Is styloglossus critical for tongue elevation? A computer simulation investigation of styloglossus recruitment in tongue elevation

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1. Introduction

The elevation and backward movement of the tongue is a key coordinative gesture in velar stops and high back vowels [1]. Based on anatomical location [2] and electrophysiological studies [3], the styloglossus muscle is assumed to contribute to this gesture. However, the tongue has a complex fiber structure with dense motor nerve endings enabling many control strategies to execute a single gesture [4]. Perrier [5] reported that velar articulatory trajectories can be achieved with the coordinated action of styloglossus, genioglossus posterior and inferior longitudinal. In contrast, Harandi [6] observed minimal styloglossus activity in velar consonant production. In the present study, the necessity of styloglossus in tongue elevation is assessed by manipulating its recruitment in a biomechanical model including intrinsic and extrinsic tongue muscles.

2. Method

Styloglossus recruitment was systematically manipulated using ArtiSynth, a computer simulation platform [7].

i. Baseline Tongue Model

The tongue model consists of independently controlled left and right bundles for genioglossus (posterior, GGP; anterior, GGA; middle, GGM), styloglossus (STY), geniohyoid (GH), mylohyoid (MH), inferior longitudinal (IL) muscles. Superior longitudinal (SL) muscle is represented as a single muscle. In the finite element model, the extrinsic tongue hyoglossus (HG), vertical (VERT), transverse (TRANS), IL, GH, and MH muscles are fixed to their attachment points in the skull, mandible, and hyoid. The relative positions of the bones are fixed. To create the baseline model, laterally symmetric muscle activations were manually chosen to achieve an elevated and backward tongue posture mimicking velar closure as shown in Fig 1D [5]. After reaching the target tongue shape, 6 virtual markers were placed on the tongue dorsum: 2 medial, 2 left lateral, and 2 right lateral (Fig 1A) and their positions were used as targets for the inverse simulation when styloglossus activity was manipulated.

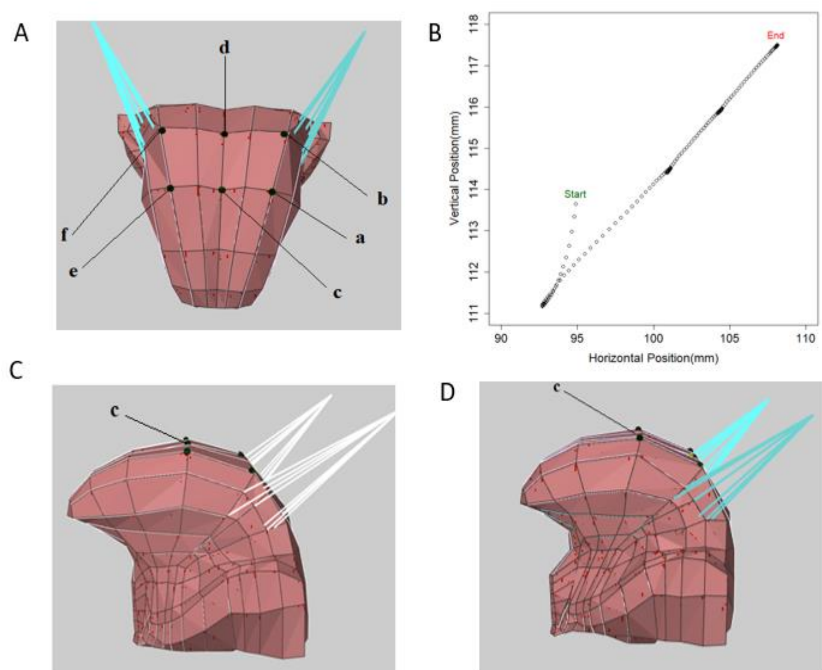

Figure 1: A) The six tongue markers: a,b are right lateral; c,d medial; e,f left lateral. B) Position trajectory for the tongue marker c with marked start and end positions. C) Neutral tongue position D) Target tongue position.

ii. Attenuated Styloglossus Model

Inverse simulation was used to estimate muscle activation patterns as a function of STY recruitment. The extracted marker positions from the baseline model were used as the target final posture for the tongue. The baseline STY strength of 3.83 N was systematically reduced by a scaling factor of ½ that resulted in five main scaling factors: 1 (baseline), ½, ¼, ⅛, and 0 (complete inactivity). Additional exploratory simulations were conducted at smaller increments between the five main scaling factors (min scaling factor=1/65536), resulting in a total of 23 simulations of 2.5s in length. Simulation regularization terms for muscle excitation redundancy (L2, 0.001) and damping (0.0001) were set based on model stability. For each simulation, the resulting muscle excitations for the 11 muscles and marker c position were recorded.

3. Results

The results of the five main scaling factors are reported in Table 1. All the manipulated STY conditions resulted in tongue elevation towards the target. At 2.0s the system was not moving, and the muscle excitations had become constant. At this time point, the distance between point c and the target position was recorded and the sustained muscle excitation pattern was compared to baseline using cosine similarity. As STY strength was reduced, IL, T and MH increased in muscle excitations to achieve the target tongue shape. However, for the lowest STY strength ("inactive"), MH excitation saturated and the target was closely restored (error <1mm). In addition, as STY strength and excitation decreased, GGP, GGM, GGA, and SL excitations reduced. The muscle recruitment pattern with lowest STY strength is almost orthogonal to the baseline pattern.

STY scaling factor	Baseline (1)	1/2	1/4	1/8	Inactive (0)
STY Strength (N)	3.83	1.92	0.958	0.479	0
STY muscle excitation	0.403	0.818	1.00	1.00	0
Marker c distance (mm)	0	0	0.128	0.764	0.965
Cosine similarity	1.00	0.958	0.692	0.592	0.104
GGP muscle excitation	0.142	0.144	0.0446	0.0308	0.00185
GGM muscle excitation	0.132	0.127	0.046	0.164	0.020
GGA muscle excitation	0.0695	0.0741	0.0483	0	0
GH muscle excitation	0.0583	0	0	0	0
MH muscle excitation	0	0	0.7945	1.00	1.00
HG muscle excitation	0	0	0	0	0
VERT muscle excitation	0	0	0	0	0
TRANS muscle excitation	0.117	0.120	0.014	0.274	0.226
IL muscle excitation	0.038	0.096	0.110	1.00	1.00
SL muscle excitation	0.102	0.100	0.053	0.056	0.047

Table 1: Muscle excitations at 2.0 seconds, as a result of the STY strength reduction. Each muscle name corresponds to the muscle excitation value. A muscle excitation value of 1 represents complete saturation of the muscle.

4. Discussion

When the STY strength is deliberately reduced in a simulated tongue model, increased recruitment of IL, MH, T and decreased activation of GG and SL can closely restore the tongue elevation gesture. The observed reductions in GG and SL excitations suggest antagonistic behavior between GG, SL and STY. In line with Harandi [6], the present results report the increased activation of T muscle, as well as floor of the mouth muscles in the elevation and backward movement of the tongue, with a reduced role of STY. The present study also supports findings by Perrier [5] that STY may play a role in velar trajectories. These results highlight that variability in STY recruitment could be the result of control strategies rather than variation in individual anatomy. The present simulations have multiple limitations including a fixed hyoid and mandible which may have restricted the MH ability to raise the floor of the mouth. A more ambitious vertical target for the elevation gesture could further limit the compensatory mechanisms observed. Importantly, the present findings demonstrate variability in control strategies in STY recruitment for tongue elevation, and question to what extent STY is employed in velar production.

5. References

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