Investigating the *Voce Faringea*: Physiological and Acoustic Characteristics of the Bel Canto Tenor's Forgotten Singing Practice

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Summary: Several historical sources from the first half of the nineteenth century mention a distinct third register mechanism particular to tenor voices of that period. This so-called *voce faringea*—often described as an "intermediate" register—is a virtually forgotten historical singing practice used to extend the upper range of the voice, where the singer modifies falsetto, typically a weak and often feminine sound, into a more powerful, tenor-like vocal quality. Based on an evaluation of historical voice register theories, training strategies and the sound ideals of the historical period, an informed discussion of that technique is developed. For this study acoustic and electroglottographic signals for tones produced on the vowel /a/ by a professional tenor/countertenor in different vocal register mechanisms—*voce faringea*, falsetto, chest and *mezza* voce—were recorded using the *VoceVista* system. Analysis of the EGG and audio data revealed specific characteristics of the *voce faringea* with regard to both the laryngeal mechanism and the sound spectrum, including high EGG contact quotient (CQ_{EGG}) and low speed quotient (SQ_{EGG}) values. EGG pulses were skewed significantly to the left and displayed a distinct knee shape during the de-contacting phase of the vocal folds, which consequently indicates a vibration with a clear mucosal wave. The long-term average spectrum (LTAS) and power spectrum exposed a considerable amplification and dislocation of F2 in the direction of high frequencies, thus boosting the third harmonic and showed a strong concentration of acoustic energy in the area of the singer's formant cluster.

Key Words: *voix mixte*–falsetto–register–vocal technique–electroglottography.

INTRODUCTION

Many tenor roles in the operas of the *primo ottocento* have an exceptionally high tessitura—often with notes well above C5 or D5. The best-known example is probably Arturo's arioso *"Credeasi misera"* from Bellini's *I Puritani,* which is composed up to F5; in another instance, the duet *"Sulla tomba che rinserra"* from the opera *Lucia di Lammermoor* requires Edgardo to sing an E5 flat. Normally, such high passages are beyond the vocal compass of modern tenors; thus, roles like these not only raise the question of how tenors in the early nineteenth century would have coped with such tessitura and extreme high notes—but also questions regarding historically informed performance practice, the aesthetics of Western classical music, and how singers today should perform such roles in an effective and vocally healthy way.

The so-called *voce faringea* offers an answer to these questions. Essentially, it is a forgotten historical singing practice used to extend the upper range of the voice; here, the falsetto, typically heard as a weak or feminine sound, is modified by the singer into a vocal quality that is a more tenoral and powerful. During the period of its employment, the resulting sound was considered homogenous with that of the lower registers and no longer perceived as a falsetto vocal color. In an exemplary fashion, this register mechanism mirrors a pre-romantic vocal ideal of sound that seems clearly divergent from ones prevalent today. In his 1851 work, Sieber pointed out that tenors possessing this technique could sing with the greatest ease and practically without force up to highest tenor ranges. The quality of their high notes was so unlike a contemporary falsetto sound that it probably gave rise to the often-heard, and likely erroneous, opinion that they sang these high notes in chest voice.[1] By balancing between registers, the singer would gain a beautiful, marrow-like, mixed tone, seeming to retain the strength of chest voice and yet protect the voice as in falsetto, yet without its feminine sound, as Schmidt remarked in his vocal textbook. Rennie wrote that this vocal timbre was both the sweetest and most brilliant sound the male voice could produce, possessing incomparably more pathos than any chest sound.[3]

18th- and 19th-century vocal pedagogical literature employed various, confusing and even contradictory terminology for the different voice registers[4]; however, most pedagogues were in agreement regarding the particular aesthetic merits of each register—mainly, chest and falsetto. In addition to these two registers, some vocal treatises of the era make mention of a third register mechanism tenors could employ to particular artistic advantage. It was often described as an intermediate register or a special mechanism connecting the falsetto and the chest register, and was perceived as a mixture of the two, often called *voix mixte* (mixed voice)[1, 2, 5-10]. Vocal *maestri* and physiologists used different terms to denote this vocal mechanism, including head voice[5, 10-20], falsetto or *fausset*/*faucet*[5, 11, 19-25], *voce mezzo-falso* or *middle-falsetto*[26], *Schlundkopfregister*[17], *feigned voice* [25, 27, 28], *voix sur-laryngienne*[5, 11, 21, 22] and *voix pharyngienne* (*pharyngeal voice* or *voce faringea*)[5, 11, 19, 21 22].

The term *pharyngeal voice* was coined by Herbert-Caesari and was first used to describe this particular vocal mechanism in his 1950 article “The Pharyngeal Voice”, in *The Musical Times*[29], and further in a chapter from his book *The Voice of the Mind*[30] (1951). Herbert-Caesari explains that the term *pharyngeal voice* is translated from the Italian *voce faringea*, and was used by exponents of the “old school” solely to describe a peculiar tonal quality produced by a distinctive mechanism. He adds that the tenors of the Rossini/Bellini/Donizetti period were taught to sing with *voce faringea*—very carefully mixed with both the falsetto and chest registers—and furthermore, that this method enabled (particularly) tenors to sing their highest notes with ease and brilliance.[29]

In accordance with formerly prevalent vocal ideals, at least according to historical written sources, these *tenori di grazia* did not produce their voices with dramatic force, but rather with elegance and suppleness up through their highest range. And yet the special vocal technique they employed to produce high notes considerably beyond C5 with absolute security and facility—as well as gradations between *pianissimo* and fortissimo throughout their entire range—gradually fell into obscurity.

During the second half of the nineteenth century, the vocal tradition of these great tenors ultimately went out of fashion and a new, more dramatic *verismo* vocal ideal took hold. Musicological scholarship attributes Gilbert Louis Duprez' interpretation of Arnold in Rossini's *Guillaume Tell*, first in an 1831 performance in Luca, Italy but more significantly in the 1837 Paris revival, as being a primary catalyst for this development. Duprez' high C5 (*ut de poitrine*) was not sung in the traditional *bel canto* falsetto-dominant vocal mechanism, as the famous *tenori di grazia* Adolphe Nourrit, John Braham or Giovanni Battista Rubini had sung it, but rather in modal (chest) register—similar to contemporary tenors. Duprez' *ut de poitrine* became the turning point after which the vocal ideal of the *bel canto* tenors, and subsequently the technique for developing *voce faringea,* were lost.[31] The term *voce faringea* has been chosen over other terms in order to avoid confusion and unwarranted associations with the modern falsetto voice, as well as misconceptions surrounding various other terms.

Observations made by vocal pedagogues, medical doctors and physiologists, documented in several vocal treatises[1, 2, 5-8, 11-13, 18, 21, 23, 24, 32] as well as physiological and anatomical writings[9, 10, 16, 17, 20, 22, 28, 33, 34] from the early nineteenth century, are particularly revealing with regard to training different vocal registers in the corresponding operatic tradition. Accordingly, many authors have mentioned the importance of specific muscular adjustments in both, the vocal tract and the larynx for producing the "mixed" voice. Bennati, an ENT specialist at the Paris Opera and trained singer, could study the physiological differences between vocal registers on himself and the best singers of the time. Both a contraction of the pharynx by lateral approximation of the pharyngeal walls in the area of the *isthmus faucium* and a narrowing of the aryepiglottic space was identified by him and other *maestri*[1, 5, 6, 11, 18, 21, 23, 24] and physiologists[10, 16, 17, 22, 34] of that time as a requirement for the production of the mixed register. Lepelletier de la Sarthe illustrated this constriction of the pharyngeal space in *voix pharyngienne* (the French term for *voce faringea*) also observed by Bennati (Figure 1). But in addition, an increase of vocal folds mass by slightly altering the coordinative contraction of the TA and CT muscles and a strengthening of glottal adduction were mentioned as physiological basis for developing a falsetto tone into the mixed voice.[6, 23, 24, 33, 34]

Although today the physiological and acoustic principles of the chest and falsetto registers have been extensively investigated, the modulating mechanisms influencing vocal fold vibration and the vocal tract in *voix mixte* are not yet sufficiently understood.[35] Some authors doubt the existence of a mixed register and designate the *voix mixte* as a pedagogical fiction.[36] For van den Berg, the *mid voice* is not an independent register, but a mixture of both the chest and falsetto registers. By fine-tuning the contraction of the cricothyroid and thyroarytenoid muscles and precise adjustments of the glottal adduction and subglottal pressure, a simultaneous longitudinal tension of the vocalis muscle and the vocal ligament can be achieved, resulting in a mixed phonation.[37] In contrast to the idea of blending the chest and falsetto registers, some authors argue that the mixed voice is always produced in a preset laryngeal mechanism.[38, 39] Castellengo et al. found that the *voix mixte* can be produced by an increase in sound intensity in falsetto mechanism (M2) as well as by reducing the intensity of the laryngeal mechanism of the chest register (M1). Typically, it is produced in mechanism M2 by females and in mechanism M1 by male subjects.[39] Consequently, the artistic goal of smoothing the register transition could only be accomplished by modifying the form of the vocal tract.

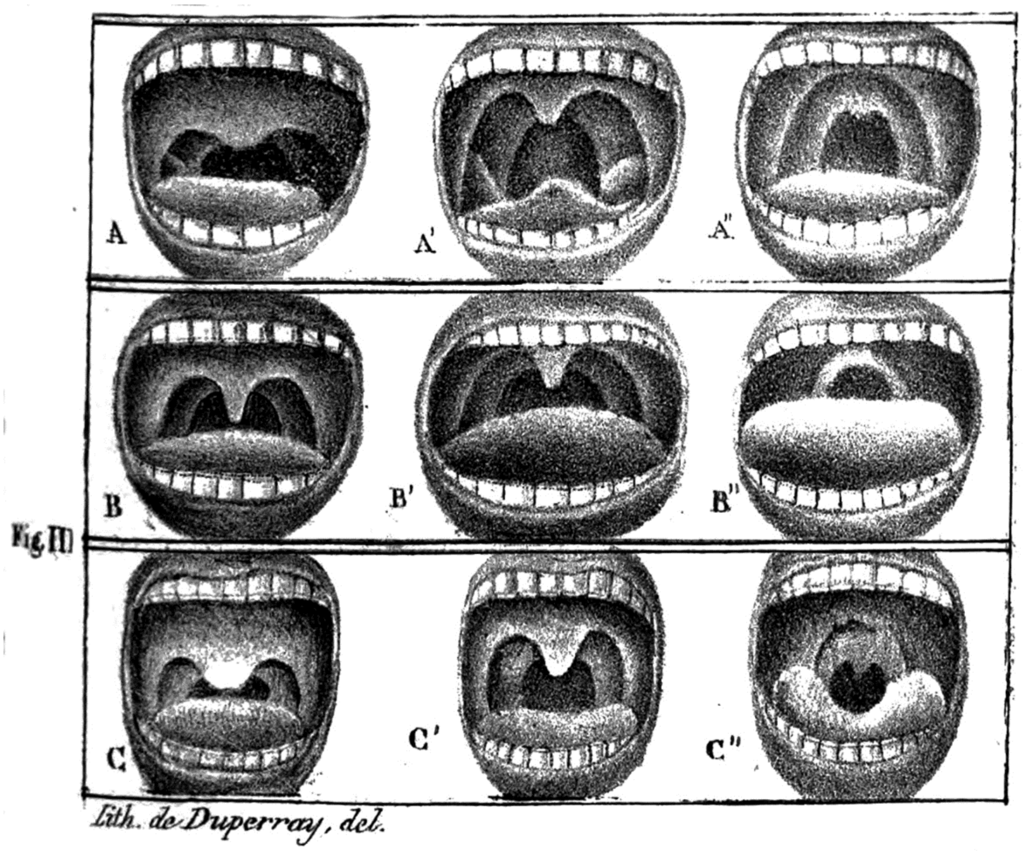

FIGURE 1. The mouth cavity of A: a soprano at rest, A': in chest voice, A": in head voice. B: a tenor at rest, B': in chest voice, B": in *voix pharyngienne*. C: a baritone at rest, C': in chest voice, C": in *voix pharyngienne*. Table made from studies by Francesco Bennati. (Lepelletier de la Sarthe A. Physiologie médicale et philosophique: Volume 4. Paris: Chez Germer Baillière; 1833:appendix).

This present pilot study is part of a broader investigation positioned at the intersection of theory and practice by demonstrating the historical basis for the *voce faringea*, reconstructing the training techniques and showing how these techniques can be used in contemporary performance practice. It aims to describe some distinctive physiological and acoustic characteristics of the *voce faringea*—and beyond this, also attempts to demonstrate that this register mix is a result of both specific laryngeal mechanism and resonance adjustments.

Electroglottography, introduced by Fabre in 1957, is a relatively simple and non-invasive technique for monitoring and investigating the glottal contact area during phonation.[40-43] An electric current of minimal intensity and high frequency is made to flow between two electrodes placed on the neck of a subject laterally alongside the thyroid cartilage. The contacting and de-contacting of the vocal folds cause fluctuations in impedance, which are subsequently represented in a curve form. Several studies have documented that the shape of the EGG signal is related to the vocal register.[44-46] In contrast to falsetto, due to a relatively rapid closing phase and longer opening phase of the glottis, the EGG shape typically shows a marked asymmetry in chest register. These differences can be explained by a change in the vertical glottal contact. Correlations between the EGG signal and physiological processes such as increasing glottal adduction, vertical phasing and medial vocal fold bulging have been investigated by Titze.[47, 48] A significant parameter for describing laryngeal mechanisms is the EGG contact quotient (CQ_{EGG}), defining the proportion of the glottal closure within a vibration period.[49] Henrich et al. and Miller et al. observed a sudden decrease of the EGG contact quotient during the transition from chest register to falsetto.[50, 51] However, it should be mentioned that the EGG contact quotient depends on the choice of algorithm used for determining the contacting and de-contacting events and must therefore be interpreted with caution.[52-54]

Various vocal registers are typically associated with distinctive resonance strategies in singing.[55, 56] The vocal tract acts as a filter which—depending on its geometrical shape—allows certain frequency regions (generally known as formants) to transmit more acoustical energy than others. Each modification of the vocal tract—for instance, tongue position, lip shape and jaw opening, the area of the pharynx or the vestibule—changes the formant structure and, accordingly, the sound spectrum. The two lowest formants F1 and F2 are determined by the vowel being articulated. The formants F3, F4 and F5 are more related to the vocal timbre, constituting the singer's formant cluster, essentially a concentration of acoustic energy in the frequency spectrum range between 2.5 and 3.5 kHz, which is the reason classically trained (particularly male) singers' are perceived as brilliant, metallic or focused. Since the singer's formant cluster typically lies in a frequency range where the human ear is very sensitive and where the classical orchestra sound is relatively weak, singers can be heard over the orchestra.[57] The long-term average spectrum (LTAS) represents an efficient tool for quantifying the quality of vocal sounds.[58-60] It displays the average strengths for various frequency areas of the vocal sound over a longer period of time. These reflect both the characteristics of the glottis function as well as of the vocal tract. The moment-to-moment sound pressure level of a tone's fundamental and its partials can be investigated by a power spectrum. It is directly related to the vocal tract's shape and exhibits diverse resonance strategies for various vocal registers.[61]

METHODS

Sound samples sung by a professional opera singer and voice pedagogue (a tenor and countertenor – the author of the study) in the chest and falsetto registers as well as in *voce faringea* and *mezza voce* were recorded. For the purposes of this study, falsetto will be termed a usage of the falsetto register appropriate for classical singing. Herbst also described this form of falsetto - as opposed to abductive, "naïve" falsetto - as adducted or countertenor falsetto.[62] Heretofore, *voce faringea* will be termed a falsetto-dominant mixed phonation, one the author—based on scientific analysis of historical sources—has artistically developed and trained with the intention of producing a sound perceptually more similar to his tenor voice than to his falsetto. In accordance with Miller[56], the term *mezza voce* will be further used for a soft chest dominant register mechanism, one Garcia referred to as *mezzo petto*[63]. Sustained tones (executed at constant volume or with a *diminuendo* from *forte* to *pianissimo*) with a length of approximately 8 seconds on C5 as well as descending (D5 – A4) chromatic scales were sung on the vowl /a/. For recording and analyzing the sound samples the *VoceVista* system, developed by Donald G. Miller, was used. This system consists of the computer software *VoceVista Pro* and a small portable electroglottograph, enabling the researcher to investigate and analyze characteristics of the glottis function and the vocal sound spectrum. Thus, two signals were measured: the audio signal was taken from a headset microphone with omnidirectional access and linear frequency, and the EGG signal was taken from two electrodes placed on the neck of the singer. These signals were both transferred to the computer (Microsoft Surface Pro 3) by means of an audio interface (Tascam US-144 Mk2). During this process, the level of volume for the audio and EGG was set to avoid distortion and strain. In order to constitute a more realistic impression of the balance between individual frequency components, a typical vibrato rate of approximately 5 Hz was normalized by setting the average time on 200 milliseconds.[61] To attain a better comparison, the signals were then normalized to a level of 85%, using the software Adobe Audition CC.

An analysis of the EGG contact quotient and the EGG signal symmetry for the register mechanisms falsetto, *voce faringea* and chest was carried out using the *VoceVista* software. Sustained tones (C5) sung in various laryngeal mechanisms were then compared. In addition Eggworks, a free UCLA software by Henri Tehrani, was used for automated computing of the EGG contact quotient (CQ_{EGG}) and the ratio of the contacting and de-contacting time during a vibration period—also referred to as the EGG speed quotient (SQ_{EGG}). For processing the CQ_{EGG} and the SQ_{EGG} 500 ms sequences of the sound samples (sustained tones on C5) in falsetto, *voce faringea*, *mezza voce* (B4) and chest register were used. The software automatically calculates the EGG contact quotient by 4 methods: (1) a threshold method[43] with a threshold set to 25%; (2) a "Hybrid" method[64], where the closing peak in the derivative is used to define the moment of closing and the threshold EGG signal the moment of opening; (3) in addition to this, a method using the opening and closing peaks of the EGG's derivative for calculating the CQ_{EGG}[65]; and (4) Henry Tehrani's method, which determines the closing peak of the derivative as the contacting event, with the same y-value of the EGG signal—measured at the time of that peak and then found again during the opening phase of the EGG signal—and its own time taken as the de-contacting event.[66] Herbst has analyzed and compared several threshold and DEGG methods for measuring the CQ_{EGG}. He found highest matches of CQ_{EGG} values with corresponding videokymographic data for threshold methods with a criterion level of 0.2 and 0.25, and suggested this method for estimating the CQ_{EGG} in male voices.[67] For this reason the threshold method, with a criterion level of 0.25 provided by the Eggworks software, seems adequate for this study. The software also offers the possibility to calculate the EGG speed or skew quotient (SQ_{EGG}), thus representing the symmetry of the EGG signal shape.[68, 69] The skewness of EGG signals is a useful indicator of various phonation types. As chest phonation pulses are usually shorter in rising and longer in falling, their EGG signal shape is typically skewed, whereas falsetto phonation pulses, with comparable contacting and de-contacting durations, show a more symmetrical shape.[70] The SQ_{EGG} values were computed by default at a 10% threshold.[71]

For comparing the LTAS of chest voice, falsetto and *voce faringea*, descending chromatic scales from D5 to A4 were sung on the vowel /a/ in each register mechanism. For this, a spectrum average was set to 7000 ms. In addition, power spectra were employed for analyzing resonance strategies in different vocal registers; the two lowest formant frequencies of sound samples with a length of 500 ms (C5) were measured by means of the Burg algorithm, embedded in the Praat software by Paul Boersma and David Weenink.

Furthermore, CQ_{EGG} values, the EGG signal symmetry and the resonance spectrum (power spectrum) during a continuous *diminuendo* from *forte* to *pianissimo* in *voce faringea* on B4 were measured using *VoceVista* and Eggworks. To this end, a period of 500 ms respectively from the beginning and the end of the *diminuendo* maneuver was taken. For comparing falsetto-dominant mixed phonation, *voce faringea* and the chest-dominant mix *mezza voce,* these parameters were also measured.

RESULTS

Figure 2 shows a power spectrum (left) with the audio and EGG signals (right) of sound samples in (A) falsetto, (B) *voce faringea*, (C) *mezza voce* and (D) chest register. The vowl /a/ was sung in falsetto, *voce faringea* and chest voice on C5, in *mezza voce* on B4. The displayed values for the EGG contact quotient, measured by the *VoceVista* software using a criterion level of 0.25, are 0.43 for falsetto, 0.60 for *voce faringea*, 0.57 for *mezza voce* and 0.70 for chest. A further investigation of the CQ_{EGG} computed over a period of 500 ms by the Eggworks software yielded corresponding results as shown in Figure 3.

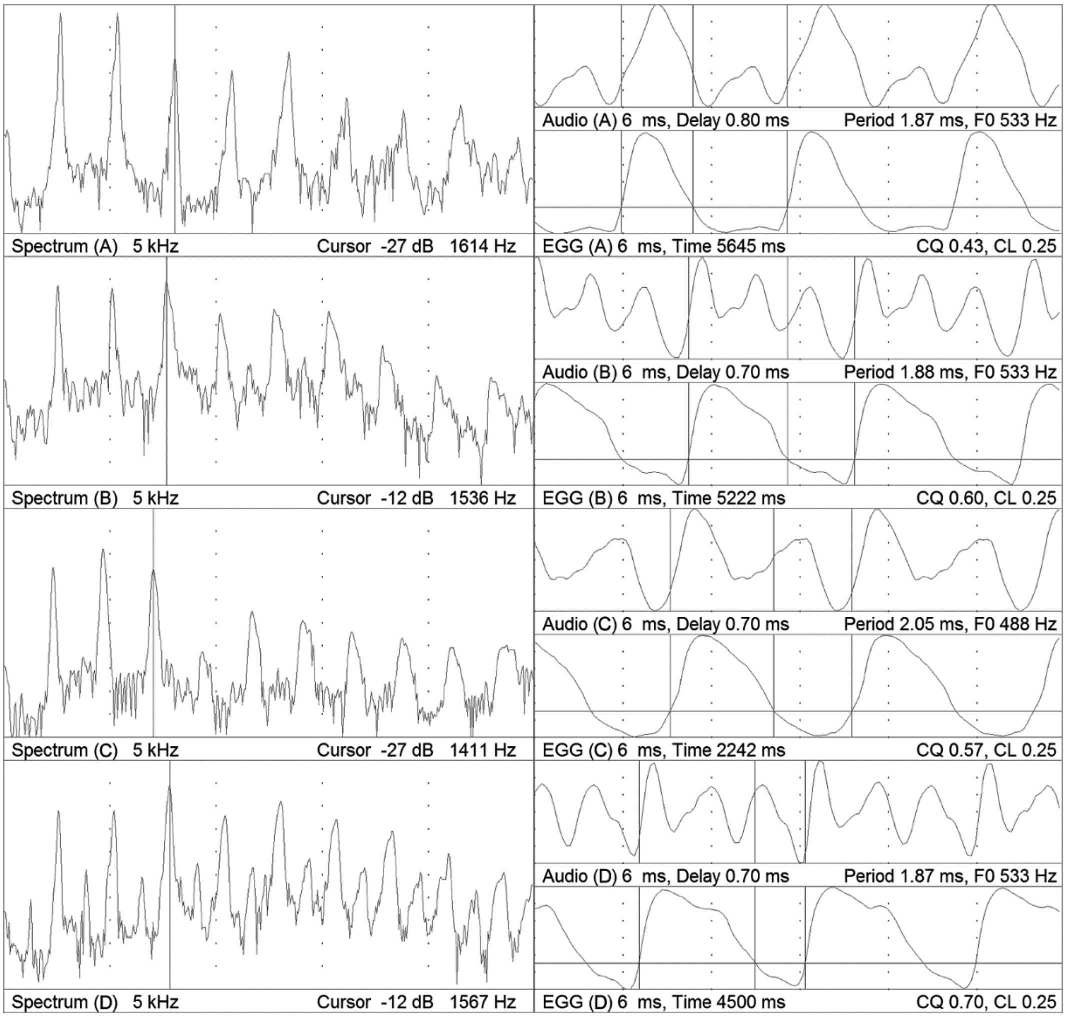

FIGURE 2. Comparison of power spectra (left) and audio and EGG Signals (right) of sounds sung on the vowl /a/ on C5 in falsetto (A), *voce faringea* (B), *mezza voce* (C) and chest register (D) displayed by the *VoceVista* software.

While the EGG signal of the falsetto tone exhibits a symmetrical shape, the signal in *voce faringea*, *mezza voce* and chest register exhibits a conspicuous skew (Fig. 2, EGG A - D). This asymmetry is due to a relatively shorter contacting and longer de-contacting duration of the vocal folds in different vocal register mechanisms (Figure 4) and can be quantified by the EGG speed or skew quotient (SQ_{EGG}). As displayed in Figure 5, the highest average SQ_{EGG} value (0.61) was computed for falsetto, while for *voce faringea* and chest register identical SQ_{EGG} (0.28) values were calculated. Detailed EGG data—including CQ_{EGG}, SQ_{EGG}, contacting and de-contacting time and the standard deviations, which were determined by means of the Eggworks software—are summarized in Table 1.

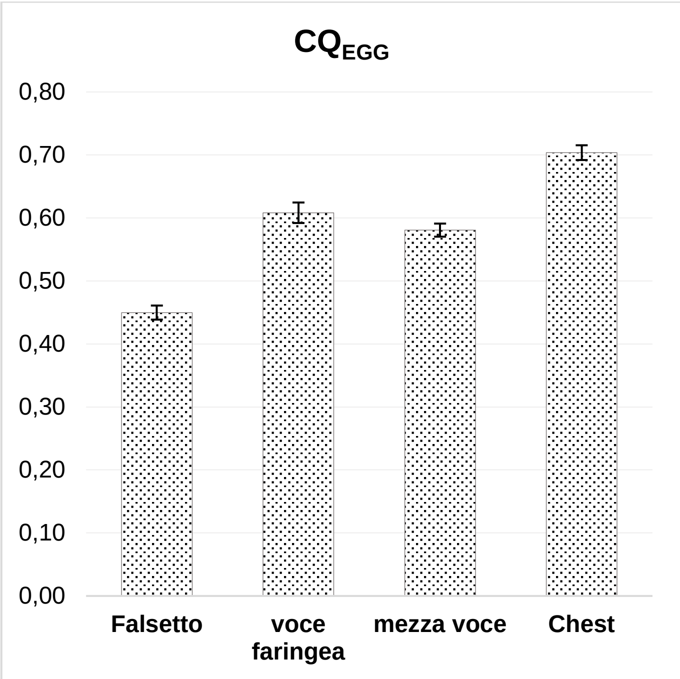

FIGURE 3. Comparison of the EGG contact quotient values in falsetto, *voce faringea*, *mezza voce* (B4) and chest register of sustained tones sung on the vowl /a/ on C5 computed over a period of 500 ms by the Eggworks software.

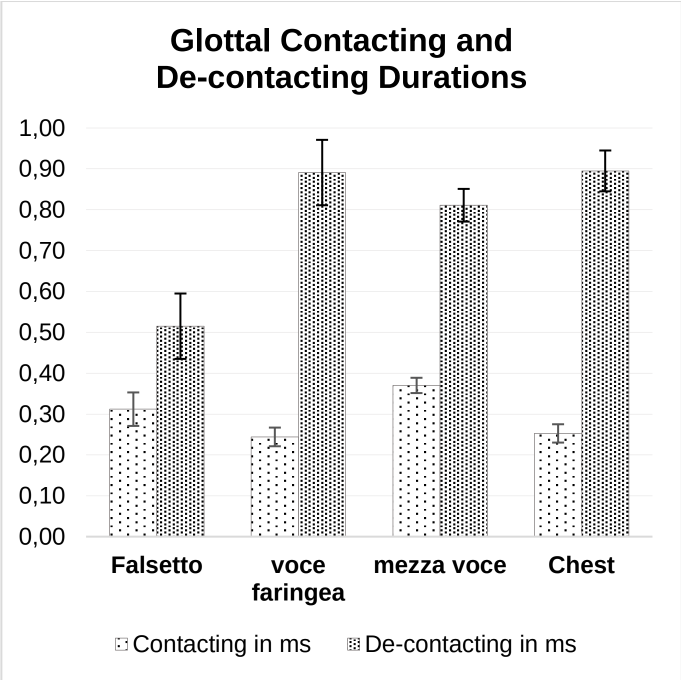

FIGURE 4. Comparison of the glottal contacting and de-contacting durations in ms in falsetto, *voce faringea*, *mezza voce* (B4) and chest register of sustained tones sung on the vowl /a/ on C5 measured over a period of 500 ms by the Eggworks software.

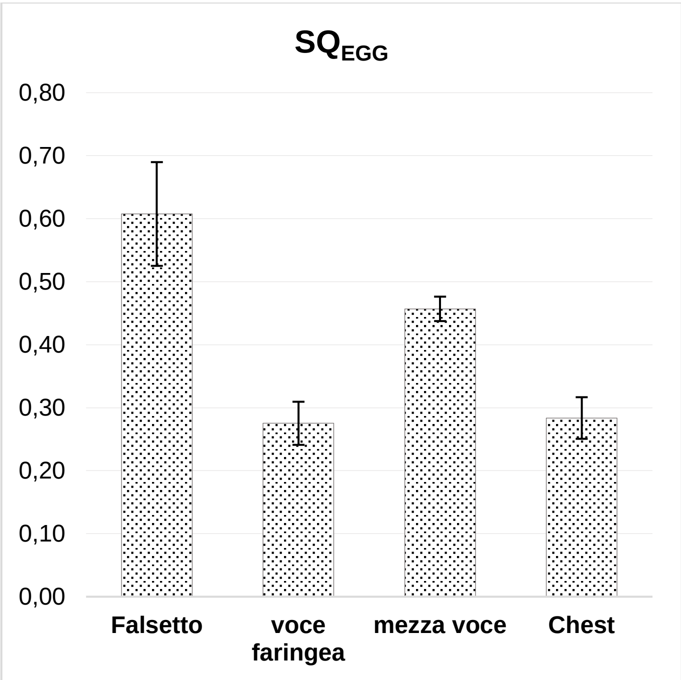

FIGURE 5. Comparison of the EGG speed (skew) quotient values of tones sung on the vowl /a/ on C5 in falsetto, *voce faringea*, *mezza voce* (B4) and chest register computed over a period of 500 ms by the Eggworks software.

TABLE 1 Values for the CQ_{EGG}, contacting and de-contacting durations and the EGG speed (skew) quotient of tones sung on the vowl /a/ on C5 in falsetto, *voce faringea*, *mezza voce* (B4) and chest register computed over a period of 500 ms by the Eggworks software.

Mechanism	*CQ*	*SD/CQ*	*CD*	*SD/CD*	*DD*	*SD/DD*	*SQ*	*SD/SQ*
Falsetto	0.45	0.01	0.31	0.04	0.52	0.04	0.61	0.08
voce faringea	0.61	0.02	0.24	0.02	0.89	0.08	0.28	0.03
mezza voce	0.58	0.01	0.37	0.02	0.81	0.04	0.46	0.02
Chest	0.70	0.01	0.25	0.02	0.90	0.05	0.28	0.03

Abbreviations: CQ – EGG contact quotient; *SD/CQ* – EGG contact quotient standard deviations; *CD* – contacting duration of the vocal folds in ms; *DS/CD* – contacting duration standard deviations; *DD* – glottal de-contacting durations in ms; *DD/SD* – glottal de-contacting durations standard deviations; *SQ* – EGG speed quotient (ratio of the contacting and de-contacting durations); *SQ/SD* – EGG speed quotient standard deviations.

A comparison of long-term average spectra (LTAS) for falsetto, *voce faringea* and chest register (Figure 6) reveals different resonance strategies in these vocal register mechanisms. The LTAS shows that the singer's formant cluster, an essential element of classical singing technique, is weaker in falsetto (A) than in *voce faringea* (B) and chest register (C). Within a frequency range of 2756 Hz and 2868 Hz, similar sound pressure levels were measured in *voce faringea* (-52 dB) and chest (-51 dB) and a lower SPL value in falsetto (-63 dB). In contrast to falsetto, showing two peaks below the singer's formant cluster within the frequency ranges of F0/F1 and F2, the LTAS of the *voce faringea* and chest display a strong third peak between 1400 Hz and 1800 Hz with a comparable SPL of -51 dB (chest) and -52 dB (*voce faringea*). Presumably, this is related to the fact that in falsetto the formants F1 and F2 were close to the fundamental (F0) frequency and H2 and in *voce faringea* and chest they were close to the second and third harmonic.

Variations in resonance are also illustrated by the power spectra for falsetto, *voce faringea*, *mezza voce* and chest voice (Figure 2, left A-D). However, the dominance of H3 in *voce faringea* (B) and chest (D) is conspicuous, while in falsetto (A) the fundamental and H2 are dominant and the third harmonic is relatively weak. A SPL of -12 dB was measured for H3 in *voce faringea* and chest and in falsetto a 15 dB lower value (-27 dB) was found.

Figure 7 shows the average frequencies of the first and second formants and their standard deviations, computed by means of the Burg algorithm embedded in the Praat software. The measured frequency averages of F1 and F2 were in falsetto 530 Hz (SD: 11 Hz) and 1067 Hz (SD: 7 Hz), in *voce faringea* 606 Hz (SD: 26 Hz) and 1586 Hz (SD: 39 Hz), in *mezza voce* 499 Hz (SD: 11 Hz) and 1348 Hz (SD: 73 Hz) and in chest voice 601 Hz (SD: 15 Hz) and 1488 Hz (SD: 44 Hz).

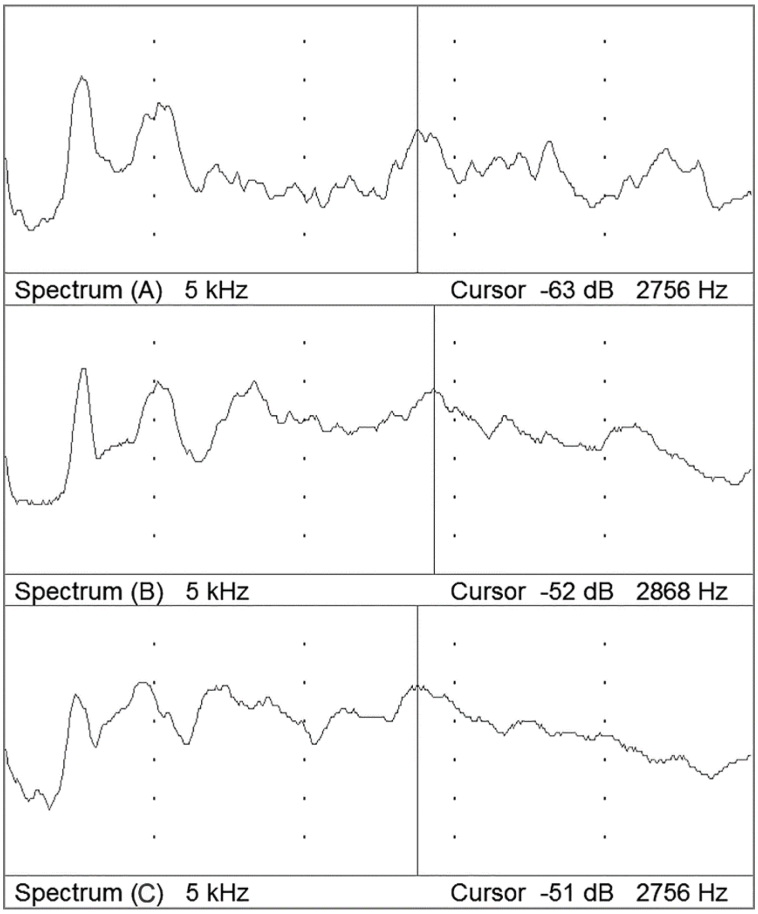

FIGURE 6. Comparison of long term average spectra (LTAS) of descending chromatic scales from D5 to A4 sung on the vowl /a/ in falsetto (A), *voce faringea* (B) and chest (C) displayed by the *VoceVista* software.

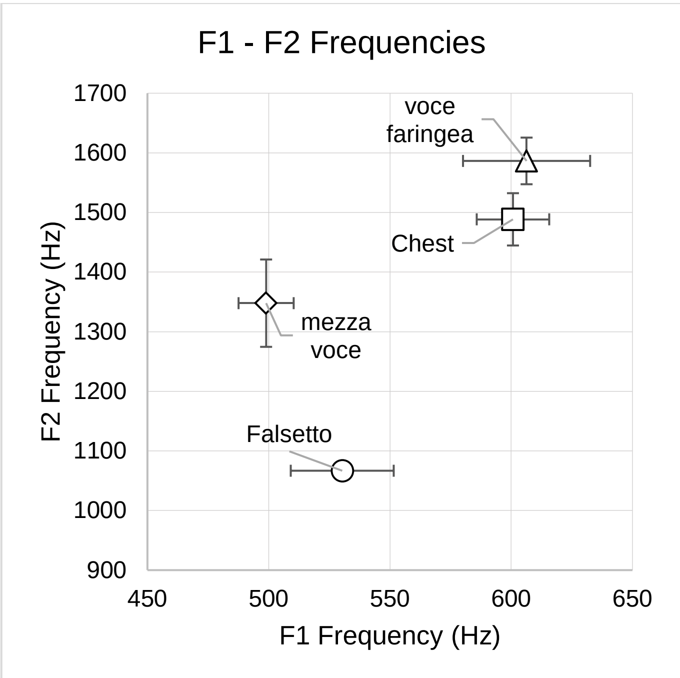

FIGURE 7. Average frequencies and standard deviations of the first and second formants of the vowl /a/ sung on C5 in falsetto, *voce faringea*, *mezza voce* (B4) and chest register estimated by means of the Burg algorithm, embedded in the Praat software.

Two moments of a continuous diminuendo executed from forte (below: spectrum B and EGG B) to *pianissimo* (above: spectrum A and EGG A) on B4 are displayed in Figure 8. A knee shape in the vocal folds' de-contacting phase can be seen both in *forte* and *pianissimo*. Calculation of CQ_{EGG} yielded an average value of 0.54 in *forte* and 0.60 in *pianissimo*. A slightly shorter contacting duration in *forte* than in *pianissimo* is indicated by a steeper EGG pulse during the glottal closing, also documented through automated calculation. The ratio of the contacting and de-contacting time (SQ_{EGG}) is slightly higher in *pianissimo* (0.36) than in *forte* (0.27). Table 2 shows the average measured values for CQ_{EGG}, contacting and de-contacting duration, SQ_{EGG} and the corresponding standard deviations between each respective 500 ms sequence from the beginning of a *diminuendo* in *forte* and from the end in *pianissimo* sung in *voce faringea*.

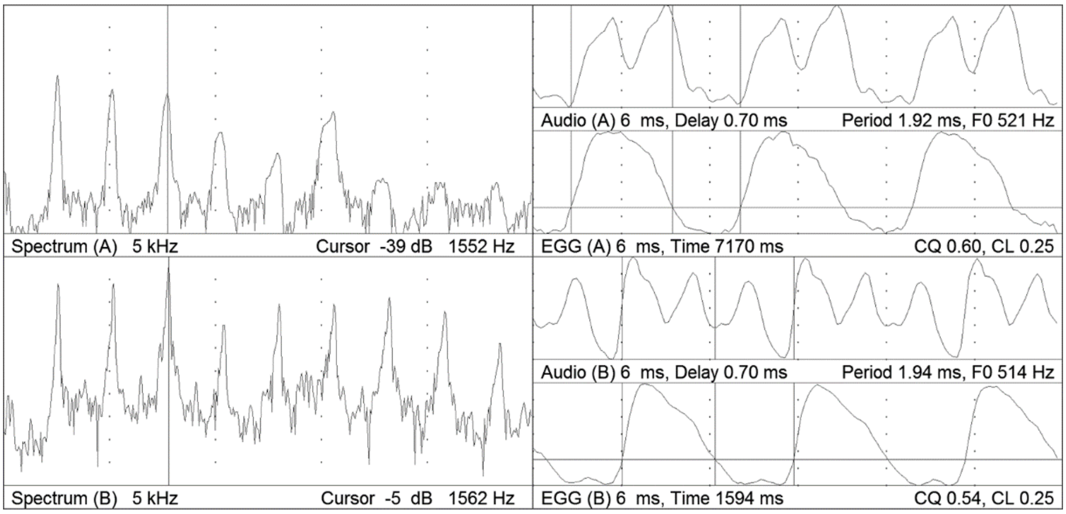

FIGURE 8. Comparison of power spectra (left) and audio and EGG Signals (right) of a 500 ms sequence from the beginning of a *diminuendo* (B) in *forte* and from the end (A) in *pianissimo* sung on the vowl /a/ on C5 in *voce faringea* displayed by the *VoceVista* software.

TABLE 2. Values for the CQ_{EGG}, glottal contacting and de-contacting durations and EGG speed quotient computed over a period of 500 ms by the Eggworks software, at the beginning and the end of a *diminuendo* tone from *forte* to *pianissimo* sung in *voce faringea* on B4.

Volume	*CQ*	*SD/CQ*	*CD*	*SD/CD*	*DD*	*SD/DD*	*SQ*	*SD/SQ*
forte	0.54	0.03	0.21	0.02	0.77	0.08	0.27	0.04
pianissimo	0.60	0.02	0.28	0.03	0.80	0.08	0.36	0.04

Abbreviations: CQ – EGG contact quotient; *SD/CQ* – EGG contact quotient standard deviations; *CD* – contacting duration of the vocal folds in ms; *DS/CD* – contacting duration standard deviations; *DD* – glottal de-contacting durations in ms; *DD/SD* – glottal de-contacting durations standard deviations; *SQ* – EGG speed quotient (ratio of the contacting and de-contacting durations); *SQ/SD* – EGG speed quotient standard deviations.

Electroglottography confirmed only slight differences between *forte* and *pianissimo* in *voce faringea*. More significant in this regard are the distinctions in the resonance spectrum, as can be seen in Figure 8. In *forte*, H3 is the dominant partial in the sound spectrum (-5 dB) while in *pianissimo*, the fundamental is dominant. H3 falls by 34 dB in *pianissimo* (-39 dB) as H6 in the range of the singer's formant cluster between 2900 and 3100 Hz only loses 26 dB (-47 dB in *pianissimo*) as compared with *forte* (-21 dB).

The power spectrum of a *mezza voce* sound (B4) exhibits neither a dominance of H3 nor a dominance of F0. With a SPL of -18 dB, the strongest partial in the spectrum is H2. Compared to a soft tone in *voce faringea* approximately corresponding in volume to the *mezza voce* (*mezzo piano*/*piano*), the SPL of H3 (-27 dB) and H6 (-50 dB) are 10 dB lower in the latter (Figure 9).

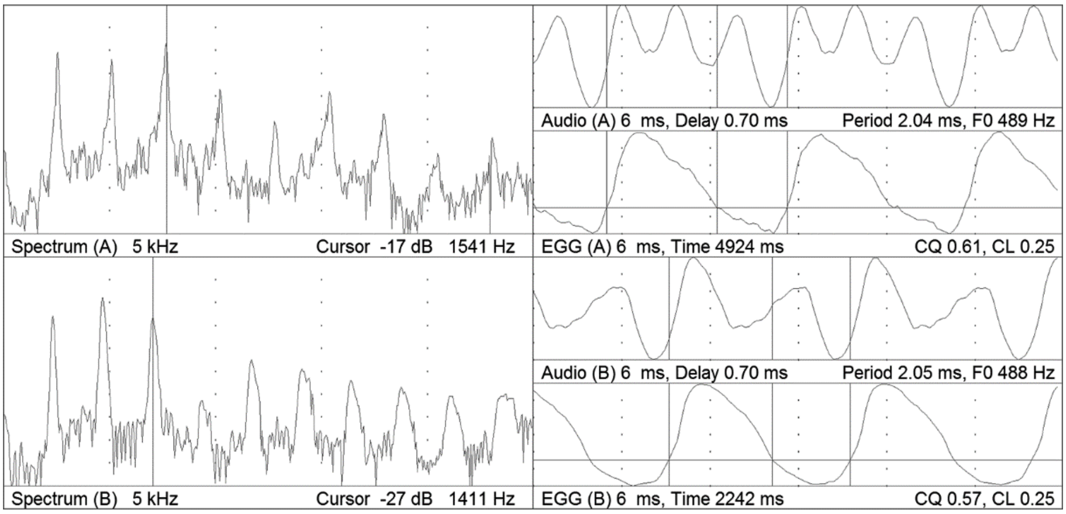

FIGURE 9. Comparison of power spectra (left) and audio and EGG signals (right) of sounds sung on the vowl /a/ on B4 in the falsetto dominant mixed mode *voce faringea* (A) and in the chest dominant register mix *mezza voce* (B) displayed by the *VoceVista* software.

DISCUSSION

The results of this single-subject investigation, obtained by analysis of EGG data and sound spectra, revealed specific peculiarities of the falsetto-dominant mixed phonation *voce faringea*. Furthermore, a clear distinction from falsetto and chest registers as well as from the chest dominant *mezza voce* could be documented. The study in particular confirmed assumptions made in several historical written sources that the production of *voce faringea* requires a distinctive configuration of both the laryngeal mechanism and the vocal tract.

For decades, the physiological/functional differences between modal and falsetto register have been a focus of scientific voice research. Today it is generally agreed that vocal registers are related to specific vibrational patterns of the vocal folds. The chest register differs from the falsetto through an increased tension in the vocalis muscle which thickens the body of the vocal folds and leads to a greater vibrating mass. As described by Hirano[72], through a tensed vocalis muscle the body of the vocal folds is stiffened against their surface, which creates a mucosal wave with a vertical phase difference. In falsetto, due to stretching in the outer layers of the vocal folds and low activity of the vocalis muscle, there is a considerable reduction in the mucosal wave and hence also a shorter closed phase of the glottis. As found by several investigations, the EGG signal for the chest (modal) register reveals a longer contact period of the vocal folds and thus a prolonged closed phase of the glottis as compared to falsetto.[44, 45, 73] According to Miller, in chest register an EGG contact quotient of more than 0.50 can be expected; in falsetto, this value is usually less than 0.40.[56]

The measurement of the average CQ_{EGG} values (Table 1) showed, as expected, significant differences between falsetto (0.45) and chest register (0.70). Remarkable, however, is the value of 0.61 found in *voce faringea*, which is exceptionally high for a falsetto-dominant register mix and closer to the value measured for chest than that for falsetto. As Titze described, due to increased glottal adduction and membranous medialization via thickening of the vocal folds' body and the bulging of their edges ("surface bulging") in chest register, a characteristic knee shape in the EGG wave form occurs.[47, 48] Such a knee indicates a vibration pattern with a clear phase difference between the body of the vocal folds and their cover, causing a prolongation of the contact period and an enlargement of the vocal folds' vertical contact area. A bulging of the vocal folds' edges in mixed register was already observed in the nineteenth century by the vocal pedagogue Hey.[6] As he described, through strengthening the vocalis activity and glottal adduction the sound of the falsetto could be amplified into the mixed voice, which was similar to the chest register in timbre and finally took place of the falsetto. As displayed in Figure 2, the EGG pulses of the chest register and *voce faringea* show distinct similarities: both signals exhibit a pronounced knee which is (as expected) absent in the curve form of the falsetto. Through the greater longitudinal tension of the vocal ligaments and minor vocalis activity, the vocal folds in falsetto vibrate with decreased mass and a reduced phase difference, as evidenced in this investigation by lower CQ_{EGG} and a higher SQ_{EGG} values. Hence, high CQ_{EGG} and low SQ_{EGG} values as well as the skewed shape of the EGG pulse in *voce faringea* indicate that significantly increasing glottal adduction and the tension of the vocalis muscle are essential for developing the *voce faringea* from falsetto. Raised glottal adduction in *voce faringea*, as compared to falsetto, was also found by means of a flow-glottogram in an earlier study of the author.[74] Lower values of the *normalized amplitude quotient* (NAQ: pulse amplitude / MFDR * fundamental frequency), representing the adductive strength were measured for *voce faringea* than for falsetto.

As the contact quotient and the vocal folds' adduction typically rise and fall with the volume of a sound[75], a reduced CQ_{EGG} would have been expected at the end of a *diminuendo* performed in *voce faringea*. By contrast, in fact, slightly higher CQ_{EGG} values have been found at the end of a *diminuendo* than at the beginning—which underlines the significance of the adductive forces exerted by the lateral cricoarytenoid muscles (LCA) and the interarytenoid muscles (IA) for the production of this vocal register mechanism. A long contact phase of the vocals folds is presumably advantageous for equalizing vocal power of the chest register and a falsetto-dominant mixed mechanism: when the glottis is closed the vocal tract is a significantly better resonator, disproportionately boosting the higher frequency components.

LTAS and power spectrum of the *voce faringea* and the chest register revealed significant similarities regarding their resonance structure. In both register mechanisms the third partial, boosted by a strong second formant, is dominant in the spectrum; both exhibit a more powerful singer's formant cluster than in falsetto. One explanation for this is an effective excitation of the higher harmonics resulting from increased vocal adduction and sharp, relatively extended vocal closures in chest register as well as in *voce faringea* (whereas the falsetto typically has a strong fundamental and rather weak high frequency components)[37, 76]; another explanation would be the specific configuration of the vocal tract here. Since in this case the vocal tract in falsetto (sustained tone on C5) assumed a convergent shape, with a widening of the laryngopharyngeal space and the larynx kept in a low position, the frequency of the first and second formants were lowered until a coupling of F1/H1 and F2/H2 could be established. Hence, the timbre of the vowel /a/ assumed a darker color (/ə/). This resonance strategy, also referred to as “hoot” or “whoop” coupling[61, 77], is typically used by males singing in falsetto[55] and by females singing in their higher ranges. Accordingly, falsetto timbre assumes a round, soft and prevailing feminine character. In order to successfully blend falsetto and the chest voice into one timbre, in his 1841 vocal treatise, Garcia stipulated that a singer must fuse the “metal” of the two registers into a single one[23] This singer (the author of the present study) found that altering the vocal tract’s shape through velar lowering, slightly lifting the back of the tongue, narrowing the pharyngeal space and minimal laryngeal rising as well as narrowing the aryepiglottic sphincter to be necessary physiological and functional conditions to develop the *voce faringea* from falsetto. Corresponding to Fant’s findings[78] that pharyngeal narrowing boosts F2, an increase in frequency and SPL of the second formant and a strengthening of the singer’s formant cluster could be observed in *voce faringea*. When the F2/H3 coupling was established, a tendency of the vowel color towards an /æ/ was evident. Significant increases in amplitudes of F_2, F_3 and F_4 and a dislocation of the second formant to a higher frequency bandwidth were also mentioned by Hanayama and co-workers[79] as characteristic for a metallic vocal mode. The essential acoustic and physiological characteristics they observed in metallic mode—pharyngeal narrowing, aryepiglottic contraction, a lowering the soft palate and a shortening of the vocal tract—are largely consistent with those of the *voce faringea*. As the palatopharyngeal muscle is connected to the oblique arytenoid muscle (a vocal fold adductor) via the aryepiglottic fold, pharyngeal contraction may have an effect on the aryepiglottic sphincter and the vibration mode.[80]

Several researchers have discussed the acoustic effects of aryepiglottic constriction. As Sundberg explained, the laryngeal tube acts as a separate resonator, amplifying the sound significantly when its size is smaller than one-sixth the cross-sectional area in the pharynx.[81] It was found that the intensity of the singer’s formant cluster is associated with aryepiglottic constriction.[82] Therefore, the sound showed strong energy in the bandwidth around 3 kHz when the aryepiglottic sphincter was narrowed, and less energy when the sphincter was open or relaxed. This offers an explanation for the differences in the power spectra of *voce faringea* and *mezza voce*. Though both mixed phonation modes show similar CQ_{EGG} values and comparable EGG signal shapes, they are based on different laryngeal mechanisms. By widening the pharyngeal space the second formant was lowered and by relaxing the aryepiglottic constriction the acoustic energy around 3 kHz dramatically decreased in *mezza voce*. Furthermore, a shorter contact phase and a greater SQ_{EGG} in *mezza voce* than in chest voice reflects a reduced glottal adduction and vocalis activity. In contrast, due to a shift of F_2 in the direction of high frequencies, the spectrum of a sound of comparable volume (*mezzo piano*/*piano*) in *voce faringea* exhibits a dominant third harmonic and, due to a narrowed aryepiglottic sphincter, increased acoustic energy in the bandwidth of the singer’s formant cluster. Relatively shorter contacting and longer de-contacting durations in *voce faringea* than in *mezza voce* indicate a sharper closure and higher adductive forces.

CONCLUSION

The analysis of EGG data and sound spectra of a falsetto-dominant mixed phonation mode, also referred to as *voce faringea,* has here provided evidence that may help to define certain characteristics of a forgotten singing practice of the *bel canto* tenors in the *primo ottocento*. This investigation revealed specific physiological and acoustic peculiarities of the

voce faringea; a clear distinction from the falsetto and chest registers could be documented. Assumptions that the production of *voce faringea* requires peculiar configuration of both the laryngeal mechanism and the vocal tract were confirmed.
Findings regarding the physiological and acoustic characteristics of the *voce faringea* can be summarized as follows:

1. Significantly higher CQ_{EGG} values than for falsetto and slightly lower values than for chest were found for *voce faringea*.
2. Due to a relatively shorter contacting and a longer de-contacting time of the vocal folds, as compared to falsetto, the EGG pulses in *voce faringea* and chest were strongly skewed to the left, while in falsetto they were more symmetrical. Thus, in *voce faringea* and chest, approximately equal low values of the speed quotient and in falsetto considerably higher SQ_{EGG} values were calculated.
3. In *voce faringea* and chest voice, a distinct knee shape—indicating a vibration pattern with a phase difference between the vocal folds' body and their cover (mucosal wave)—was shown in the EGG signal during the glottal de-contacting phase which was missing in falsetto.
4. A long term average spectrum (LTAS) revealed a strong concentration of acoustic energy in the area of the singer's formant cluster for *voce faringea* and chest, while for falsetto the SPL around 3 kHz was more than 10 dB lower.
5. Analysis of power spectra and formant structure for the different register mechanisms revealed a significant amplification and a dislocation of F_2 in the direction of high frequencies in *voce faringea* and chest register, considerably boosting the third harmonic. In contrast, tuning the first formant to the fundamental was the resonance strategy typically employed in falsetto for amplifying the sound.
6. A comparison between the falsetto-dominant mixed phonation *voce faringea* and the modal-dominant register mix *mezza voce* showed comparable results regarding the EGG contact quotient values, which were slightly lower than in chest and significantly higher than in falsetto. A higher SQ_{EGG} in *mezza voce* is assumed to be an indication for lower applied glottal adduction than in *voce faringea*. The smaller concentration of acoustic energy around 3 kHz and H_3 in *mezza voce* is probably related to the relaxing of the aryepiglottic sphincter and a widening of the pharyngeal space, while in *voce faringea* a narrowed pharynx and aryepiglottic sphincter strengthens the singer's formant cluster, enhancing and shifting F_2 to a higher bandwidth until a coupling of F_2/H_3 is established.

Using the *voce faringea* concept, characteristics of the chest register can be combined with those of falsetto, enabling tenors to produce the highest tessituras with absolute assurance and ease. As a complementary vocal technique for producing exceptionally high notes of the tenor repertoire in an effective and healthy way, the *voce faringea* concept could constitute a valuable contribution to singing, particularly as a historically informed performance practice for vocal literature of the primo ottocento. In another vein, this pilot study might also constitute a contribution towards better understanding the physiological and acoustic particularities of different types of mixed phonation.

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