Vocal Tract Morphology in Inhaling Singing: An MRI-Based Study

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Summary: Objectives/Hypothesis. Inhaling singing is a recently developed singing technique explored by the soprano singer Françoise Vanhecke. It is based on an inspiratory airflow instead of an expiratory airflow. This article describes the anatomical structural differences of the vocal tract between inhaling and exhaling singing. We hypothesize that the vocal tract alters significantly in inhaling singing, especially concerning the configuration of the anatomical structures in the oral cavity and the subglottal region.

Study Design. This is a prospective study.

Methods. A professional singer (F.V.) performed sustained tones from F5 chromatically rising up to Bb5 on the vowel /a/. Vocal tract anatomy is assessed by magnetic resonance imaging.

Results. Wilcoxon directional testing demonstrates (1) that the vocal tract volume above the glottal region does not differ statistically in contrast to the subglottal region and (2) significant changes in the configuration of the tongue, the upright position of the epiglottis, the length of the floor of mouth, and the distance between the teeth.

Conclusions. The narrowing of the subglottis is considered to be secondary to suction forces used in the inhaling singing technique. The changes in the anatomical structures above the vocal folds possibly suggest a valve-like function controlling the air inlet together with the regulator function of the resonator capacities of the vocal tract.

Key Words: Inhaling singing–Reverse phonation–Ingressive phonation–Vocal tract morphology–Imaging–Vocal fold oscillation–Resonance.

INTRODUCTION

Voicing is a result of propagation of a sound wave through resonance chambers. Usually, sound production in speaking and singing is the result of vocal fold oscillation, driven by airflow through the glottis. The resonance properties depend on the speed of the airflow and biomechanical features of the resonance chambers.[1]

Exhaling voicing

During normal phonation, the airflow is expiratory, running from the lungs toward the mouth over the glottal narrowing. The pressure in the trachea and subglottal region is nearly equal to the lung pressure, and the pressure immediately above the major constriction, namely the glottis, is nearly zero. This transglottal pressure drop enhances the vocal fold adduction according to Bernoulli's law, and in response of the interplay between the aerodynamic flow and the biomechanical tissue characteristics, vocal fold oscillation, and hence sound production, is generated. The sound wave propagates further downstream, toward the vocal tract. The faster the airflow, the larger the pressure drop will be and the more turbulence occurs. This causes a raise in energy dissipation immediately after the major constriction hence being a component of the vocal tract resonator features, next to the vocal tract shape, its volume, and its tissue characteristics. The role of the vocal tract resonances and their influence on the spectral envelope have been well documented in literature.[2-7] Especially, because of the vocal tract anatomical properties (volume, configuration, and tissue characteristics), the resonator capacities are much weaker upstream (the trachea and subglottal region are small rigid structures) than downstream (the vocal tract contains a larger volume and exists of plastic muscular tissue), which is confirmed by Wolfe et al[4] who studied the structural similarities and functional differences between the voice and musical wind instruments and stated that the resonances of the upstream duct for voice (the trachea) and for wind instruments (vocal tract) are much weaker compared with the resonances of the downstream tract.

Inhaling voicing/singing

An inspiratory airflow from the lips into the lungs is a consequence of expanding the thorax and lowering the diaphragm. Normally, while inspiring, the glottis is open, not hampering the airstream and thus causing only little turbulence in the flow. Only if a glottal narrowing is consciously provoked, an inhaling sound or reverse phonation is produced. Sound production on an inspiratory airflow has been described in ethnic music or in experimental/therapeutical setting. Ellingson,[8] for instance, mentions ingressive phonation in the Tibetan singing style. Finger and Cielo[9] recently performed a literature review regarding reverse phonation and eventual application in vocal treatment. Other authors report on the eventual therapeutic benefit of reverse phonation for relaxation and hence widening of the supraglottal structures.[10,11] Robb et al compare the acoustic features of ingressive and egressive vowel production and Orlikoff et al described some acoustic and physiologic aspects of inspiratory phonation. However, neither of them did focus on singing or on the anatomy of the vocal tract.[12,13] To our knowledge, however, except for the submitted article of Vanhecke et al,[14] no report exists

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concerning actual singing on an inverse airstream. Singing defined by "making musical sounds with the voice, uttering words or sounds in succession with a set tune," demands a continuous control of the glottal characteristics (for instance muscle tonicity for changing tone), of the airflow characteristics (for instance speed and thus the amount of turbulence and energy dissipation), and of the vocal tract characteristics (for instance tongue position and morphology influencing the spectral envelope). A singer must be able to utter words on a tessitura which, concerning inhaling singing, happens on an inspiratory flow. As the glottis remains the place of major constriction in the tube, the same physical features cause the vocal folds to oscillate, albeit on an inspiratory airflow (from the lips to the lungs). Being able to control the vocal folds' tonicity foresees in the possibility to change tone. However, next to varying vocal fold muscle tonicity for obtaining pitch modulation, an actual singer must be able to control the spectral slope, which depends not only on the speed of the inspiratory airstream (and hence the energy dissipation and resonator features) but also on the structural configuration of the resonator cavities. In singing on an inspiratory flow, the airflow remains the driving force for the vocal fold vibration and the sound generation, but regarding the resonance, the "richest" and most modifiable resonator is now located upstream, in contrast to traditional singing. Downstream, a tube with only little resonator capacities is present, the trachea.

This article is an addition to the article by F. Vanhecke et al[14] which describes the development of the inhaling singing technique (registered as ISFV by Françoise Vanhecke) and its spectral features. As far as we know, Françoise Vanhecke is currently the only singer who fully masters this technique. This article goes deeper into the morphology of the vocal tract changes. The vibratory pattern of the vocal folds is under research and will be described in a separate article.

On the basis of the spectral analysis reported by Vanhecke et al[14] and on the fact that there is no audible difference between the tones sung by the inhaling or exhaling technique, we hypothesize that the vocal tract remains the major determinant of the resonance features. However, we expect the subglottal region to narrow in inhaling singing, secondary to the inverse airstream. Meanwhile, we also question if the morphology of the supraglottal vocal tract would significantly change.

MATERIALS AND METHODS

A female professional singer and composer (F.V.) sung six prolonged tones starting at F5 and chromatically rising up to Bb5 on the vowel /a/ in a decline position under magnetic resonance imaging (MRI), both in the exhaling and inhaling manner. This experiment in fact repeated the experiment reported in the study by Vanhecke et al[14] where the recording was done in a professional audio recording studio. All images were performed on a 1.5T Philips Achieva scanner (Philips Medical Systems, Best, The Netherlands) by using sensitivity-encoding 16-channel head and neck coil. A single-shot sagittal T2 sequence was used with TR 15000, TE 90, and turbofactor 59 while singing when inhaling and exhaling. The images were obtained using a matrix of 256×163 and a slice thickness of 5 mm. The acquisition time was 8 seconds. All images were evaluated on an Agfa PACS system. This study only involved objective measurements, so window-level settings did not affect the results. This provided 12 midsaggital images (2×6). Various anatomical structures (distances, angles, and areas) were manually measured by an experienced radiologist who dragged the cursor onto landmark points, after which the software automatically calculated the distance or angle (Table 1; Figures 1 and 2).

STATISTICAL ANALYSIS

Wilcoxon directional testing was performed on all measurements (Table 1).

RESULTS

A statistically significant difference is found for the area of the complete vocal tract (feature 17 + 18 + 19 in Table 1; area A + B + C in Figure 1). The vocal tract is larger in exhaling singing compared with inhaling singing. Focusing on its components, we notice that there is no statistically significant difference for the volume of the area of the anterior oral cavity (feature 17 in Table 1; area A in Figure 1), nor for the area of the oro-hypopharyngeal region (feature 18 in Table 1; area B in Figure 1) or the sum of both. The statistical significance is mainly due to a decrease of the subglottal area in the inhaling singing condition (feature 19 in Table 1; area C in Figure 1). The anteroposterior distance at the subglottal level is significantly larger in the exhaling singing technique (feature 16 in Table 1). There is also a statistically significant change in the tongue configuration (features 3, 4, and 5 in Table 1), in the distance between the teeth (feature 1 in Table 1), in the length of the floor of mouth (feature 14 in Table 1), and in the position of the epiglottis (features 10 and 11 in Table 1).

DISCUSSION

Our results demonstrate a statistically significant difference in the subglottal morphology and supraglottal morphology between exhaling and inhaling singing.

Subglottal region

The overall area measurement reveals significantly larger values in exhaling singing mainly because of a larger volume at the subglottal level. There is no significant change in the volume of the area of the oral cavity or the oro-hypopharyngeal area. Ventura et al[15] studied the morphology of the vocal tract during spoken and singing tasks. Their results indicated that mainly an increase in the oral cavity volume was responsible for the measured overall volume change in the singing voice, in contrast to the acting voice in which the overall volume change was mainly due to an increase in the pharyngeal volume. Apparently, neither of both areas takes part in the changes observed in inhaling singing as performed by Françoise Vanhecke. In contrast to normal inspiration, where the glottis is open, not hampering the airstream, preventing turbulence, inhaling singing aims at vocal fold vibration. A main