Oscillatory Characteristics of the Vocal Folds Across the Tenor Passaggio

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Summary: Introduction. Recent research has revealed that classically trained tenors tend to constrict epilaryngeal structures when singing in and above the passaggio (ie, the frequency region where register events typically occur). These constrictions complicate visibility of vocal fold oscillatory patterns with transoral rigid high-speed video endoscopy, thus limiting the current understanding of laryngeal dynamics in the passaggio region of tenors.

Materials and Methods. This investigation analyzed seven professionally trained western classical tenors using high-speed digital imaging (HSDI) at 20,000 frames per second via transnasal flexible endoscopy. The participants produced transitions (a) from modal to falsetto register and (b) from modal to stage voice above the passaggio (SVaP) during ascending pitch glides from A3 (220 Hz) to A4 (440 Hz) on vowel /i/. HSDI data were complemented by simultaneous acoustic and electroglottographic recordings.

Results. For many subjects both transition types were associated with constrictions of the epilaryngeal structures during the pitch glide. These constrictions appeared to be more distinct for the SVaP than for falsetto. No major irregularities of vocal fold oscillations in the sense of fundamental frequency jumps were observed for either transition type. However, during the transitions, the open quotient derived from the glottal area waveform (OQ_{GAW}) increased; in falsetto, the OQ_{GAW} was greater and the electroglottographic cepstral peak prominence was lower than in SVaP.

Conclusions. Epilaryngeal constrictions should be considered typical for tenors singing at high fundamental frequencies. Vocal fold oscillatory patterns are changing not only for the register shift from modal to falsetto but also for the transition from modal to SVaP, indicating a need for laryngeal adjustments during these transitions.

Key Words: tenor–registers–high-speed digital imaging–electroglottography–modal.

INTRODUCTION

Voice production in singers' upper pitch range is a challenging task, independent of classification, Fach, or genre. Great tension has to be applied to the vocal folds in order to increase stiffness and thus the rate of vocal fold oscillations.[1,2] Furthermore, the subglottic pressure has to be adjusted. An increase in subglottic pressure is associated with an increase in both sound pressure level and fundamental frequency (f_o).[2] Therefore, high subglottic pressures are often observed at high phonation frequencies.[2] With regard to vocal registers, adjustments to the subglottic pressure,[3] laryngeal muscles,[4,5] and/or the vocal tract[6–9] are also likely to occur.

Especially for tenors, the frequency range where registration events (ie, a register shift from modal to falsetto register) usually occur, often denoted as the passaggio region,[1,7,10–12] is of particular interest in voice education. The technique of voice production employed above the passaggio when singing on stage without amplification (stage voice above the passaggio, SVaP) and the passaggio itself is not yet fully understood.

For untrained singers, sudden changes from modal to falsetto register frequently occur within the passaggio region. This involuntary register change is often associated with pitch jumps due to nonlinear properties of the voice production system.[13–15] It has previously been shown that many characteristics differ between the modal and falsetto registers: for the modal register, the vocalis muscle activity,[4,16,17] the closed phase during the glottal cycle,[3,9,18,19] and the intensities of partials in the voice source spectrum are greater, and therefore the difference between the intensity of the first and the second partial (H1−H2) is lower.[3]

Because abrupt and spontaneous acoustic changes of the radiated sound[20–22] are not desirable in western classical singing, equalization of the sound differences between the registers and/or adjustments to the voice source production are necessary. As noted in a previous publication,[8] the authors suggest that, in general, several options could be considered to achieve an appropriate voice quality for SVaP: (1) to remain in the modal register but increase subglottic pressure to such a degree that f_o can be raised, (2) to change to a falsetto voice source but avoid sudden pitch jumps by laryngeal adjustments and—at the same time—equalize sound differences among the registers through vocal tract adjustments, and (3) to enable a higher degree of freedom for the oscillatory system avoiding bifurcations by improving vocal tract/voice source interaction, etc. Although increase of subglottic pressure is not exclusive for (1), it could be additionally used also for (2) and (3). However, if used alone, the rise of subglottic pressure is considered limited in producing frequency range expansion (the rise of subglottic pressure by one cmH_2O is related to an increase of f_o of approximately 3–4 Hz[2]) and additionally could be associated with an increase of vocal

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impact stress.[23] (2) is associated with a rather weak voice source.[3] It could be suggested that up to the 1830s, when Duprez arrived at the Paris opera house, this solution for the passaggio and SVaP was the most common. Light orchestral textures made this possible compared with the dense orchestration of later years. Even now, some classically trained professional tenors might use this solution for their SVaP. However, because singing with a strong voice source is generally considered important for modern tenors, the third option could be assumed to be the most relevant current strategy for the SVaP.

On stage, it is of importance that the voice system remains stable during phonation, thus avoiding the pitch jumps that usually occur for untrained voices in the passaggio region.[13] To achieve this, modulation of the subglottic pressure[24] or modulation of the phonation type and associated grade of adduction could contribute to stabilization. Here, it could be expected that both the collision pressures and oscillatory amplitude will be changed by the grade of adduction. Furthermore, it is of importance to maintain vocal fold contact in order to generate a strong interruption of the transglottal airflow and thus high voice source overtone intensities. A theoretical approach demonstrated that constriction of the epilaryngeal tube increases inertive reactance, and by means of an interaction with the vocal folds might help vocal efficiency as long as no harmonic crosses a resonance.[25] Indeed, in a previous study using rigid high-speed digital imaging (HSDI) techniques, the authors failed to analyze the passaggio region in professional tenors due to constrictions of the epilaryngeal tube.[26] Furthermore, it could be expected that other vocal tract adjustments might also contribute to the stabilization of voice production by changing possible interactions with the oscillatory system and/or the flow pulse. Zanartu et al[14] observed a more stable vocal fold oscillatory system when the vowel condition avoided a crossing of f_o and vocal tract resonances. Changes from modal to falsetto were also associated with only minor changes in vocal tract shape compared with major changes associated with transitions from modal to SVaP.[27] This included changes of the larynx height, pharynx width, and the uvula elevation. The latter seems to suggest that nasalance may also be involved.

The vocal fold oscillatory behavior for transitions from modal register to SVaP avoiding a register shift to falsetto has not yet been clarified. In a previous investigation, the authors failed to analyze differences in oscillatory patterns between a register change from modal to falsetto and a transition from modal to SVaP in professional tenors.[26] Here, the epilaryngeal tube was strongly constricted for the transition from modal to SVaP. In the cited study, the HSDI technique was limited to 4000 frames per second (fps) and rigid endoscopy. Because the vocal tract of tenors is modified for a transition to SVaP,[27] it could not be excluded that the rigid endoscope had prevented necessary vocal tract adjustments or led to an epilaryngeal compression. Therefore, it remains unclear whether the observed constrictions are a consequence of the rigid endoscopy technique or the task. In recent years, HSDI techniques have much improved, allowing transnasal endoscopy with a frame rate of 20,000 fps.[28] Even if the task causes a constriction, it should be possible to analyze vocal fold oscillations as—in contrast to the rigid technique—the angle to the glottis can be adjusted.

This study aims to analyze the differences in vocal fold oscillations in professionally trained western classical tenors concerning a register change from modal to falsetto and a transition from modal to SVaP, respectively, using transnasal high-speed video endoscopy. In contrast to rigid endoscopy, this technology safeguards that (a) adjustments to the epilaryngeal tube would be visible while still allowing for sufficient visibility of the vibrating vocal folds in order to allow analysis of laryngeal dynamics; and (b) the phonation of the participants was as natural as possible, eliminating the need to pull the epiglottis anteriorly (as would be the case in rigid endoscopy, in order to allow for full visibility of the vocal folds). It was hypothesized that no sudden pitch jumps or other types of instabilities occur for the transition from modal to SVaP, whereas such changes do occur for the register change from modal to falsetto. Furthermore, it was hypothesized that the open quotient (OQ) remains nearly stable for the transition from modal to SVaP but increases for the transition from modal to falsetto register.

MATERIALS AND METHODS

After approval from the local ethical committee, seven professionally trained western classical tenors were included. None of the subjects had taken part in previous studies by the authors that utilized rigid endoscopy.[26] Laryngoscopic examination revealed no signs of vocal fold pathology in any subjects. The classification of the subjects according to the Bunch and Chapman taxonomy,[29] their respective Voice Handicap Index scores,[30,31] and their age are indicated in Table 1.

The subjects were asked to perform a pitch glide from A3 (f_o 220 Hz) to A4 (f_o 440 Hz) over a time period of approximately 1 second on the vowel /i/ in two conditions: First, they were asked to perform a glide with a register change from modal to falsetto. This condition was introduced as a "baseline" measure simulating the "untrained" or "naïve" approach to the passaggio. In the second task, the same participants were asked to sing the same glide as they would perform it on stage, thus demonstrating their transition from modal to SVaP. The vowel /i/ was used

TABLE 1.
Taxonomy According to Bunch and Chapman,[29] Voice Handicap Index (VHI),[30,31] and Age of All Subjects

Subject	Taxonomy	VHI	Age
T1	7.2 Full-time voice student university	0	26
T2	3.1b National minor principal opera	1	34
T3	7.2 Full-time voice student university	22	29
T4	3.1a National major principal opera	1	43
T5	2.1 International opera principal	Not assessed	38
T6	2.1 International opera principal	0	46
T7	7.2 Full-time voice student university	3	27