

Skull and Vocal Tract Growth from Fetus to 2 Years

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This research is designed to study the acquisition and the development of speech and its motor control in the light of its relationship with craniofacial growth from prenatal period to 2 years. The morphogenesis of the vocal tract depends strictly on bony structures and their development and the cranio-facial growth during ontogenesis is far from being linear. We observe in particular a complex reshaping of the face and the cranial base with a flexion of the anterior sphenoidal-ethmoidal-frontal (prechordal) segment on the posterior sphenoidaloccipital (parachordal) segment. This flexion and the growth of the maxilla and the mandible have important repercussions on the position and the dimensions of the vocal tract with regard to the cervical vertebrae and to the mandible. The palatal region is modified and the dimension of the palatal vault increases and it is important to point out an important phenomenon during growth: the mandibular angle is closing inducing a movement of the root of the tongue towards the anterior part of the cervical vertebrae. Therefore, pharyngeal cavity presents a very different evolution from that of the oral cavity (see figure).

At birth, the sagittal dimension of the oral cavity (from lips to the pharyngeal wall) is twice as long as the vertical dimension of the pharyngeal cavity (from velum to glottis). For adults these two dimensions are equivalent (with a difference of 10% between women and men). For the speech production and more particularly the vowel production, these modifications should provoke adjustments of the tongue control.

At birth, breathing, sucking and swallowing are yet mature functions before the creation and the control of the complex pattern governing mastication. Around 7 months, babbling can be considered as the real starting up for the emergence of speech (MacNeilage, 1998). At about 12 months of age, the bipedalism modifies the position of the bony and muscular structure of the head and neck and the orientation of the vocal tract. Between 11 and 14 months, the acquisition of the first words can be observed with the coarticulation between vowels and consonants, *i.e.* the control of the syllabic structures, achieved at about 4 years of age. At the level of the motor control, different studies allowed to observe the emergence of different steps in differential control of the lips (Munhall and Jones, 1998), tongue and mandible (Canault, 2007) and the emergence of motor control representation (Menard *et al.*, 2008).

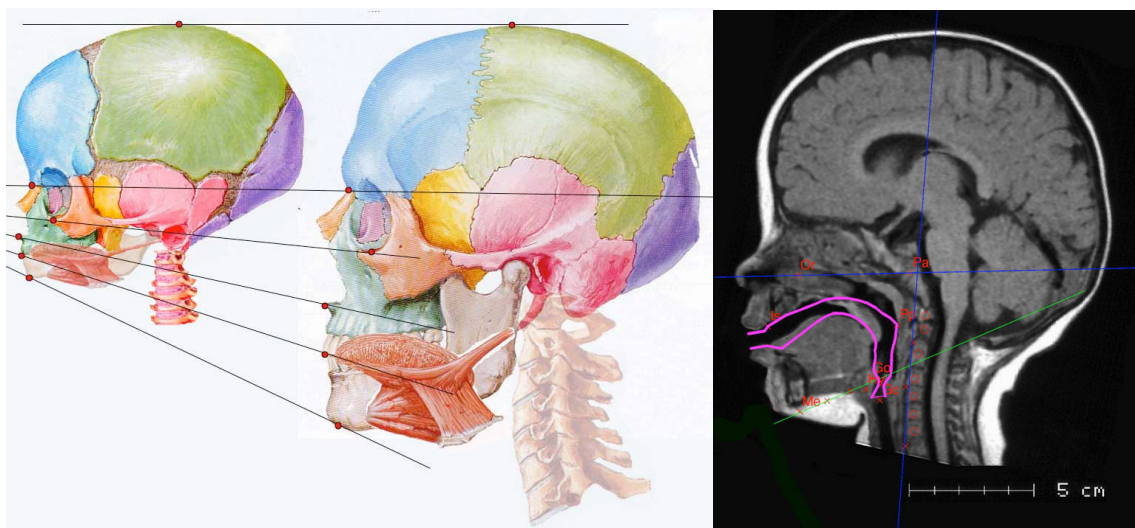
ANATOMY OF SOFT TISSUES IN RELATIONSHIP WITH BONY STRUCTURE

The anatomy of the soft tissues which constitute the walls of the vocal tract (mucous membranes, muscles and ligaments) and their geometry are well known for adult, adolescent and even for child. But they are not known as well for the fetus and for the baby between the birth and the age of two years. Our paper will concern four important points for anatomy and speech production: (i) The position of the hard palate compared to anterior part of the cervical vertebrae: about at the level of the atlas for the adult and higher for newborn; (ii) The horizontal position of the tongue in the oral cavity and its distance to the pharyngeal wall: it depends on the mandibular angle and on the position of the hyoid bone to which the tongue is attached; (iii) The height of the pharynx: it depends on the height of the mandible and on the position of the hyoid bone at which the larynx is attached. The height of the pharynx modifies the length of the vocal tract that determines the range of its resonance frequencies; (iii) The position and the width of the velum which is important for the production of oral phonemes oral versus nasal phonemes. We will present quantitative and dynamic illustrations of these modifications.

2D GEOMETRIC MODELING OF THE VOCAL TRACT AND BABBLING

In order to study vocal tract growth from an anatomical point of view and to model this process from birth to 2 years, it is crucial to determine the position of the vocal tract relatively to the skull structure. The goal of this part is to characterize, using an articulatory model, (i) the evolution of the vocal tract, positioned into the skull relatively to the cervical rachis and (ii) to generate vowel spaces and prototypical configurations for cardinal vowels during growth from birth to 2 years (iii) to simulate babbling.

The parameters available in the improved version of our model (derived from VLAM model) allow a control of tongue flattening, pharyngeal walls and inclination angle of the head. The articulatory model is controlled by 14 parameters: three anatomical parameters (palate height, front-back dimension of the oral cavity and the pharyngeal-laryngeal height); one positional parameter (inclination of the head relatively to the cervical rachis), height articulatory parameters (lip opening and protrusion, tongue body, tongue back and tongue tip position, degree of tongue flattening, jaw opening and position of the larynx), age which determines the ratio between the front-back dimension of the oral cavity and the pharyngeal-laryngeal height (this parameter also determines F0 value). This model will be adjusted to midsagittal Xray and MRI images, namely data from children aged 7 months to 2 years (Vorperian *et al.*, 2005) et adults (figure). From the sagittal function delivered by the model, a set of coefficients are applied to obtain an estimation of the area function. From this function, an acoustic model is used to calculate the transfer function of the vocal tract, the related formant values, the maximal vowel and consonant spaces (Schwartz, Boë, 2007). Then it is possible to generate dynamic sound sequences from sequences of area function variations (controlled by articulatory parameters). We will present [bababa] synthesized sequences of babbling derived from analysis.



Figures. Non-linear transformation: Bony architecture and tongue growth. Note the differences between the mandibular angle and the tongue position with regard to the cervical vertebrae. The articulatory model (handled by 13 parameters) adjusted to a 6 month old (Vorperian *et al.*, 2005). The model delivers midsagittal functions allowing to simulate syllables.