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Can the location of the vocal tract bending constrain individual vowel articulation? Evidence from biomechanical modelling.

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Although native speakers of a given language all use the same phonemic inventory, speakers vary from one to another with respect to their acoustics and articulation. The variability among speakers may be driven by a variety of factors. This paper focuses on anatomical factors, in particular on the position of the bending of the vocal tract relative to its total length. For most acoustic tube models the relative position of the vocal tract bending does not matter for the simulation of vowels, since these models treat the vocal tract as a straight series of tubes. In contrary, the relative position of the vocal tract bending is supposed to be fundamental for tongue biomechanics, since the soft tongue body has to fit its surrounding vocal tract borders and muscles may not generate forces in exactly the same direction. If the relative bending position of the vocal tract is rather anterior (model A), the length of the horizontal dimension (palatal region) is short in comparison to the vertical dimension (pharynx). A more posterior location of the vocal tract bending (model B) corresponds to the reverse, if a similar vocal tract length is considered in both models. We expect a larger articulatory variability in the vertical dimension for model A and a larger variability in the horizontal dimension for B.

In order to test these hypothesis two biomechanical models were built. Both models were based on MRI data of one speaker. For model A we lengthened the original tissue contours of the pharynx by 1.5 cm in the vertical direction and for model B the oral cavity in the horizontal direction. For each model 8000 simulations were run by varying motor commands of the six major tongue muscles randomly around their values at tongue rest position. The biomechanical models were coupled with a harmonic acoustical model based on a distance to area function conversion to calculate the corresponding formants. Since we assume that auditory targets are the primary goal of speech production, the vowel targets for /a/, /u/ and /e/ were defined as identical formant ellipses for both models.

Results of our simulations provide evidence that articulatory variability of the tongue in the horizontal dimension is larger for model B than A, reaching the same acoustic vowel target ellipsis for /e/. For /u/ this effect is similar, but smaller. Furthermore, model A showed more articulatory variability in the vertical dimension than model B for vowel /a/ which is in agreement with the relatively large pharynx length. In our experiment articulatory variability is constrained by the relative position of the vocal tract bending. This position can shape the allowed degrees of freedom and constrains speaker specific articulatory precision for a given vowel target.