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## Vocal tract growth from birth to adulthood, applications for articulatory studies in infants and biomechanical modeling of the vocal apparatus

*Guillaume Barbier<sup>1</sup>, Louis-Jean Boë<sup>1</sup>, Anne Vilain<sup>1</sup> and Guillaume Captier<sup>2</sup>*

<sup>1</sup>GIPSA-lab, UMR CNRS 5216 & Grenoble Universités, Grenoble, France

<sup>2</sup>Faculté de Médecine, Laboratoire d'Anatomie, Montpellier, France

**Introduction.** The growth of the vocal apparatus is far from linear, and reflects several important changes during ontogeny. How are children able to reach acoustic targets in such a context? To counterbalance the nonuniform growth of the vocal tract, adequate motor control of the supra-laryngeal articulators is crucial<sup>[1]</sup>. Therefore, prior to understand the development of speech production, not only in the acoustic space, but in respect with the articulatory-to-acoustic relationships evolution, it is crucial to study vocal tract morphology.

**Material and Methods.** To understand morphological changes during ontogeny, a longitudinal set of X-rays for 68 subjects (33 females, 35 males) aged from 1 month to 25 years was used. These X-rays were provided by several orthodontic studies, such as the Denver, Iowa, Michigan, and Oregon growth studies. 49 bony landmarks were marked in each of these 966 X-rays (see figure 1), for hard palate, mandible, cervical vertebrae, and the outlines of several soft tissues, such as the tongue, velum, lips and pharyngeal wall, were traced. So the evolution of the main dimensions of the vocal tract could be calculated, and provided individual growth patterns for each subject. Furthermore, the evolution of the vocal tract included in the bony architecture could be examined, which is important, since vocal tract geometry depends on bony architecture.

**Results.** Our dimension measurements were compared to those of several anatomical growth studies: Goldstein, 1980<sup>[2]</sup> (which groups several medical studies), Riolo et al. 1984<sup>[3]</sup> (orthodontic study), and Fenart, 2003<sup>[4]</sup> (anatomical study). Our results are consistent with these 3 studies, as they are with Fitch and Giedd, 1999<sup>[5]</sup>, and Vorperian, 2000<sup>[6]</sup>. These data have shown that (1) the vocal tract length doubles from birth (80mm) to adulthood (160mm) with two important periods of growth (see figure 2), (2) men-women differences are due to a different size of the pharyngeal cavity (longer for men, from puberty on), (3) the size of the velum is already important at birth, and its growth is very slow, (4) the mandible develops regularly to reach the adult size at 17 years of age, and (5) the vocal tract mainly evolves in a vertical dimension (see figure 3). To summarize our main findings, some parts of the vocal tract are already well developed at birth, like the velum or the lips, and some changes correspond to important developmental landmarks, like the descent of the glottis, the descent of hyoid bone, or the growth of the mandible. Therefore, vocal tract growth can be considered as a true anamorphosis.

**Discussion.** The growth of the vocal tract and its main dimensions have already been studied (Goldstein, 1980 ; Fitch and Giedd, 1999 ; Vorperian, 2009), but our goal is not to study the vocal tract length only. This study aims at proposing specific measurements on the vocal apparatus (like the pharyngeal point against which the velum flattens, the first point of the tongue root, or the specific landmarks for tongue muscle insertions, like stylohyoïd, genioglossus, and so on), to improve the accuracy of articulatory phonetic tools, such as ultrasonography or vocal tract modeling. Further investigations are planned in relation with the evolution of motor control for speech gestures during ontogeny. To investigate motor control evolution, a 2D biomechanical model of the tongue<sup>[7]</sup> inserted in a geometric model of the vocal tract will be built for 4-year-old infants, based on our data and information about

tongue muscle insertions and orientations. This model could help us to understand infants' articulatory strategies, articulator-by-articulator, and will provide a better understanding of the evolution of speech gestures. In parallel, 4-year-old infants' speech productions will be studied, by coupling acoustic recordings and articulatory recordings (using audio recording, ultrasonography and infrared optical tracking (e.g. Optotrak)). To sum up, our project aims at understanding articulatory-to-acoustic relationships, and by comparing data to the model, we hope to get a better understanding of the evolution of motor control for speech gestures.

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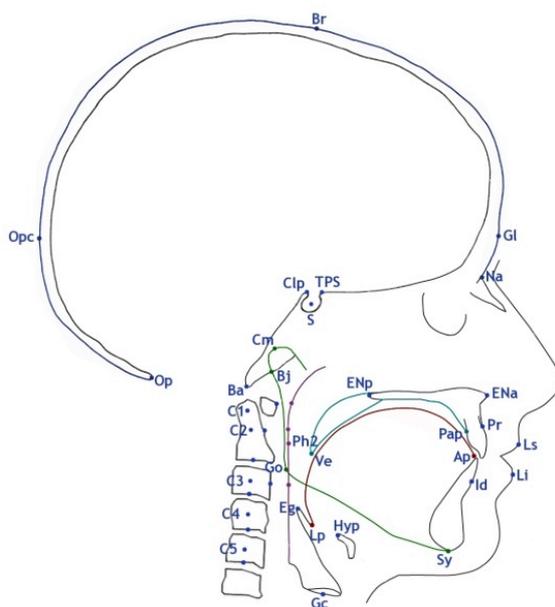


Figure 1 - Bony landmarks and soft tissues measured in the present study.

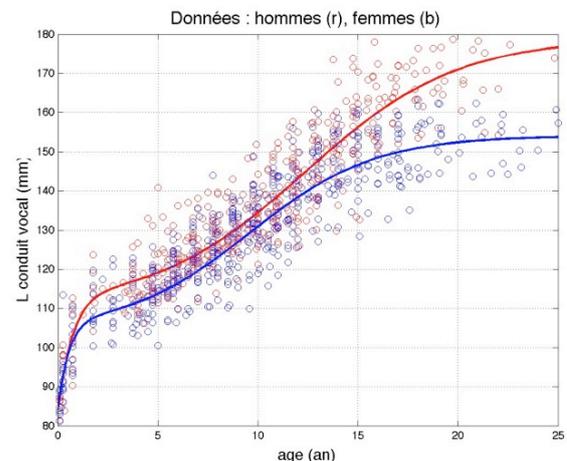


Figure 2 - Vocal tract length for men (red) and women (blue) as a function of age.

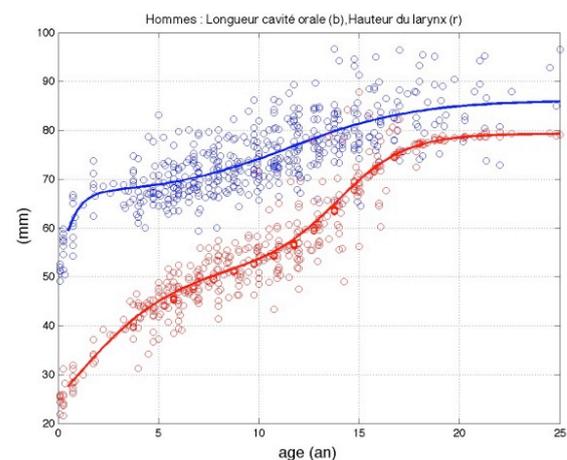


Figure 3 - Evolution of the oral cavity (blue) and the pharyngeal cavity (red) for men.