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Heathy Vocal Folds between the Vocal Tract and the Subglottal Region

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I. Introduction

Preserving a healthy voice is one of the most important issues in vocal education. Healthy vocal folds are considered as crucial for physical and mental well-being. They are key prerequisite for a fulfilling lifelong musical experience in professional singers' careers as well as in hobby singers and speakers.

Vocal folds connect two resonating systems: the vocal tract resonances and the subglottal region. Even small changes in specific areas of the vocal folds can be revealed by means of a visual examination by a laryngologist using stroboscopy. However, internationally successful classically trained and performing singers do not always have "perfect" vocal folds. Slight anatomic irregularities do not seem to be obstructive to a resilient and expressive voice. Furthermore, the single vibratory cycle of the vocal folds is too fast to be influenced in its different stages from closed to open, thus, one environmental setting fits for all stages of the cycle.

The vocal folds are influenced muscles and tissue of the "voice box," the vocal tract and the subglottal region. The surroundings of the vocal folds support vocal health and help to prevent nodules or other stress symptoms in the vocal folds. The vocal tract and the underlying subglottal region are usually observed in a wider perspective, representing nonetheless important areas within the vocal system.

Vocal formation provides guidance in human sound production. Change management of the vocal activity supports the process of adaption of the muscles involved with the aim of an ergonomically efficient sound production. Developing the physical awareness to distinguish between desired and undesired vocal qualities is a core competency for a singer. Additionally, finding efficient strategies for physical and mental practice and for coping with undesired results represent crucial steps in vocal formation. An assistance with a professional teacher and/or psychological supervision is highly recommended.

In the present contribution we focus on techniques to influence the surrounding of the vocal folds by either using images or by using an externally generated sound. Furthermore, the proposed methods aim at an increased awareness of the acoustical phenomena useful for singing and include both the vocal tract and the subglottal region.

II. Usage of Images to Induce Changes within the Geometry of the Vocal Tract:

Resonances within the vocal tract guide singers to “place” the voice in desired positions. Magnetic resonance images (MRI) highly enrich our present knowledge about the dynamics of the mouth opening, tongue, jaw, velum, throat, and the larynx during singing. We want to draw attention to the use of images to induce geometric changes within the vocal tract.

The following images were taken with a relaxed vowel [e] during phonation and with an adjustment of the vocal tract in order to have a vibrational sensation at the three positions indicated in figure 1: at the hard palate, close to the velum, and within the throat.

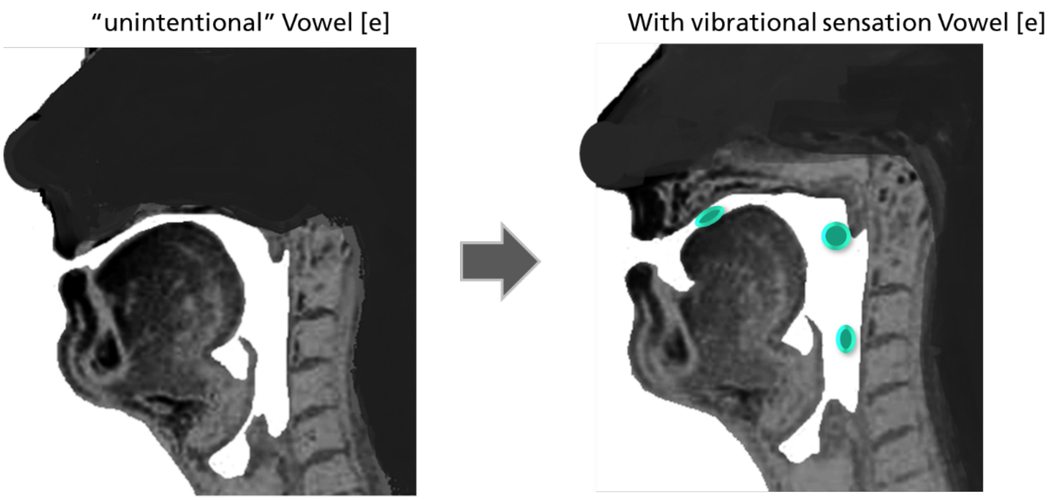

Figure 1: Sagittal MRI sections of the vocal tract during phonation (Martin Blaimer, Fraunhofer EZRT, Würzburg, Germany). Left side: nonadjusted vowel [e] in a relaxed position without vibrational sensation. Right side: adjusted vocal tract to obtain a vibrational sensation indicated by the green circles.

These and similar images can help even vocally nonexperienced participants to change their vocal tract position, thus experiencing an increase in resonance sensation. Interestingly, the positions of the vibrational sensation correlate with simulations of the fourth vocal tract resonance.[1]

III. Resonances during Breathing and Singing

Vocal tract resonances can be identified by computational analysis using the vocal spectrum during singing or speaking or more specific during vocal fry. Externally applied sound sources can drive vocal tract resonances with or without vibrating vocal folds. Thus, an analysis of the resonances with closed glottis and during the respirational cycle becomes feasible.[2]

In a study with eighteen advanced singing students, we analyzed the resonances during phonation, with closed glottis and during breathing. The participants were asked to maintain the anatomically perceived geometry of the vocal tract throughout all phases of the exercise—i.e., during phonation of a chosen vowel—followed by a stop of breathing with closed glottis, followed by restarting breathing without phonation, followed by phonation as in the beginning of the exercise. Figure 2 illustrates the overall setup for measuring the sound output and resonance conditions using an iPhone replacement buzzer as sound source.

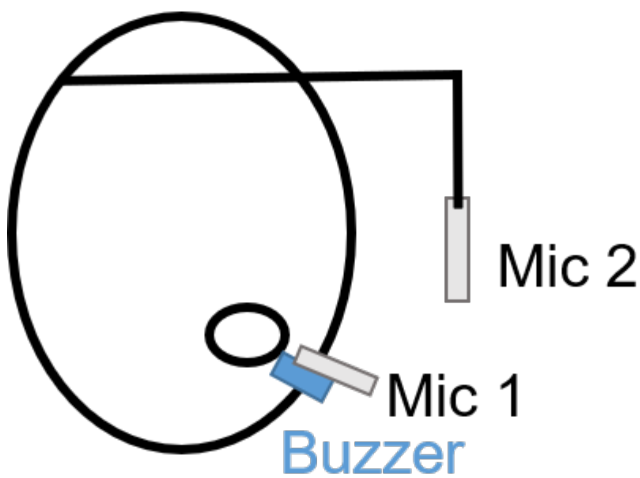

Figure 2. Setup for measuring the sound output and resonance conditions. Mic 1: Microphone 1 (Sennheiser MKE 2-P); Mic 2: Head-mounted microphone 2 (GRAS AF 46); and Buzzer: iPhone 5s replacement buzzer.

For detailed description of the procedure please refer to Hoyer et al.[3] Figure 3 shows a spectrogram and illustrates the performed task. After a calibration of the deterministic noise with closed mouth, the singer phonated a given vowel at a given pitch. Without any other intentional changes, the singer closed the glottis (a), exhaled (b), and inhaled (c). After the respiratory cycle the vocal sound was reproduced. Both microphones show similar information, however, the high intensity of the vocal output can only be recorded with microphone 2.

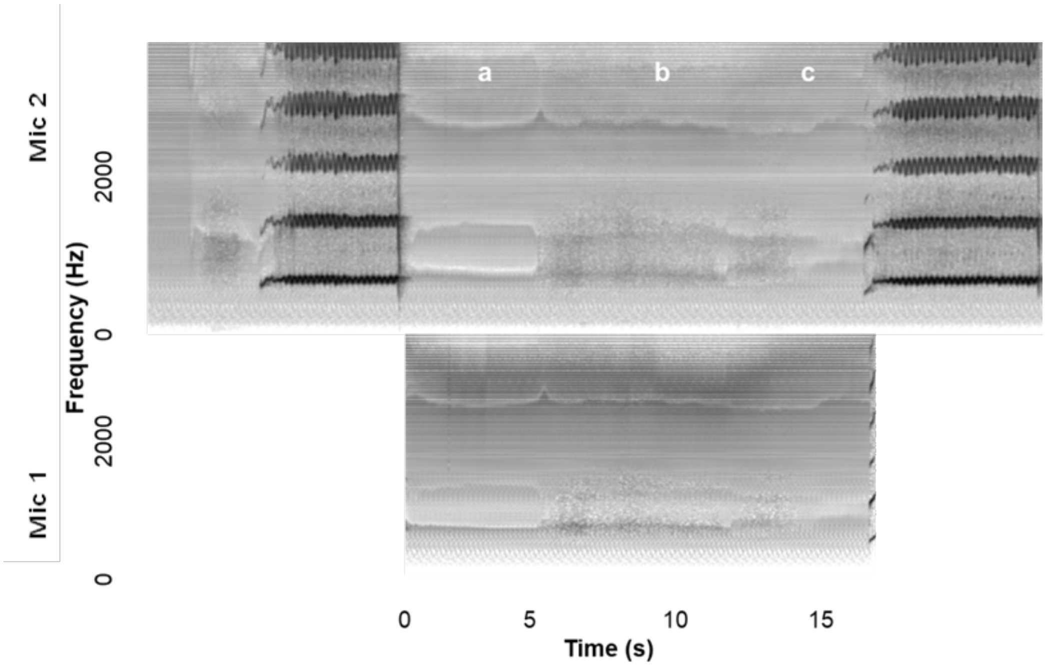

Figure 3: Spectrogram form 0 to 4000 Hz during the sequence of the experimental procedure: sustained vowel [a] at g5, a: closure of the glottis, b: exhaling, c: inhaling and repetition of the sung vowel. SPL of the deterministic noise and the vocal output were 72 dB and 119 dB at 17cm respectively.

From these measurements the spectra of the voice can be compared with impedance data with the subglottal airways closed—i.e., closed glottis, section (a) in figure 3—and during exhalation or inhalation.

Figure 4 shows the results of a soprano singer performing the vowel [e] at pitch d5. While the resonances in figure 4 show additional peaks in the frequency region below 1800 Hz as indicated by the grey arrows, the resonances at higher frequencies are altered only slightly by changes in the glottal opening.

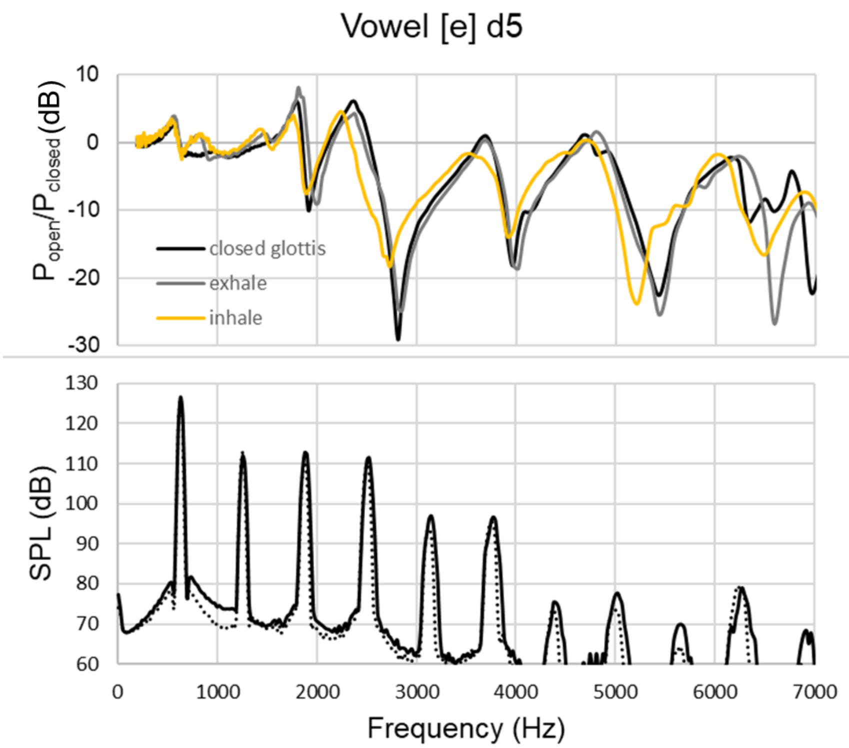

Figure 4: Soprano (advanced student) with her airways adjusted to support the vowel [e] at pitch d5. Upper part: Impedance data measured from the open mouth without phonation with closed glottis, during exhalation and during inhalation. Lower part: spectrum of the sung vowel. Straight line: spectrum before the respirational cycle, dotted line: after the respirational cycle.

This behavior is frequently found in resonances above 2 kHz. The analysis supports the idea of singing and breathing with similar adjustment of the acoustically active airways regardless of the glottal opening.

IV. External frequencies induce geometric changes in the vocal airways without phonation

The vocal tract resonances are defined as frequencies that are enhanced by the vocal tract. The vocal tract can support many different frequencies. During phonation, the singer changes the vocal tract as to support different resonances resulting in the vowels desired.

A sound source close to the open mouth can offer one or several frequencies that couple with the air within the vocal tract.[4] In the proposed exercise, the singer adopts the internal airways to enhance the frequencies one by one or as an ensemble. As an external sound source is used. These exercises do not require vocal activity. Only the resonances of the total airway or (with the glottis closed) of the vocal tract will be addressed.

In our study, 18 singing students adjusted their vocal tract to a combination of 1–3 standard training frequencies of 400 Hz, 550 Hz, 800 Hz, 900 Hz, 1200 Hz, 1300 Hz, 2700 Hz and 3100 Hz. Furthermore, individual resonances obtained during the analysis as shown in figure 4 were used to induce changes without phonation and up to six sinusoidal frequencies were included in acoustic files. The duration of the training was between three and five weeks. The actual time varied with the compliance or the need of the students. Figure 5 shows the experimental procedure.

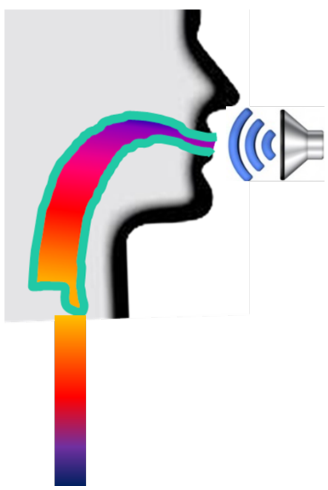

Fig. 5: Schematic view on the adjustment procedure of the vocal tract (with the glottis closed) or of the total airway (with the glottis open) to enhance frequencies coming from a mobile phone buzzer.

The addressed output of the mobile phone was held close to the open mouth and the sound level used was well below 40 dB. The sinusoidal frequencies were mixed regarding the sensitivity of the ear and of the mobile device with the higher frequencies being about 1% of the first vocal tract resonance. The training time was 30 sec. for

Individual sets of vowel dependent frequencies were used in addition to preformed sounds. Figure 6 shows the individual frequencies obtained for the male and female participants for the vowel [o].

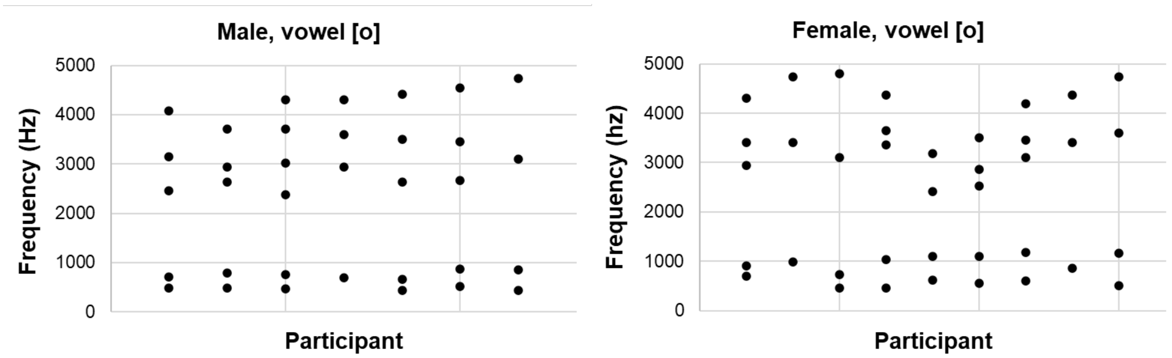

Figure 6. Individual frequencies of the singers obtained from impedance measurements of pitch b3/4 with closed glottis for male and female voices respectively.

The participants used their private smartphones. The preformed frequencies were recorded in stereo mode with only output channel active and the other muted. The students were advised to use a silent environment and lower the volume of the mobile phone so even during amplification of the selected frequencies with the mouth, the volume was only audible to themselves.

At the end of the training period a questionnaire was filled in, and additional comments were collected. Figure 7 shows results toward two essential questions. Over 80 percent noticed change in their voice and an increase in resonance after the training.

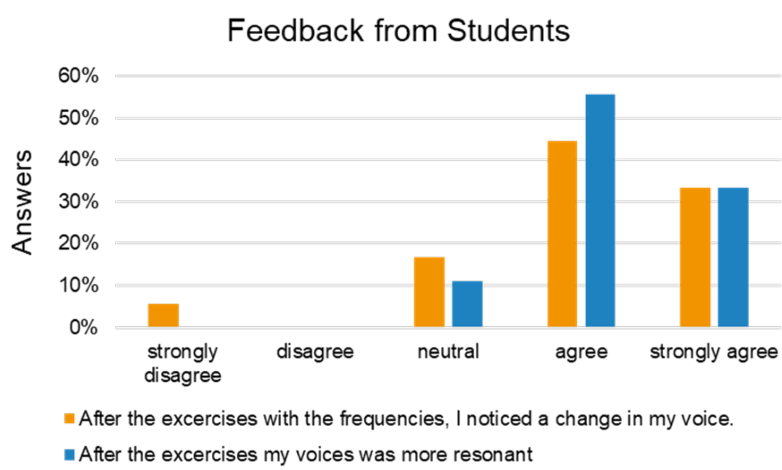

Figure 7. Results of the returned questionnaires (N=18) about their experience after a resonance enhancement using externally supplied frequencies.

V. Conclusion

The aim of the contribution is to offer additional pathways towards sensitivity on the one hand and adjustment of the vocal tract and the total airway on the other hand. The underlying ideas are that the experience of these resonances are beneficial to vocal training and that vocal folds—being placed in a supporting environment of the upper and lower airways—will be more resilient toward strain or fatigue.

We showed first encouraging results towards a guided development of the voice by using MRI images and external frequencies. However, we want to stress that the mechanisms regarding the human voice are manyfold and the presented tools to influence the voice must be regarded in a broader picture of vocal performance.

For further information, please feel free to contact patrick.hoyer@zv.fraunhofer.de.

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[1] H. Takemoto, P. Mokhtari, and T. Kitamura, "Acoustic Analysis of the Vocal Tract During Vowel Production by Finite-Difference Time-Domain Method," *Journal of the Acoustical Society of America* 128, no. 6 (2010)."

[2] Noel Hanna, John Smith, Joe Wolfe, "How the Acoustic Resonances of the Subglottal Tract Affect the Impedance Spectrum Measured through the Lips," *Journal of the Acoustical Society of America* 143, no. 5 (2018).

[3] Patrick Hoyer et al., "Vocal Tract and Subglottal Impedance in High Performance Singing: A Case Study," *Journal of Voice* (2022), online ahead of print.

[4] Patrick Hoyer and Simone Graf, "Adjustment of the Vocal Tract Shape via Biofeedback: A Case Study," *Journal of Voice* 33, no. 4 (2019): 482–89; Simone Graf et al., "Adjustment of Vocal Tract Shape via Biofeedback: Influence on Vowels," *Journal of Voice* 34, no. 3 (2020): 335–45.