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CURVILINEAR ANALYSIS OF TONGUE MUSCLE MOVEMENT DURING SPEECH PRODUCTION

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INTRODUCTION

Speech production is a fundamental contributor to the quality of life of most humans, and is largely mediated by tongue motion (which is also present in mastication and swallowing) through interaction between active contraction patterns and passive volume preserving deformation [1]. This study is motivated by the need for understanding how local muscle behavior is linked to global motion patterns within the tongue. For example, muscle activation usually results in shortening along the line of action of the muscle. However, most muscles in the tongue are interdigitated with others and their lengths do not necessarily form a straight line [2]. The presented approach, analysis of a curve in 3D space, effectively simplifies the analysis of displacement field data, while capturing the kinematic behavior of a given muscle. This is promising, since the tongue moves continuously during speech and different regions experience different demands; thus, the mechanical consequences of activation by a muscle or its neighbors can be complex and not limited to contraction or elongation. In this study, we show that intonation of different words translate in to quantifiable differences in curvilinear kinematic properties consistent with the expected qualitative muscular behavior.

METHODS

This study examined five kinematic properties (below) associated with a curve in the approximate line of action of the superior longitudinal (SL) muscle during the pronunciation of two words: "ashell", and "asouk". The approximation of line of action was derived by manually identifying 6 anatomical landmarks in a high-resolution volumetric MRI of the tongue, $\boldsymbol{P}$ (i = 1,2,...,6). One set of points was obtained form the left and right sides of the tongue. The points in 3D were parameterized using a hermite spline that provides evaluated at 5 points between each landmark. The anatomical landmarks were tracked over time using tagged images via HARP in-plane analysis with an incompressible interpolation algorithm to obtain 3D results (Fig. 1) [3-4]. Tacked landmarks, $\boldsymbol{p}$ were parameterized in an identical fashion as the original points.

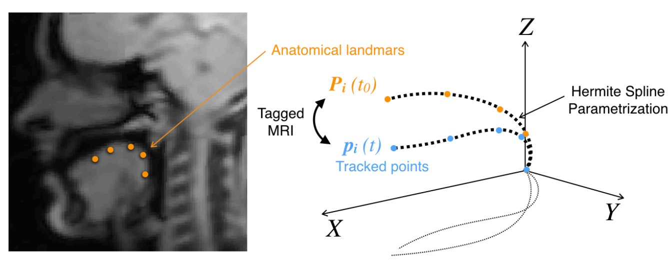
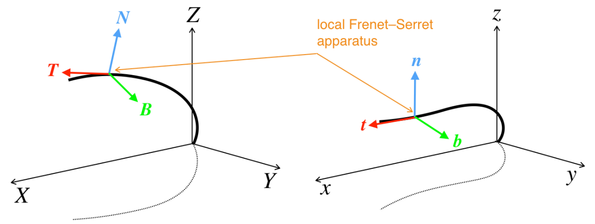


Figure 1: Curvilinear parameterization of anatomical landmarks.

Temporal variations in curvilinear shape were quantified by calculating rotations of the Frenet-Serret apparatus derived from the local parameterization, which consists of the tangent **T**, normal **N,** and binormal **B** vectors (Fig. 2). The rotations were calculated by solving the Euler's angles associated with the alignment rotation between the reference and deformed time frames. The five resulting kinematic properties, some of which can be defined as global (one value for the entire curve per time frame) and local (values distributed in time and along the curve), were defined as:

- Global bulk motion: Magnitude and rotation of temporal changes in the curve's centroid
- Stretch (local or global): Distance between interpolated points indicative of percent change in the curve's length (positive values indicate stretch, negative values indicate contraction.)



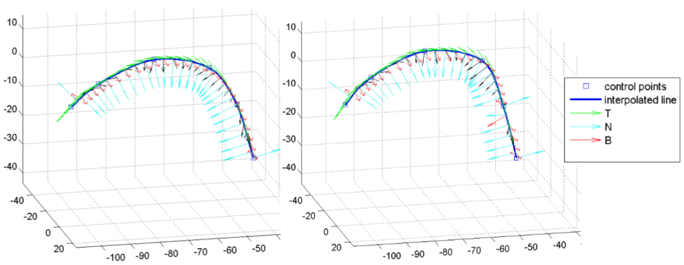
a) *b)*

Figure 2: Relative changes in shape obtained from rotations in the local Frenet-Serret apparatus in the parameterized curve.

- Curvature (local or global): Magnitude of the rate of change in the tangential vector, associated with bend in either direction
- Rotation about **T** (local or global), which is associated with torsion Rotations about **B** or **N** (local or global), which are associated with bending about orthogonal directions.

RESULTS

Figure 3 shows a side-by-side comparison of one of the landmark points at the reference and a latter time frame. Visual inspection of the tracings indicate bulk changes in location, and an increase in curvature at the latter time frame. Some of the vectors in the local Frenet-Serret apparatus suggest large and localized bending and torsion.



a) *b)*

Figure 3: Approximate line of action at two times. Compared to the reference time frame (a), the latter time frame (b) appears to have experienced bulk motion and changes in curvature.

Time histories of global centroid rotation in the left side of the SL are shown in Fig. 4. Although there is an increasing trend on time frames 1 to 10 in both words, the trace's concavity in the mean curve was opposite in time frames 11-26.

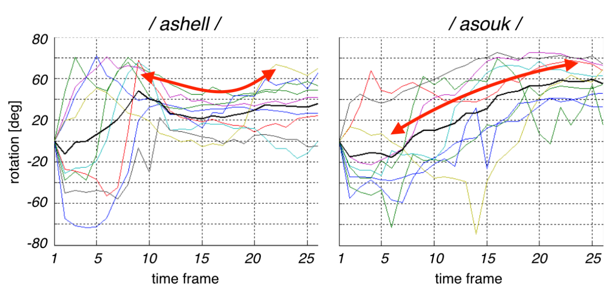


Figure 4: Time history of global centroid rotation. Colors are used for individual volunteers, the dark line represents the mean. The red arrow indicates areas with the most change.

Figure 5 shows differences in global stretch across time (SL left side). For the word "ashell", a mean increment in total length was observed between time frames 7 and 12. An increment of similar magnitude (approx. 5\%) occurs in the latter half of the word "asouk".

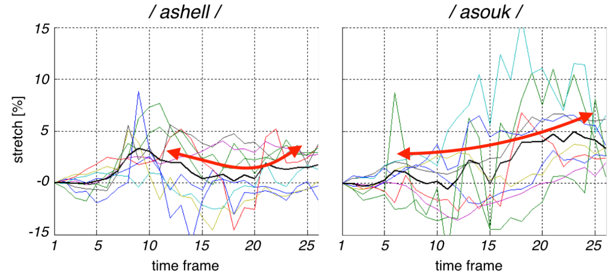


Figure 5: Global stretch time history. Colors are used for individual volunteers, the dark line represents the mean. The red arrow indicates areas with the most change.

Local curvatures across time (SL left side) are shown in Figure 6. A negative change in curvature occurs near the posterior portion of the muscle during "ashell", while the anterior side shows an increase in curvature. This result was consistent with Fig. 3. The deformation pattern for the word "asouk" noticeably different exhibiting a temporal shift in curvature across the entire muscle near time frame 15.

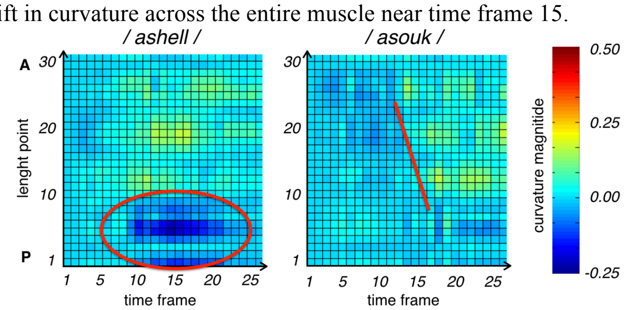


Figure 6: Curvature time history. A change in curvature is shown with the red circle for "ashell". A temporal shift in curvature was shown with a red line for "asouk". A = anterior, P = posterior.

DISCUSSION

To some extent, the SL muscle simply reflects the motion of the tongue's surface, which may result in shortening even in the absence of muscular activation. Nevertheless, from the global stretch slide (Fig. 5) it appears that SL stretches from /uh/ to /sh/ (frames 1-10), which is reasonable as the tongue elevates, which will stretch the surface. The SL shortens and possibly activates as the tongue moves from /sh/ into /e/ (frames 11-15), then stretches again into the /l/ (frames 20-24). This is sensible in terms of the tongue shape changes and likely role of SL. For souk, SL stretches with time, mostly at the end, reflecting the elevation and rounding of the tongue associated with /uk/. In terms of local curvature, the analysis produces appreciably differences between the two words, and the patterns are consistent with visual inspection.

In the selected preliminary results, the data are not time aligned. Time alignment is a natural next step in terms of analysis, because different speakers speak at different rates. Future research includes improvements in landmark parameterization and tracking to smooth tracking and fitting artifacts, as well as expressing the cumulative results in terms of mechanical strain energy [5].

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REFERENCES

1. Gilbert RJ, et al. J Exp Biol. 2007 Dec;210(Pt 23):4069-82.
2. Sanders I, Mu L. Anat Rec (Hoboken). 2013 Jul;296(7):1102-14.
3. Osman NF, et al. Magn Reson Med. 1999 Dec;42(6):1048-60.
4. Liu X, et al IEEE Trans Med Imaging. 2012 Feb;31(2):326-40.
5. Duncan JS. IEEE Trans Med Imaging. 1991;10(3):307-20.