biomechanical principles governing lingual movement in speech. A long-term goal is to appropriate the method for the analysis of speech disorders resulting from structural defects or neurogenic movement disorders.

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