A Biomechanical Tongue Model of a Neanderthal

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Introduction. The emergence of the capacity for spoken language in humans during the course of human evolution is a widely debated question. The complexity of this question lies in the difficulty of studying fossil hominins due to the poor preservation of the phonatory apparatus. Soft tissues and cartilage do not fossilize, while bones can be damaged, deformed or eroded. Qualitative observations currently support the idea that fossil hominins had the ability to speak (Steele et al., 2012; d'Errico & Colagè, 2022). However, no quantitative measurements have been able to provide measurable evidence in this direction.
In this scientific context, our long-term project aims at providing a quantitative evaluation of the suitability of the biological characteristics of fossil hominins with the capacity of articulated speech. Our approach consists of three main steps: (1) predicting from the geometry of the skull, the mandible and the vertebrae the morphology of the missing tongue and of the missing soft tissues surrounding it in the oropharyngeal cavity; (2) building a biomechanical model of the predicted fossil tongue and its surrounding structures in the oral, that includes the muscles that are responsible for its movements and shaping; (3) evaluating with this model the maximal movement magnitudes of the tongue in the anterio-posterior and the vertical dimensions, the range of variation of the achievable vocal tract shapes, as well as the capacity of fossil hominins to sufficiently hold stable differentiated tongue postures, in order to provide a basis for the production of distinctive articulated sounds. Because it includes a realistic account of intrinsic physical characteristics of the tongue and of its neurophysiological control, this work enables us to go beyond the precursor modeling studies that have combined geometrical reconstructions and geometrical models of the vocal tract of fossil hominins (Boë et al. 2002; Boë et al, 2007) to provide preliminary evidence in support of their capacity to produce distinctive vowels.

Methods. To generate the biomechanical model of fossil hominins we relied a method that has been designed for the automatic generation of finite-element biomechanical models of human and non-human primates by morphing a reference model of a living male human subject. It has been carefully assessed on its capacity to generate an accurate model of a Baboon tongue, which was chosen for evaluation because of its large morphological differences with humans (Alvarez et al., In review). The method is based on a 3D binary-image registration technique available in the Elastix library (Klein et al., 2009), that uses 3D X-Ray scans of the head and neck region and achieves two successive major morphological registrations: (1) an affine registration that aligns the two skulls (2) a non-rigid "B-Spline" registration that provides more detailed transformations within the skull (Bijar et al., 2016). The displacement field created by this two-step registration is applied to the tongue finite element model of a living human (Calka, 2023). The process of creating this tongue model is illustrated in Figure 1 (upper panel). In the current study it has been applied to a neanderthalensis called "La Ferrassie 1" (man, 70-50 ka).

Results. The obtained tongue model for La Ferrassie 1 is shown in Figure 1 (lower panel, left). The lower panel of Figure 1 shows the 3D model inside the skull of the Neanderthal (middle) as well as the result of a simulation in which tongue muscles are activated (right). The activated muscle are the styloglossus and the superior longitudinalis, two muscles involved in the articulations of vowel /u/.

Discussion. It is obviously impossible to quantitatively validate the accuracy of the model. However, the validation of the method provided in Alvarez et al., incite us to be confident in the prediction. In addition, the general shape of the predicted tongue within the oral cavity (Figure 1, lower panel) seems reasonable, considering data on non-human primates (Riede et al., 2005). In terms of shapes and dimensions our results seem consistent with those of Boë et al. (2013). The strength of our biomechanical modeling approach is that it will enable us to study the stability of tongue postures in the context of variations in muscle activations, as well as the sensitivity of the range of articulated sounds to various mechanical parameters, such as the stiffness of tongue tissues, the force generation capability of the muscle or the hyoid bone position. In a short term, the simulation of the production of consonants and of crucial vowels, such as /i/, which does not seem to exist in non-human primates, will shed a new light on the emergence of speech in Neandhertal.

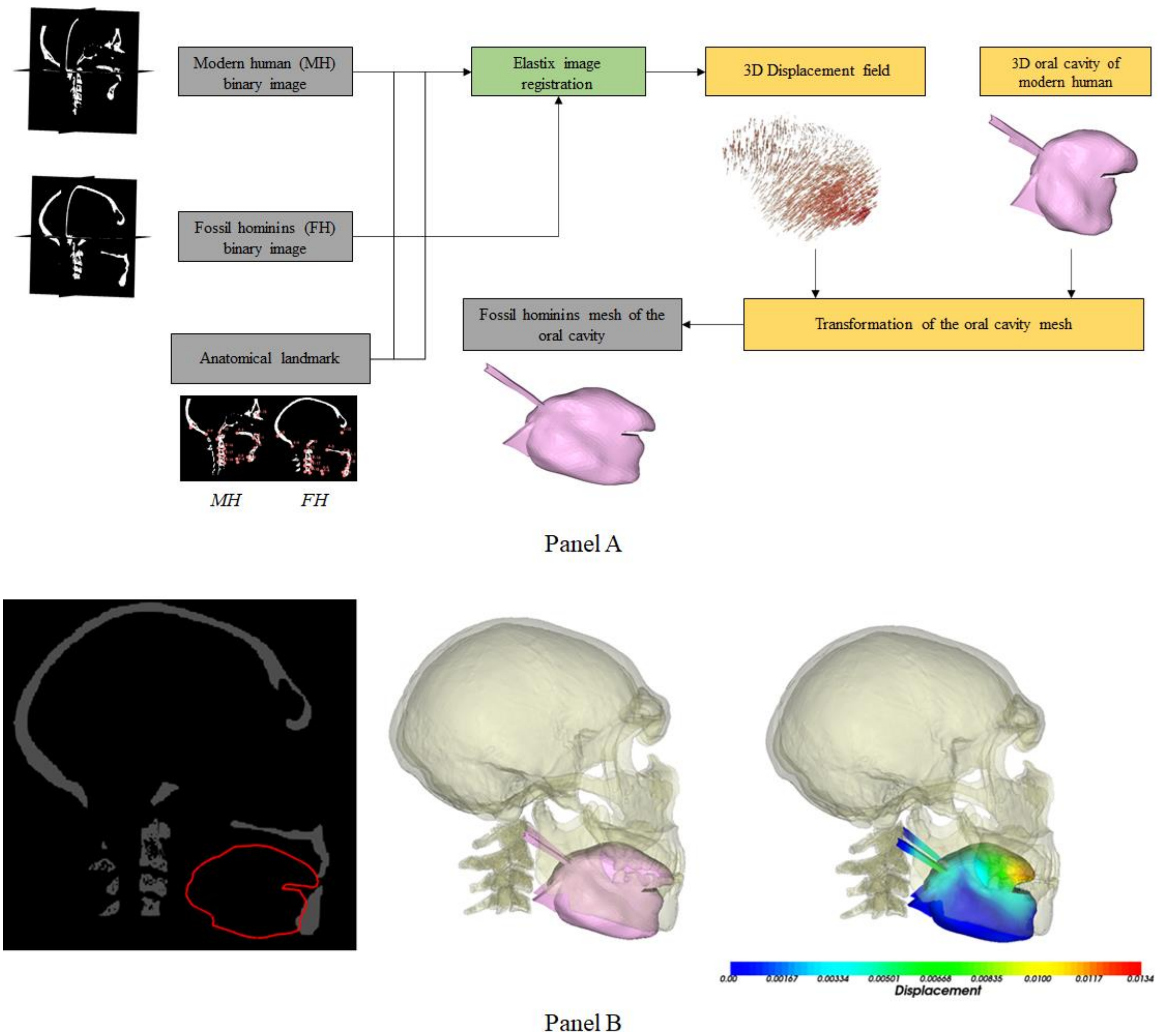

Figure 1: *Panel A - The process of creating a fossil hominin tongue model. Panel B - La Ferrassie 1's tongue model. Left: Generated tongue (in red) superimposed on volumic image of his skull. Middle: Mesh of the La Ferrassie 1's tongue inside his skull. Right: Simulation of a quasi-/u/ phoneme using La Ferrassie 1's.*

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