Investigating Laryngeal "Tilt" on Same-pitch Phonation—Preliminary Findings of Vocal Mode Metal and Density Parameters as Alternatives to Cricothyroid-Thyroarytenoid "Mix"

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Summary: Objectives. The objective of this work was to study the parameters "metal" and "density" and their combinatory conditions in relation to the vocal modes Overdrive, Edge, and Curbing from the pedagogical method Complete Vocal Technique by means of laryngostroboscopic imaging, high-speed videoendoscopy, electroglottography (EGG), long-time-average spectrum (LTAS), and acoustics.

Study Design. This is a three-subject exploratory study.

Methods. Three singers were recorded performing various metal and density conditions of Overdrive, Edge, and Curbing from the Complete Vocal Technique method by means of laryngostroboscopic imaging using a videonasoendoscopic camera system and the Laryngostrobe program, high-speed videoendoscopy, EGG, LTAS, and acoustic signals using *SpeechStudio*.

Results. A laryngeal tilt was discovered as related to the condition of "reduced density" on same-pitch phonation, with observations of the thyroid cartilage tilting forward, stretching of the mucosa covering the cricoid-arytenoid complex and the posterior cricoid, and an upward posterior, slightly superior, contraction of the middle constrictor muscle in the pharyngeal wall. A resulting associated reduced contact quotient was observed on EGG, as well as a lowered mean sound pressure level. On LTAS, the laryngeal tilt was associated with a decrease of spectral energy in areas between the 7th and the 20th harmonic. The subjects of the study were able to perform the tilt without changing pitch or volume.

Conclusions. Singers can perform laryngeal tilt during same-pitch phonation in the vocal modes Overdrive, Edge, and Curbing. The parameters of density and metal establish a more precise and anatomically grounded terminology than "mix register."

Key Words: Laryngeal tilt−Complete Vocal Technique−Mix register−Density−Metal.

INTRODUCTION

A recent vocal trend referring to vocal qualities as "thyroarytenoid (TA) dominant" or "cricothyroid (CT) dominant" has emerged among voice pedagogues and singers. Such terms are, problematically, not derived from direct measurement of laryngeal mechanisms.[1] Accordingly, recent scientific studies have instigated a line of inquiry trying to establish a relationship between CT and TA muscle activities and what some refer to as register changes in ascending or descending pitch investigations. This line of thinking has developed out of some singers and singing teachers using terminologies such as "mix," "chest-mix," and "headmix"[2] or "head dominant mix" and "chest dominant mix"[1,3] in an attempt to establish voice production strategies as being perceivably either TA or CT dominant.[1] The thinking builds on the notion that vocal registers are dependent upon the tension of the vocal folds, with contraction of the CT muscle changing the angle between the thyroid and cricoid cartilages.[4] While data on mix voice are relatively sparse,[5] some have hypothesized that low and midparts of the voice range are dominated by TA muscle activity with lower CT activity, and that mid- to higher parts of the voice are dominated by CT activity with comparatively lower TA activity.[6] This line of hypothesizing builds on Hirano et al's studies showing how TA and lateral cricoarytenoid activities were highest in chest types of voice production and lowest in falsetto types of voice production.[7,8] However, in a recent electromyographic study of the CT and TA muscle activities involved in vocal register control, no empirical support was found for the CT- or the TA-dominant types of phonation as related to registers, and the authors pointed to pitch level being the main determining factor of CT-to-TA muscle activity ratios.[1]

It is well established that an elevation of the larynx and a slight tilting of the larynx are involved when ascending higher in pitch[4,9] and that CT muscles are involved in the elongation of the vocal folds for such pitch changes. Vocal pitch has been determined as a balance between the length, the tension, the vibrating mass, and the stiffness of the vocal folds, as well as sub- and transglottic pressure and airflow.[2] Accordingly, it has been demonstrated how an elevation of pitch is related to a decrease in vibrating mass and amplitude in the vocal folds because of lengthening and added tension of the vocal folds.[2] Moreover, previous acoustic, aerodynamic, and physiological

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studies using electroglottography (EGG) find that denser phonation has a higher vocal fold adduction.[1] However, results from studies of mix types of registration are contradictory. Using EGG, one study reports differences in open and closed quotients between "belt," mix, and "legit" registrations,[10] whereas another finds no such differences.[11] One study highlights how mix has been defined as the mixing of TA and thick vocal fold types of phonation with CT and thin fold vocal functions by singing pedagogues.[3] However, the authors of the study note that the participating singing pedagogues stress how, from a voice science perspective, "mix voice as a mix of registers remain a big question mark" (p.128.e8).

Registers have been used, generally, to describe four types of ranges; however, how these registers differ remains unclear.[2,6] It has been pointed out that register characterization and terminology continue to be areas of much ambiguity, debate, and disagreement among voice scientists,[1] yet remain areas of perceived importance for voice teachers. Accordingly, it has been highlighted that there is an ongoing debate and argument among singing teachers and voice scientists as to the very existence of registers.[5] Therefore, the present study does not refer to registers where possible but rather simply refers to pitch ranges: the very low, low, mid, high, and very high parts of the voice[12] so as to determine the note by sung pitch, not voice quality or resonance strategy. One such genre-free and register-free approach is offered by Complete Vocal Technique (CVT),[13] which identifies and defines four modes of singing termed Neutral, Curbing, Overdrive, and Edge. Recent investigations of Curbing, Overdrive, and Edge based on audio perception, laryngostroboscopic imaging, acoustics, long-time-average spectrum (LTAS), and EGG showed statistically significant differences between these modes of singing.[14–18] Previous studies have characterized Curbing as reduced metallic with a slightly plaintive or restrained sound,[15] Overdrive as full metallic with a direct sound and shout-like character, and Edge as full metallic with a light and somewhat aggressive sound with a more screamy character.[14,17] Upon investigation, Overdrive and Edge were found to exhibit a dominant second harmonic and higher mean closed quotients (55.3% for Overdrive, standard deviation [SD] = 8.5%, and −58.4% for Edge, SD = 7.2), as well as to show progressive observable constriction in supraglottic structures, with particular anterior and posterior narrowing between the arytenoid-cuneiform complex and the petiole, and changes in the acute angles between the aryepiglottic folds and the epiglottis.[14] Similarly, Sundberg et al, found that Overdrive is produced with a higher degree of phonatory glottal adduction and a higher F1 compared with falsetto tones, supported by findings on normalized amplitude quotient, Qclosed, and H1-H2 relations.[19] The same study found that Overdrive may be related to firmer contraction of the vocalis muscle resulting in a thicker vocal fold and a higher contact quotient (Qx). In another study comparing Overdrive and Edge with Curbing, Curbing was observed as exhibiting a higher first harmonic and lower second harmonic, somewhat lower mean closed quotients (50.95, SD = 8) with a specific rectangular appearance at the level of the ventricular folds, and a higher visibility of the vocal folds along their length, giving the impression of a medium amount of constriction, compared with Overdrive and Edge.[15]

More recently, discussion of the "density" of the vocal modes from CVT has been introduced into the CVT pedagogical terminology in the CVT smartphone application.[20] In these pedagogical descriptions, density has been defined as the degree of compactness in a sung or spoken note on a scale from 0% to 100%. Pedagogically speaking, if a note is completely "filled out" or exhibits significant weightiness, it is referred to as "full density" (from 50% to 100% density), whereas a note that is 50% or less filled out, with significantly less weight, is referred to as "reduced density."

Perceptually speaking, a reduced-density setting for the vocal modes Curbing, Overdrive, and Edge may possibly resemble what some voice pedagogues refer to as "mix voice," because such types of phonation are recognized as "being in the middle."[5] Therefore, the present exploratory pilot study aimed to investigate the three modes of Curbing, Overdrive, and Edge in relation to both reduced and full density and how this pedagogical terminology relates to the current debate on mix registration and TA-CT muscle activity.

In the CVT pedagogical approach, varying degrees of metal and density can be achieved for Overdrive, Edge, and Curbing ranging from 0% to 100% for both parameters. Therefore, the present study investigates both full and reduced metallic and full and reduced density of the three metallic modes as conditions. By means of laryngostroboscopic imaging, high-speed imaging, LTAS, EGG, and acoustics, the present study investigates whether there are observable laryngeal gestures related to the full- and reduced-density parameters, as well as compares LTAS, EGG, and acoustic measurements, on same-pitch phonation alternating between density conditions. This investigation led to the generation of the following hypotheses:

Hypothesis 1: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in Curbing and a note sung with a reduced-density setting for Curbing.

Hypothesis 2: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in full-metal and full-density Overdrive and a note sung in reduced-metal and reduced-density Overdrive.

Hypothesis 3: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in full-metallic and full-density Overdrive and a note sung in reduced-metal and full-density Overdrive.

Hypothesis 4: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in full-metal and full-density Edge and a note sung in reduced-metal and reduced-density Edge.

Hypothesis 5: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in full-metal and full-density Edge and a note sung in reduced-metal and full-density Edge.

Hypothesis 6: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sung in reduced-metal and reduced-density Overdrive and a note sung in reduced-metal and reduced-density Curbing.

Hypothesis 7: There are no observable differences in laryngeal gestures, MDVPs, or LTAS between a note sun in reduced-metal and reduced-density Edge and a note sung in reduced-metal and reduced-density Curbing.

METHODS

Participants

The study draws on data from two separate data gathering events.

For the first event, one professional male singing teacher and singer took part (coauthor MAT). The singing teacher was an authorized CVT teacher and had experience with teaching and singing according to the CVT method. The participant was 27 years old and of Danish nationality. The participant had 5 years of experience teaching CVT, with more than 20 years of experience as a singer. As a singer, the participant identified with singing styles such as gospel, pop, and soul. Laryngostroboscopic videos, as well as high-speed videos, were captured for the male singer, along with EGG and acoustic data.

For the second event, two professional singing teachers and singers took part (two men). Both singing teachers were authorized CVT teachers and had many years of experience with teaching and singing according to the CVT method. One subject was 44 years of age, had experience as a singer for 28 years, had been teaching singing for 23 years, and had been taught according to CVT for 24 years. The other subject was 44 years of age, had sung for 30 years, had been teaching for 18 years, and had been teaching CVT for 13 years. Only laryngostroboscopic videos were obtained from these two male participants for this particular study.

Instrumentation

An Olympus CV-190 Evis Exera III camera with ENF-VH HD videoscope was used with the LED200 laryngeal strobe light source (Laryngograph Ltd, Wallington, UK) and *LxStrobe* software (Laryngograph Ltd, Wallington, UK) on a digital video workstation to obtain the laryngostroboscopic videos. The *LxStrobe* system simultaneously captured synchronized video, acoustic, and EGG signals. EGG was used as a noninvasive method for obtaining data of the vocal fold activity,[21] similar to previous investigations of vocal modes.[14,22] The EGG was recorded via two electrodes placed on either side of the singer's larynx, and the audio signal was recorded using an omnidirectional microphone integrated into the Laryngograph microprocessor. The synchronized acoustic and EGG signals were processed and analyzed using the *SpeechStudio* software (Laryngograph Ltd). The EGG signal was also used to trigger the stroboscope.

Vocal tasks

All participants were instructed to sing a sustained vowel[14,15,23] on C4 (262 Hz) in one mode and condition (see Table 1 for an overview) and to alternate with another (1) mode and (2) condition. All possible alternations between modes and conditions were recorded, with the condition of full metallic and reduced density excluded because this is not taught in the CVT method, which deems this technically impossible and potentially harmful for the voice. Singers were instructed to alternate between the possible conditions three times per alternation pair for the videonasoendoscopy recordings, and once per alternation pair for the high-speed recordings. The singers sustained each vowel for approximately 2−3 seconds per condition for both the high-speed recordings and the videonasoendoscopy. Videos of each of the conditions in the model can be found in the online supplementary materials.

During the recordings, four experts were present as follows: (1) a laryngologist, (2 and 3) two authorized CVT teachers, and (4) an acoustic engineer from Laryngograph. The experts ensured that the desired task was performed by the singers and that good quality recordings and signals were obtained during each voice sample. After each vocal task sequence, the singer was also asked whether or not the desired vocal task was performed. The sample was only included in the final sample if all experts, as well as the singer, agreed on the precision and quality of the sung sequence, which is common in other pilot studies.[24]

EGG and acoustic measures

An MDVP was generated based on the recorded EGG and acoustic signals. This included both resonance-free measures[14] and resonance-dependent measures. Resonance-free measures included Qx, contact quotient standard deviation, fundamental frequency, fundamental frequency standard deviation, jitter first, jitter second, jitter factor, and relative average perturbation (RAP). The resonance-dependent measures included shimmer+, shimmer−, shimmer dB, harmonics-to-noise ratio, normalized noise energy, cepstral peak prominence, and mean sound pressure level (SPL). These measurements together formed the MDVP.

Long-term average spectrum

Following previous investigations of vocal modes, LTAS was used to evaluate and compare the spectral properties of the investigated sounds. LTAS has been established as a consistent

TABLE 1.
Alternation Conditions

	Reduced Metallic (0%−50% Metal)	Full Metallic (50%−100% Metal)
Full density (50%−100% density)	Overdrive [ε] + Edge [ε]	Overdrive [ε] + Edge [ε]
Reduced density (0%−50% density)	Curbing [I] + Overdrive [ε] + Edge [ε]	N/A

Abbreviation: N/A, not applicable.

and successful means of exploring the spectra of sound in evaluating voice quality[25,26] for objective voice classification.[27] The study included narrowband in the analysis of the generated spectra ranging from 0 to 20.000 Hz. No statistical comparisons were feasible for any of the collected data included in the study because of the fact that this was a single-subject pilot study, corroborated by findings from an additional minor study of two subjects.

RESULTS

Observed laryngeal gestures

Full-metallic and full-density Overdrive

When performing the full-metallic and full-density condition for Overdrive, the findings of this study resemble those reported by McGlashan et al.[14] Particularly, anterior and posterior narrowing between the arytenoid-cuneiform complexes and the petiole was observed, along with obscured visibility of the anterior part of the vocal folds by the petiole. An acute angle between the aryepiglottic folds and the epiglottis was observed, and some narrowing of the piriform sinuses was visible. Finally, only some activity was observed in the ventricular folds in covering the vocal folds. A still image of the full-metallic and full-density condition for Overdrive can be seen in Figure 1.

Reduced-metallic and full-density Overdrive

When participants alternated between Overdrive in the full-metallic and full-density condition and Overdrive in the reduced-metallic and full-density condition, the entire supraglottic structure seemed to progressively constrict less while maintaining the overall setting and gesture as observed earlier. An illustration of the reduced-metallic and full-density condition for Overdrive can be seen in Figure 2.

Reduced-metallic and reduced-density Overdrive

When participants alternated between Overdrive in the full-metallic and full-density condition and Overdrive in the reduced-metallic and reduced-density condition, multiple supraglottic as well as vocal fold changes were observed. The thyroid cartilages were observed tilting forward, stretching the mucosa over the cricoid-arytenoid complex and the posterior cricoid. Moreover, an upward posterior, slightly superior, contraction of the middle constrictor muscle on the posterior pharyngeal wall was observed as opening the piriform fossae. An accompanied stretching and thinning of the vocal folds were observed because of the posterior movement of the arytenoids. Furthermore, more "cupping" of the supraglottic was observed, as well as thinning of the aryepiglottic folds. The epiglottis was seen as becoming more vertical in position with flattening of the petiole, revealing the whole length of the vocal folds from vocal processes to the anterior commissure. Moreover, a lessening of the medial lateral constriction of the ventricular folds was observed, as well as a posterior backward rotation of the arytenoids, stretching the mucosa over the cuneiform cartilages. Finally, an increasing acute angle between the aryepiglottic folds and the epiglottis was observed. A still image of the reduced-metallic and reduced-density Overdrive condition can be found in Figure 3, and a video of one singer alternating between a full-density and full-metallic Overdrive to a reduced-density and reduced-metallic Overdrive can be found in the supplementary video called "Tilt Example Overdrive."

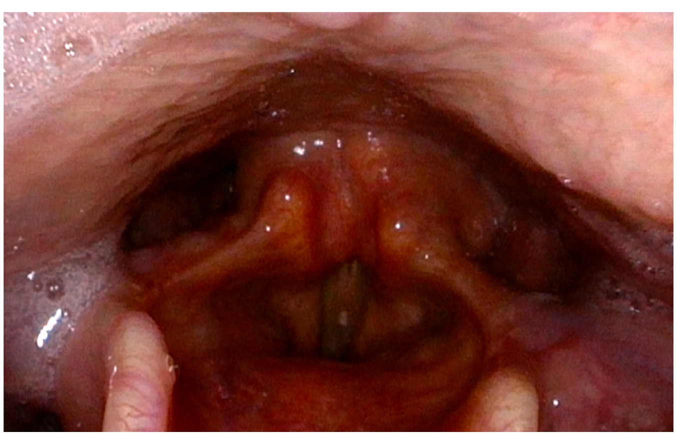

FIGURE 1. Full-metallic and full-density Overdrive.

FIGURE 2. Reduced-metallic and full-density Overdrive.

Full-metallic and full-density Edge

When performing the full-metallic and full-density condition of Edge, the findings of the present study resemble very closely those reported by McGlashan et al.[14] Particularly, the vocal

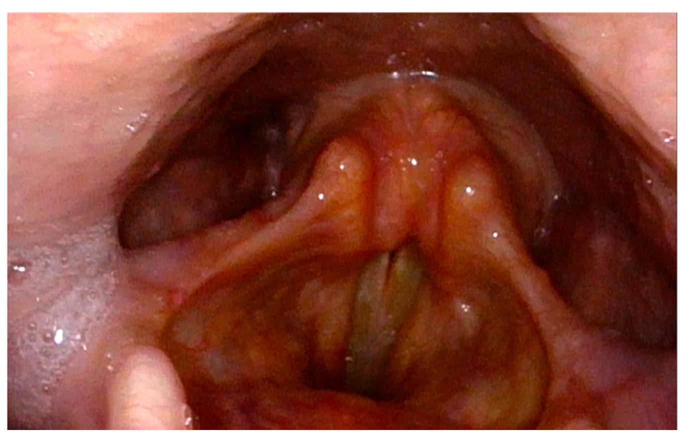

FIGURE 3. Reduced-density and reduced-metallic Overdrive.

FIGURE 4. Full-metallic and full-density Edge.

folds were observed as almost completely covered by the ventricular folds. There was further anterior and posterior narrowing between the arytenoid-cuneiform complexes and the petiole compared with Overdrive, and the cuneiforms were observed rolling in anteromedially. Moreover, a distinct triangularly shaped laryngeal inlet was observed, along with a distinct narrowing of the piriform sinuses. Finally, an elevated larynx position was observed. A still image of the full-metallic and full-density Edge condition can be found in Figure 4.

Reduced-metallic and full-density Edge

When subjects alternated between the full-metallic and full-density condition and the reduced-metallic and full-density condition for Edge, the entire supraglottic structure was observed as very slightly less constricted while maintaining the overall setting and gestures as described earlier. A still image of the reduced-metallic and full-density condition for Edge can be seen in Figure 5.

Reduced-metallic and reduced-density Edge

When alternating between Edge in the full-metallic and full-density condition and Edge in the reduced-metallic and reduced-density condition, multiple supraglottic as well as vocal fold changes were visible. There was a noticeable lessening of the constriction of the middle constrictor and a

FIGURE 5. Reduced-metallic and full-density Edge.

FIGURE 6. Reduced-metallic and reduced-density Edge.

relaxation and lengthening of the thyroid hyoid gap, resulting in a deepening of the vallecula. Furthermore, a lengthening of the vocal folds was observed with no variation in pitch, along with less anterior rotation of the arytenoids. An upward posterior, slightly superior, contraction of the middle constrictor muscle on the posterior pharyngeal wall was observed as opening the piriform fossae. Moreover, an increasing acute angle between the aryepiglottic folds and the epiglottis was observed, along with less rolling in of the cuneiforms. Finally, a lessening of the medial lateral constriction of the ventricular folds is observed, along with a reduced posterior displacement of the petiole of the epiglottis, causing less reduction in anterior-posterior narrowing. A still image of the reduced-metallic and reduced-density condition for Edge can be seen in Figure 6.

Reduced-metallic and reduced-density Curbing

As Curbing has already been established as a reduced setting,[15−17] no investigations of the full-metallic or full-density condition were attempted. When subjects performed Curbing in the reduced-metallic and reduced-density condition, findings were very similar to those previously reported by Thuesen et al[15]; particularly, the ventricular folds were not obscuring the view of the vocal folds, providing visibility of the vocal folds at their length, and the ventricular folds were observed as providing a rectangular appearance. Only a moderate amount of anterior and posterior narrowing between the arytenoid-cuneiform complexes and the petiole was observed. Moreover, there was little to no rolling in of the cuneiform complexes anteromedially and very little triangularly shaped appearance of the laryngeal inlet. When viewing the inspiration and onset of the condition, the posterior pharyngeal wall was seen moving backward, pulled by the increased activity in the inferior and, particularly, the middle constrictors, similar to the settings also identified for the reduced-density Overdrive and the reduced-density Edge conditions. Finally, a forward rotation of the whole larynx seemed to be present; however, conclusions on this finding would require further investigation by other means, such as magnetic resonance imaging (MRI) for verification. A still image of the reduced-metallic and reduced-density setting for Curbing can be seen in Figure 7.

FIGURE 7. Reduced-metallic and reduced-density Curbing.

Reduced-metallic and further reduced-density Curbing

To investigate whether or not an even further reduced-density setting of Curbing could be identified, subjects were asked to alternate between Curbing and a setting that perceptually sounded even more reduced. Only minor changes could be observed, particularly, the epiglottis becoming more vertical in position with flatting of the petiole, revealing the whole length of the vocal folds from vocal processes to the anterior commissure and a lessening of the medial lateral constriction of the ventricular folds, compared with the previously described setting. Moreover, the arytenoids were observed as pulled slightly backward, associated with some lengthening of the ventricular folds. Finally, a lessening of the constriction of the middle constrictor was observed. No change at the pharyngeal back wall was observed, and the cricoid-arytenoid complex did not change visibly. Generally, the shape of the laryngeal inlet and Curbing gesture was maintained in the alternations. A still image of the slight variations in the laryngeal gesture for the two investigated Curbing conditions can be seen in Figure 8.

LTAS narrowband comparison of Overdrive in full and reduced conditions

When comparing Overdrive in the reduced-metallic and full-density condition to the reduced-metallic and reduced-density condition, several interesting findings were noted. First, the dominant second harmonic was maintained for all three Overdrive conditions. Generally, there was more energy across all spectra for the full-density condition compared with the reduced-density condition, whereas the reduced-metallic and full-density condition resembled closely the full-density condition but with less spectral energy than the full condition and more than the reduced condition. Between 8.9 and 10.0 kHz, there were more harmonic peaks and more energy in the full-density condition compared with the reduced-density condition, with more clearly structured harmonic peaks and more spectral energy from 9 kHz and upward to 19 kHz.

FIGURE 8. Reduced-metallic and further reduced-density Curbing.

Interestingly, there was an increase in energy at the seventh harmonic for the reduced-density condition compared with the reduced-metallic and full-density condition. Compared with the reduced-metallic and full-density condition, the reduced-density condition exhibited a slightly more harmonic structure between 4.0 and 4.6 kHz, whereas the harmonic peaks from the reduced-metallic and full-density condition in the area between 4.6 and 5.8 kHz were observed as troughs, with significantly lowered loudness in the reduced-density condition. Moreover, there were slight enhancements of energy in the spectral area between 7.8 and 8.8 kHz, with a less clear harmonic structure above 9.8 kHz in the reduced-density condition compared with the reduced-metallic and full-density condition. Finally, there was the same harmonic structure between the reduced-metallic and full-density condition and the reduced-density condition between 9.8 and 12.5 kHz with noticeably less energy and not as clear a harmonic structure in the reduced condition. A graph comparing the full-metallic and full-density Overdrive condition with the reduced Overdrive condition can be found in Figure 9, and a graph comparing the reduced-metallic and full-density Overdrive condition to the reduced-density Overdrive condition can be found in Figure 10.

LTAS narrowband comparison of Edge in full and reduced conditions

Similar to the comparison of the Overdrive conditions previously mentioned, the reduced conditions for Edge seemed to exhibit less spectral energy. For all three conditions, the dominant second harmonic was maintained. There seemed to be a reduction in energy at the 8th and 10th harmonic peaks between the full-density and full-metallic Edge condition and the reduced-density and reduced-metallic Edge condition. Moreover, there was a grouping of bandings that seemed to follow similar structures in the area between 5.0 and 7.3 kHz where the rises, peaks, and falls appeared similar. The majority of the differences between the compared conditions were to be found in the area between 6.8 and 13 kHz and higher, where the reduced-density condition exhibited less spectral energy overall. A graph comparing the full-metallic and full-density Edge condition with the reduced-density Edge condition can be found in Figure 11, and a graph comparing the reduced-metallic and full-density Edge condition with the reduced-density Overdrive condition can be found in Figure 12.

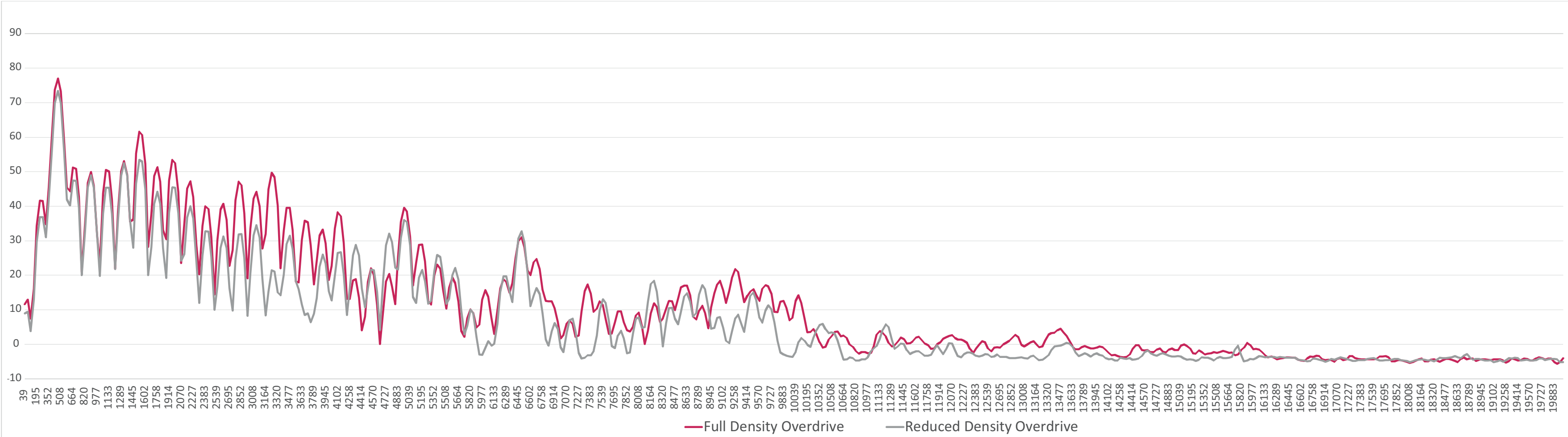

FIGURE 9. Comparison of full-metallic and full-density Overdrive to reduced-metallic and reduced-density Overdrive conditions.

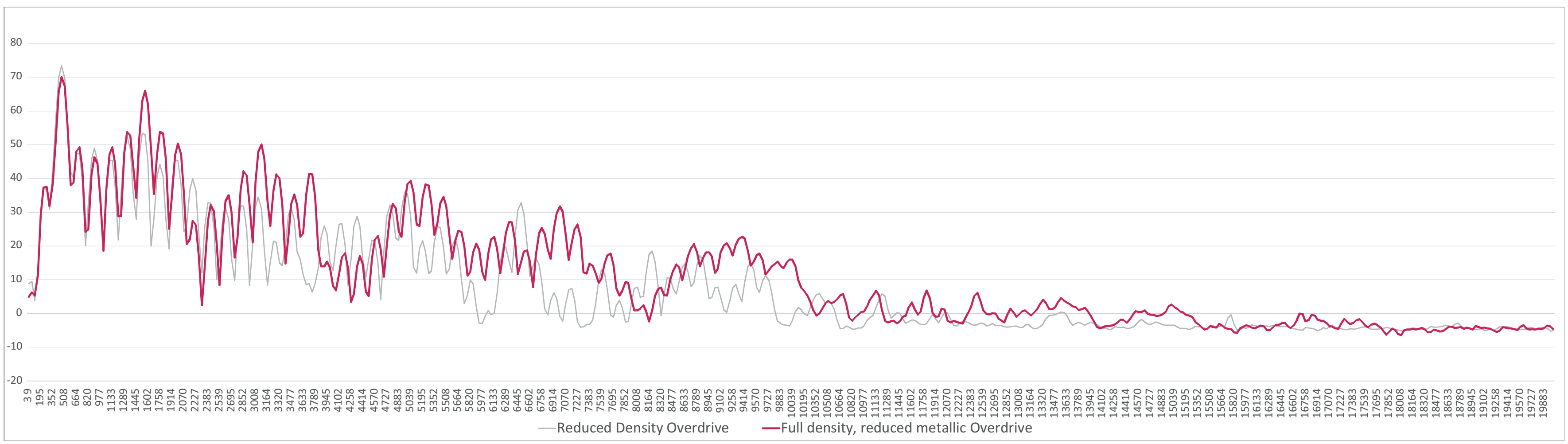

FIGURE 10. Comparison of reduced-metallic and full-density Overdrive to reduced-metallic and reduced-density Overdrive conditions.

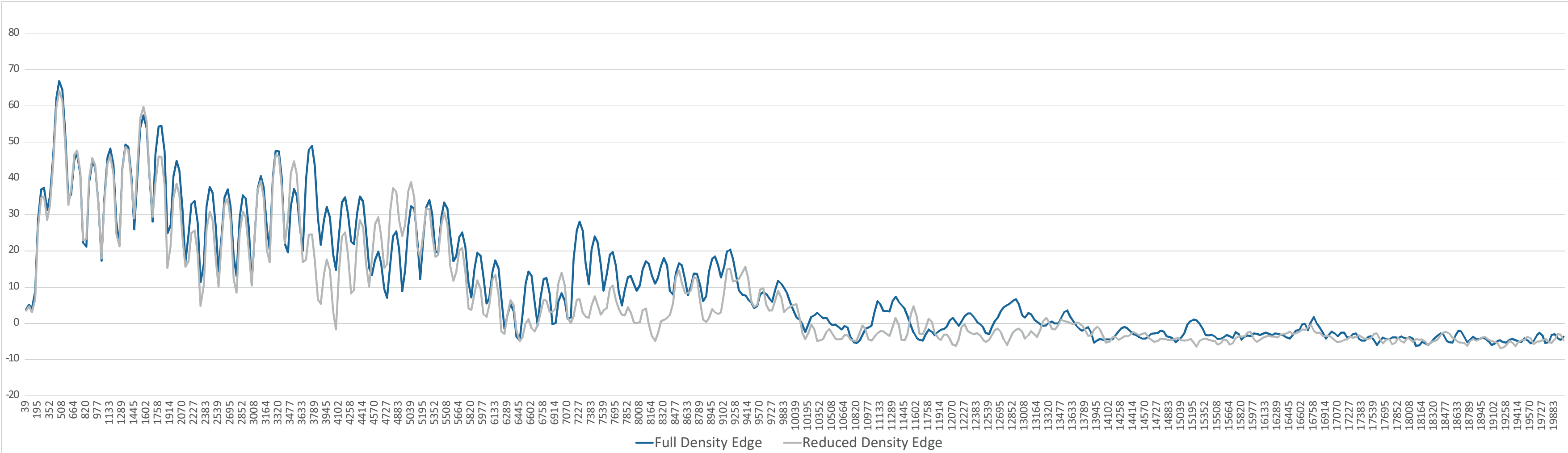

FIGURE 11. Comparison of full-metallic and full-density Edge to reduced-metallic and reduced-density Edge conditions.

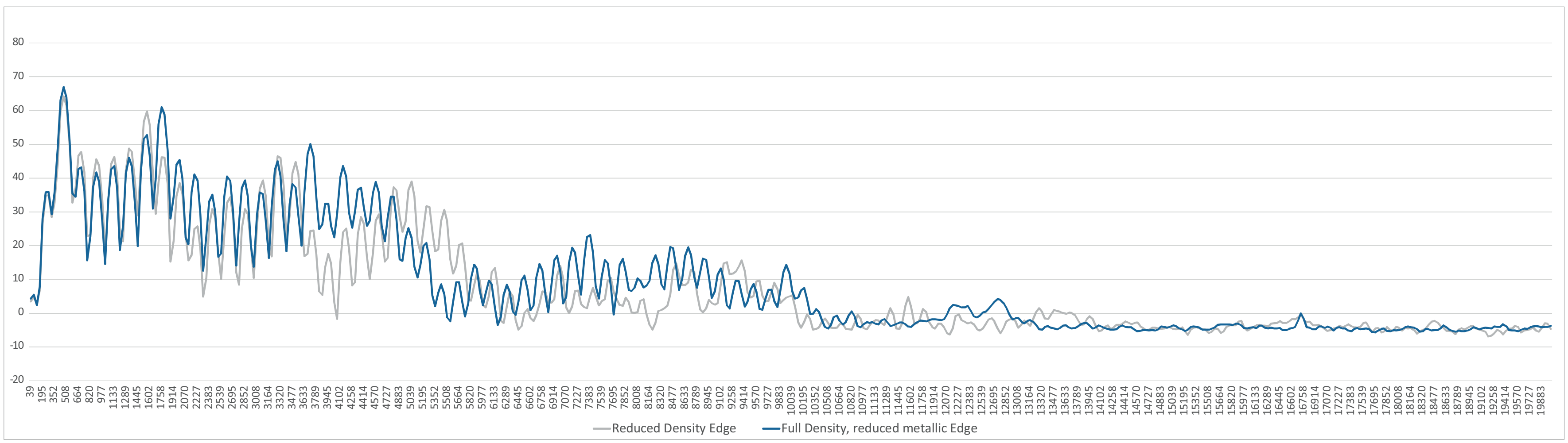

FIGURE 12. Comparison of reduced-metallic and full-density Edge to reduced-metallic and reduced-density Edge conditions.

LTAS narrowband comparison of Curbing and the attempted reduced condition

As noted on the laryngeal gesture for the Curbing conditions, there seemed to be little difference between the two tested conditions of Curbing. When attempting to reduce the already-reduced setting of Curbing, less energy across the spectra was observed, but these were only minor changes of 5 dB or less in spectral loudness. The two conditions seemed to exhibit similar acoustic responses, and there were no structural changes to the banding, but the relative balance between the areas was somewhat changed. In the area between 5 and 8 kHz, the fullest of the two Curbing conditions seemed to be exciting more spectral energy in an increasing slope up to 6.5 kHz with a decrease, although higher than the reduced condition, up to 8.3 kHz. Comparatively, the reduced condition seemed to be more evenly excited from 5 to 8 kHz. The reduced condition exhibited a peak at 5.7 kHz, whereas the fuller condition exhibited a peak at 6.5 kHz. A graph comparing the reduced-metallic and reduced-density condition to an even further reduced-density condition for Curbing can be found in Figure 13.

MDVP comparing the various metallic and density conditions

The MDVP of one of the male subjects can be found in Table 2. Noticeable differences can be observed for the Qx measurements, the jitter and shimmer measurements, the noise measurements, and finally SPL levels.

For all of the vocal modes, it seemed that an increase in density allowed for the singer to achieve higher SPLs. For Curbing, an increase of 4.7 dB was observed when the singer changed from a reduced-density setting for Curbing to a fuller setting in Curbing. Similarly, an increase of 8.2 dB was observed when the singer changed from a reduced-density setting for Overdrive compared with a full-density Overdrive setting. Finally, an increase of 4.89 dB was observed when the singer changed from a reduced-density setting in Edge to a full-density setting in Edge. The same tendency was observed for the average Qx, where the reduced-density settings for all the three modes seemed to result in a lower Qx. For Curbing, a reduction of 2.92% was observed, for Overdrive, a reduction of 1.82% was observed, and for Edge, a reduction of 3.82% was observed.

Comparison of Curbing with the reduced-density conditions of Overdrive and Edge showed that although the reduced conditions for Overdrive and Edge did seem to equal a lower mean SPL and a lower Qx, the conditions did not seem to be approximating observed Curbing values in either condition. Whereas Curbing was observed with a mean SPL of 83.9 dB, the reduced-density conditions for Overdrive and Edge were observed at 94.9 and 95.21 dB. Similarly, where Curbing was observed with a 55.89% average Qx, the reduced-density setting for Overdrive was measured at 59.89, and that for Edge was measured at 58.69.

Several notable differences were observed when the reduced-metallic and full-density conditions were compared with the reduced-density conditions for Overdrive and Edge.

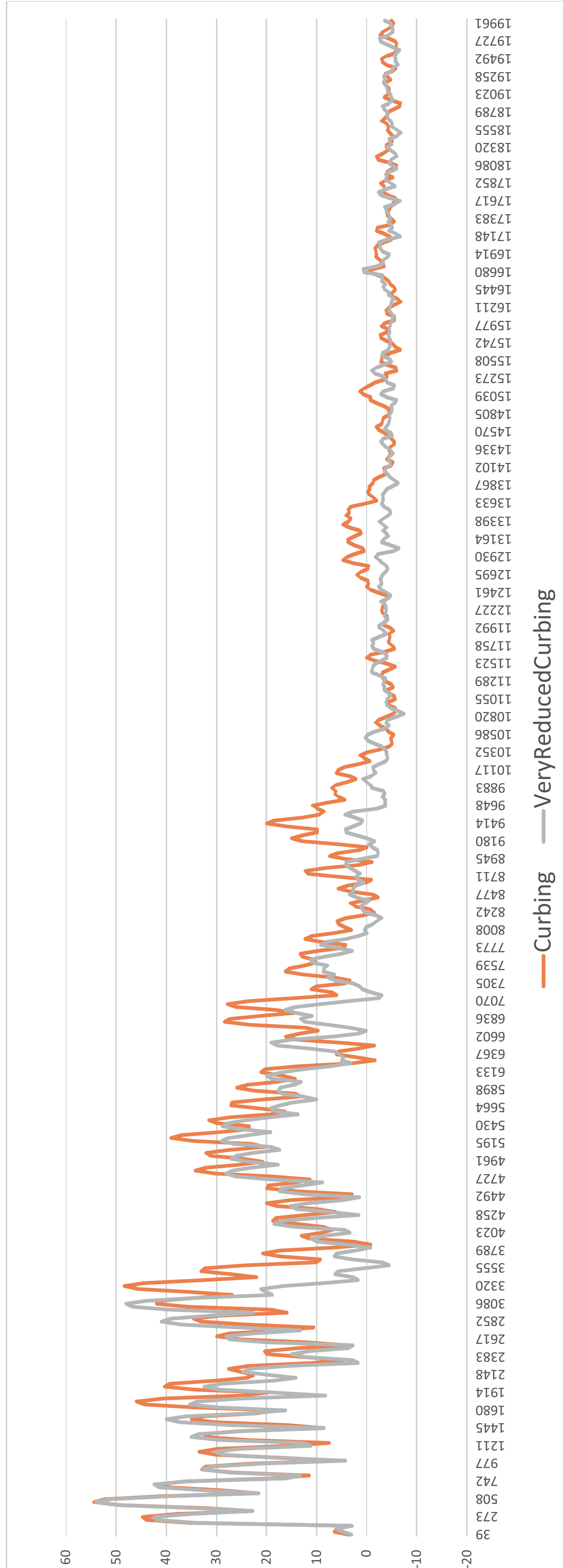

FIGURE 13. Comparison of curbing to an attempted reduced-density Curbing.

TABLE 2.
MDVP Results for Male Participants for All Tested Conditions

	Curbing	Reduced-density Curbing	Full-density Overdrive	Reduced-metallic, Full-density Overdrive	Reduced-density Overdrive	Full-density Edge	Reduced-metallic, Full-density Edge	Reduced-density Edge
Average Fx	262.15	260.42	257.1	260.57	257.6	261.15	259.01	260.65
SD Fx	0.36	0.67	0.45	0.48	0.35	0.36	0.33	0.26
Average Qx	55.89	52.97	59.95	59.72	58.13	61.4	61.3	57.58
SD Qx	0.52	0.36	0.47	0.7	0.87	0.53	0.46	0.95
Min Qx	54.64	52.15	59.04	58.06	56.45	60.1	60	54.89
Max Qx	57.37	53.55	61.17	61.08	59.89	62.16	62.36	58.69
Jitter first	0.48	0.27	0.32	0.37	0.24	0.28	0.32	0.23
Jitter second	0.32	0.17	0.22	0.24	0.16	0.19	0.21	0.13
Jitter factor	0.48	0.27	0.32	0.37	0.24	0.28	0.32	0.23
RAP	0.32	0.17	0.22	0.24	0.16	0.19	0.21	0.13
Shimmer+	3.2	2.02	0.38	1.2	0.63	1.49	1.73	1.11
Shimmer−	−4.41	−2.15	−0.55	−0.99	−0.56	−1.43	−1.07	−1.57
Shimmer dB	0.28	0.18	0.03	0.11	0.06	0.13	0.15	0.1
CPP	6.64	6.06	8.12	7.05	6.83	7.19	7.24	6.09
NNE	−19.82	−25.95	−42.03	−32.65	−37.36	−29.61	−30.64	−28.88
HNR	18.33	20.86	32.08	25.5	27.85	25.8	24.8	22.89
Mean SPL	83.9	79.2	103.1	96.1	94.9	100.1	93.9	95.21

Abbreviations: CPP, cepstral peak prominence; Fx, fundamental frequency; HNR, harmonics-to-noise ratio; NNE, normalized noise energy.

Comparison of the full-density Overdrive with the reduced-metallic and full-density Overdrive condition showed that the SPL was reduced by 7 dB, similar to the reduced-density Overdrive condition. However, whereas the reduced-density condition also involved a change in average Qx, this did not seem to be the case for the reduced-metallic and full-density condition. Here, the Qx was measured around 59%, compared with the 58% observed in the reduced-density condition. The same tendency was observed for Edge, where the two full-density conditions were observed with an average Qx around 61%, compared with the reduced-density condition measuring at 57.58%. Similar to the Overdrive observations, the SPL seemed to be reduced when the singer changed from a full-density Edge condition to the reduced-metallic and full-density Edge position, specifically, from 100.1 to 93.9db, a reduction of 6.2 dB. Looking at the three jitter measures, the two full-density conditions for both Overdrive and Edge displayed similarity in observed values with only minor changes, compared with the larger reduction across all jitter measures for the reduced-density condition. Interestingly, it would seem that the simmer+ measures for both Overdrive and Edge increased for the reduced-metallic and full-density conditions. Finally, the RAP values of the full-density conditions for both Overdrive and Edge seemed to be similar to the reduced-metallic and full-density conditions, whereas the reduced-density conditions displayed a lower RAP value.

DISCUSSION

Given the exploratory nature of the study with a sample of only three participants, the following discussion situates observations within the extant related literature to propose and inform future lines of inquiry. Accordingly, more studies should be conducted to further test and validate the findings across methods in larger population samples. The discussions center on laryngeal gestures, LTAS, and registration.

Laryngeal gestures

For all three male participants, similar gestures were observed when performing the same mode according to similar conditions. In line with previous investigations of the CVT modes,[14,15] Curbing was observed with a medium amount of intentional constriction compared with the progressively more constricted laryngeal gestures observed for Overdrive and Edge. When lowering the overall loudness of the Overdrive and Edge modes, without changing the character of the sound, the entire supraglottic structure seemed to relax very slightly the supraglottic constrictions while maintaining the overall setting and gestures of each respective mode. The male singers were able to gradually increase and decrease the volume without losing the overall setting and the perceived sound of each of the respective modes. Although not dramatic, the laryngeal gestures are visibly different, and therefore supports a rejection of Hypotheses 3 and 5.

Contrastingly, when the participants performed Overdrive and Edge in the reduced-density condition, the laryngeal gestures changed to a larger degree. What can best be described as a visible laryngeal tilt was observed on the laryngostroboscopic videos when participants performed the reduced conditions of Overdrive and Edge. Whereas laryngeal tilt related to an increase in pitch is well established in the literature,[4,9] the observed laryngeal tilt in the present study was observed while the fundamental frequency was kept constant. Accordingly, the observed laryngeal tilting involved modifications to the laryngeal gestures, such as the thyroid cartilage tilting forward, stretching of the mucosa over the cricoid-arytenoid complex and the posterior cricoid, as well as an upward posterior, slightly superior, contraction of the middle constrictor muscle in the posterior pharyngeal wall effectively opening the piriform fossae. These gestural changes, and in particular the posterior movement of the arytenoids, may be related to the observed stretching and thinning of the vocal folds, corroborated by the EGG findings with an averaged lowered Qx of 3.82% for Edge and 1.82% for Overdrive. These findings support a rejection of Hypotheses 2 and 4, because the laryngeal gestures related to a note sung in the full-density condition are clearly visibly different compared with a note sung in the reduced-density condition for both Overdrive and Edge. Thusly, in this exploratory pilot study of Overdrive and Edge, a reduced-density phonation seems to be related to a laryngeal tilt with an associated decrease in the average Qx, compared with full-density conditions. It appears that laryngeal tilt may be a mechanism not only for controlling pitch[4,9] but also for altering the density of phonation.

Coherently, Curbing has already been established as a "reduced mode" in previous investigations,[15] and interestingly, in setting up the gesture from an abducted vocal fold position during respiration, a laryngeal tilt similar to that observed in reduced-density Overdrive and reduced-density Edge was observed. When inspecting the high-speed videos, the posterior pharyngeal wall was observed to move backward, pulled by the increased activity in the inferior and, particularly, the middle constrictors. This movement was accompanied by what seemed like a forward rotation of the whole larynx. However, these findings would require further investigation by other means, such as MRI, for verification and quantification.

Comparatively, when attempting to reduce the density of Curbing even further, the singers exhibited no clear visible change in the laryngeal gesture. Therefore, there is no visual support to substantiate a rejection of Hypothesis 1. The lack of support for rejecting Hypothesis 1 is further substantiated by the fact that the average Qx observed when one male participant performed the reduced-density condition for Overdrive and Edge (58.13% and 57.58%, respectively) is similar to that observed for Curbing for the same participant (55.89%). Comparison of Curbing with Overdrive and Edge sung with a reduced density showed that laryngeal gestures as well as MDVP and LTAS measurements differ. This finding supports a rejection of Hypotheses 6 and 7, because the observed MDVP measures, such as the mean SPL, differed between Curbing and the reduced-density versions of Overdrive and Edge. Moreover, although there are similarities in terms of the observed laryngeal tilting, the laryngeal gestures of the modes remain very different, with Overdrive and Edge exhibiting progressively more constriction compared with Curbing, even when sung in the reduced-density condition where the intentional constriction of the supraglottic structures was observed as somewhat lessened.

Further investigations by other means, such as MRI or electromyography (EMG), may further elucidate the extent to which the reduced-density condition is indeed related to a single change—that is, a laryngeal tilt—or a gradual movement of laryngeal settings in which multiple possible degrees of density are available as strategies for such phonation types. In general, although the laryngostrobscopy was indeed useful for observing the laryngeal tilting related to the reduced-density conditions for all three investigated modes, more studies should be performed to investigate (1) whether the findings are generalizable beyond the three male subjects studied and (2) the quantifiability of the observed laryngeal tilt and related strategies for obtaining it. The CT-to-TA ratio investigated on EMG by Kochis-Jennings et al[1,5] or MRI investigations may be useful for such purposes.

Long-term average spectrum

Comparison of the LTAS data for the investigated conditions of the CVT vocal modes shows that for Overdrive and Edge, it seems that the full-density condition and reduced-metallic and full-density condition are similar, whereas the reduced-density and reduced-metallic condition exhibits overall less spectral energy compared with the other two conditions. All conditions of Overdrive and Edge maintain the previously identified dominant second harmonic,[14] which is well established in relation to sounds commonly referred to as "belting."[28–30] However, in the area between the 7th to the 19th harmonic for Overdrive, and from the 8th to the 15th and from the 17th to the 20th harmonic for Edge, large variations were found between the full-density condition and reduced-density condition, with the latter exhibiting the least spectral energy. This finding further supports a rejection of Hypotheses 2 and 4. Interestingly, when comparing Curbing with the attempted reduced-density condition for Curbing, no such clear changes were observed. The Curbing and attempted reduced-density Curbing exhibited similar banding and spectral energy, with minor notable differences, which may be related to the reduced mean SPL. This reduction in SPL may be related to the decrease in energy around 3.0−3.8 kHz, around the spectra in which the singer's formant cluster is typically found in men.[31,32] Further investigations should explore the relationship between changes in SPL and changes in subglottal pressure.[33] Investigations of this kind may also reveal more about differences between Curbing and Overdrive and Edge sung with a reduced density.

An additional, yet interesting, methodological finding was the quite significant impact the pulling of the tongue, which is necessary for performing high-speed imaging with a rigid camera, had on LTAS responses. All spectra from 0 to 20 kHz were impacted, with some spectra reading as much as 25 db less on the high-speed compared with regular nasoendoscopy. This finding challenges the usability of acoustic recordings obtained during high-speed investigations where the tongue position is altered artificially for the singer to accommodate the rigid endoscope. As a consequence of this, the acoustic data obtained during high-speed investigations were not used in the present study.

The mix voice

There is much debate between voice pedagogues as to the existence of registers[5] and whether or not potential mixes of such registers can take place.[1] Accordingly, some studies note that data for the “middle” voice or “mix register” are sparse and that only limited evidence exists to separate mix from “chest.”[5,34] Coherently, the findings of the present study seem to propose that rather than speaking of CT-TA muscle work as related to register changes, it may be possible to speak of laryngeal tilt and specific laryngeal gestures as related to the density of phonation across a variety of possible phonation types, such as Curbing, Overdrive, and Edge. Adopting a terminology that refers to a perceptually identifiable parameter—density—along with the well-established notion of metallic voice,[14,15,35] may lead to a more precise way of perceptually and physiologically defining phonation. Denoting of specific amounts of metal and density on scales from 0% to 100% and the combinations of these two parameters allow for an identification and detailed investigation of vocal modes in perceptually and visually observable ways.[14–16,18] This finding allows for precision and accuracy to be achieved both in research and in pedagogy compared with the compounding of such details into “registers” as a container.

These findings may also explain the previous results from studies of mix types of registration that are contradictory. Using EGG, one study reports differences in open and closed quotients between belt, mix, and legit registrations,[10] whereas another study finds no such differences.[11] One study highlights how mix has been defined as the mixing of TA and thick vocal fold types of phonation with CT and thin fold vocal functions by singing pedagogues.[3] In the present study, elongation of the vocal folds was observed in the condition of reduced density, accomplished as a result of the observed laryngeal tilting. This observation may be related to increased CT muscle activity; however, because the same laryngeal tilt was observed, not as a feature of one type of phonation but across the three investigated modes, a mix register as such cannot be supported by the evidence from this pilot study. Rather, separation and nuancing of the parameters of metallic voice and density are proposed as delineation and definition dimensions.

Previous studies of mix have not taken into account the parameters metal and density, which may account for the seemingly incongruous findings in the literature. More studies on the muscle work involved and the laryngeal gestures used for achieving full or reduced density across the various available degrees of metallic voice should be conducted to establish the specific muscle work and mechanisms related to such phonation types.

CONCLUSIONS AND LIMITATIONS

This pilot study provides some preliminary data to support the concept of two separate parameters of the singing voice, “metal” (ranging from nonmetallic to reduced metallic and full metallic) and density (ranging from reduced to full density), which can be produced across three of the vocal modes covered in CVT. Using laryngostroboscopy, high-speed imaging, LTAS, MDVP, and acoustic measures, this pilot study separated a full-density and full-metallic version of Overdrive and Edge from a reduced-metallic and full-density version, and a reduced-metallic and reduced-density version. The study also clearly separated Curbing as distinct from these variations of Overdrive and Edge. Accordingly, Curbing can be defined as reduced-metallic and reduced-density with a restrained or “held back” character. Overdrive can range from full to reduced metallic and from full to reduced density. The character of Overdrive in full density is clear and somewhat shouty, whereas the character of Overdrive in reduced density is contained or “held in.” Finally, Edge can range from full to reduced metallic and from full to reduced density. The character of Edge in full density is clear and sharp, whereas the character of Edge in reduced density is contained and held in. Another potentially important finding is that the laryngeal tilt mechanism is independent of pitch production and can be related to a variation of density or “weightiness” of a sung note. This is a line of inquiry that warrants further investigation, such as studies of women, across various pitches, and from methods such as MRI or EMG.

It is accepted that this is a limited study based on only three male singers; however, the patterns seen were similar in all cases and were intra- and interparticipant coherent. Within its limited sample, the study finds no supportive evidence of mix registers because each identified condition was identifiable as a variation of a specific vocal mode. Instead, the study has shown some preliminary data based on changes in laryngeal gesture, vocal fold contact using EGG, and a variety of acoustic measures to support the two parameters, metal and density, for denoting phonation types. These parameters could allow for more nuanced perspectives and detailed descriptions of phonation strategies, such as variations of vocal modes. Further investigations of these parameters should be conducted both by means of the same investigative measurements for a larger sample across genders and by means of MRI or EMG to reveal further details and corroborate or refute the findings. Moreover, studies quantifying the observed laryngeal activities are proposed to further investigate the boundaries of each of the tested conditions. Finally, studies focused on subglottal pressure for each of the tested conditions in the present study should be conducted to further test differences and similarities between the conditions.

The findings of the study are naturally limited because it is a pilot study. The findings and discussion set forward in the study should be seen as warranting further investigations of laryngeal tilt as a mechanism for density, specifically reduced density, rather than as generalizable conclusions.

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