Evaluation of the vocal tract with real time MRI and MRI volumetry in professional tenors

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Introduction

Vocal registers and their origins have been the subject of extensive research and controversy for more than 200 years. It is commonly assumed that vocal tract resonances influence registers and register transitions. Also, model experiments have suggested that the vocal tract interacts with the voice source [1, 2] and thus may have an influence on vocal registers. Vocal tract resonances are determined by the shape of the vocal tract. To date, however, only few studies have focused on vocal tract shape in register transitions. In two previous pilot studies we applied dynamic real time MRI for analyzing vocal tract changes during register transitions [3, 4]. Minor changes were found when two professional singers (tenor and baritone) shifted from modal to falsetto [4], but marked changes when they avoided a register shift. At the time of our pilot studies [3, 4] the laryngeal structures were too blurred to show reliable landmarks for measurement of laryngeal distances and angles. Moreover, only 2D profiles and no 3D volume information has been available to date. It was therefore the purpose of this study to employ optimized real-time MRI with high temporal update rates and additional 3D volumetric imaging at 3T for the detailed assessment of the vocal tract in professional tenors.

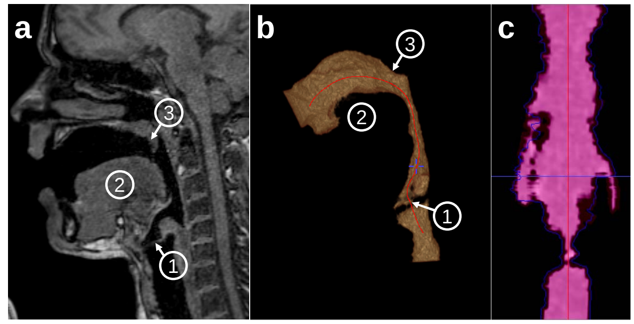

Fig.1: From the source images (a) the air-filled vocal tract is segmented and shown as a volume rendering image (b). Based on this reconstruction the centerline (red) is found semi-automatically. The volume is unwrapped along the centerline (c) and the area function is derived from perpendicular images. Numbers identify anatomical landmarks: 1, glottis; 2, tongue; 3, uvula.

Material and Methods

We analyzed the vocal tract profile in 10 professional opera tenors, who, on the vowel "a", sang an ascending scale with register shifts from modal to falsetto register. In a second condition they avoided a register shift and produced a register function which is often considered as voix mixte. All subjects were examined using a 3T MR system (TRIO; Siemens, Germany). Real time MR imaging was performed with a temporal resolution of 8 images/s in a sagittal slab of 11 mm thickness using an rf-spoiled 2D GRE sequence with the following sequence parameters: in plane resolution=1.4 x 2.2 mm^2, TE/TR=0.84/2.53 ms, FA=5°, bandwidth=650 Hz/Px, matrix=192x144, FOV 250x215 mm^2, GRAPPA reduction factor=2. The audio signal was recorded by means of an optic microphone. In a second condition, MRI volumetry with construction of the vocal tract area function was performed (3D GRE imaging, TE/TR=1.7/4.8ms, FA=12°, spatial resolution=1.0x1.6x1.3mm^3) in different register conditions in sustained tones. The datasets were analyzed on a dedicated 3D-workstation (AquariusWS, Terarecon, San Mateo, CA). Air inside the vocal tract was segmented by a combination of region growing and manual correction algorithms. The obtained masks were loaded to a vessel analysis tool to create a line through the center of gravity. The area of the vocal tract perpendicular to the centerline was recorded in 0.5cm intervals from below the vocal cord to the lips. Figure 1 presents pictures from the construction of the area function on 3D-MRI data in sustained tones. After construction the area function the Formflek-Software (Liliencrantz, KTH, Stockholm) was used to determine the resonated frequencies (formants) of the vocal tract.

Results

Real-time MR images showed clear modifications of the vocal tract shape in most subjects' transitions without any register shift to falsetto; the lip and jaw openings were widened, the jaw protruded, the pharynx width increased and the uvula elevated. By contrast, transitions to falsetto register were associated with minor changes only; the tongue dorsum was lifted and the larynx was elevated and tilted. Fig. 2 presents MRI images for a light/lyrical tenor and a more heavy Heldentenor voice. The images were taken from the sequences from modal to falsetto (a and b) and from modal to voix mixte (c and d). Modifications of the vocal tract were stronger for the heavier voice. Figure 3 presents preliminary data of 7 tenors` area function producing a sustained tone in falsetto (blue) or voix mixte (red). Obviously, modifications were stronger in the voix mixte in most of the subjects which has an influence on resonated frequencies.

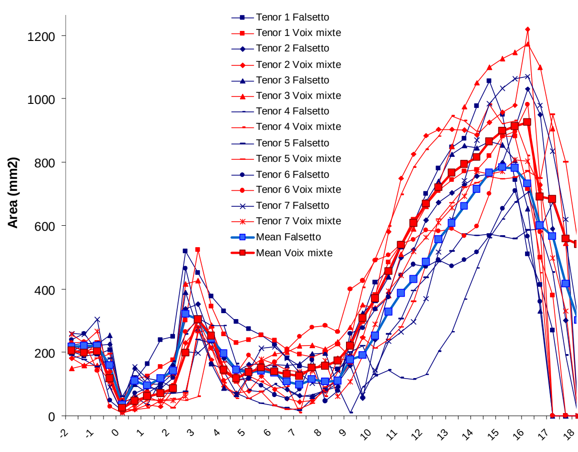

Fig.3: Area functions of the vocal tract from the glottis to the lips for seven singers in falsetto (blue) and voix mixte (red).

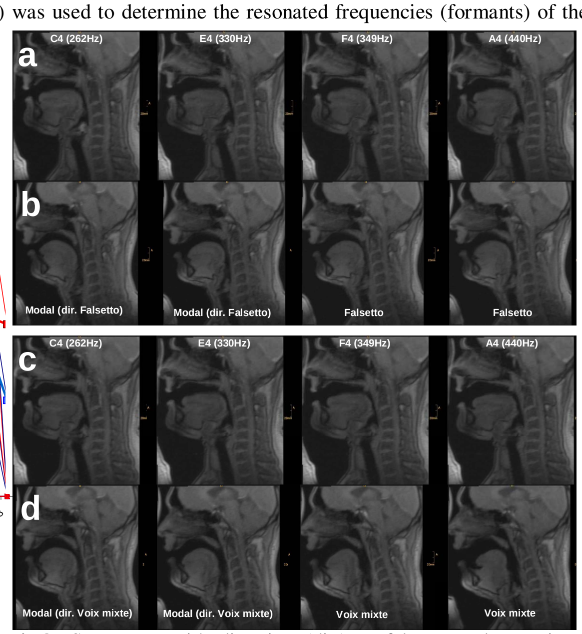

Fig.2: Sequences with direction (dir.) to falsetto and to voix mixte in a lyrical tenor (a and c) and a Heldentenor (b and d), respectively.

Discussion

This investigation presents for the first time data on vocal tract modifications associated with a shift of vocal register in a group of 10 professional opera tenors. The results confirm the observation, that vocal tract changes occurred in few parameters only, when the singer shifted register from modal to falsetto[5], while several and substantial modifications were found when the singers ended their sequence in voix mixte. At the same time our data also reveal a considerable individual variability. The strongest vocal tract changes were seen in our Heldentenor. On the other hand our data reveal that Real Time MRI technology and MRI volumetry can be successfully applied for the detailed evaluation of voice physiology.

References: [1] Titze IR et al. *J Acoust Soc Am 2008*;123(4):1902-1915. [2] Titze IR et al. *J Acoust Soc Am 2008*;123(5):2733-2749. [3] Echternach M et al. *J voice 2008*;in press. [4] Echternach M et al. *Logoped Phoniatr Vocol 2008*;33(2):67-73.