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Articulatory and acoustic differences between lyric and dramatic singing in Western classical music

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ABSTRACT:
Within the realm of voice classification, singers could be sub-categorized by the weight of their repertoire, the so-called "singer's Fach." However, the opposite pole terms "lyric" and "dramatic" singing are not yet well defined by their acoustic and articulatory characteristics. Nine professional singers of different singers' Fach were asked to sing a diatonic scale on the vowel /a/, first in what the singers considered as lyric and second in what they considered as dramatic. Image recording was performed using real time magnetic resonance imaging (MRI) with 25 frames/s, and the audio signal was recorded via an optical microphone system. Analysis was performed with regard to sound pressure level (SPL), vibrato amplitude, and frequency and resonance frequencies as well as articulatory settings of the vocal tract. The analysis revealed three primary differences between dramatic and lyric singing: Dramatic singing was associated with greater SPL and greater vibrato amplitude and frequency as well as lower resonance frequencies. The higher SPL is an indication of voice source changes, and the lower resonance frequencies are probably caused by the lower larynx position. However, all these strategies showed a considerable individual variability. The singers' Fach might contribute to perceptual differences even for the same singer with regard to the respective repertoire.
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I. INTRODUCTION

In voice research, many studies on the singing voice are analyzing voice production with respect to gender, age, or the voice classification. Concerning the latter, human voices are frequently classified by their absolute frequency range and the range where the subject mostly performs as well as their timbre. A basic voice classification could be made into soprano, mezzo-soprano, alto, tenor, baritone, and bass.

Most studies on singing voice physiology pooled the subjects by this kind of voice classification. In this respect, it has been shown that both the vocal fold dimensions (Roers *et al.*, 2009a) and the vocal tract dimensions differ with respect to the classification (Roers *et al.*, 2009b). Formant tuning strategies (i.e., voice source partials being tracked by vocal tract resonances [f_{Rn}]) found in soprano voices (Echternach *et al.*, 2010a; Garnier *et al.*, 2010; Joliveau *et al.*, 2004; Köberlein *et al.*, 2021; Sundberg, 1975, 2009) were not necessarily found in male voices (Echternach *et al.*, 2016a; Henrich *et al.*, 2014; Sundberg *et al.*, 2013). Also, clustering vocal tract resonances $f_{R3–R5}$ are more present in lower voice classifications than in higher ones (Sundberg, 1987). Furthermore, it has been shown that tenors modify the vocal tract differently from male professional altos (Echternach *et al.*, 2011b; Echternach *et al.*, 2014).

Although such pooling by means of voice classification might be necessary in order to describe systematic changes, such a pooling might be insufficient to describe challenges concerning voice production for defined repertoire. With respect to Western classically trained voices in singing practice as well as in the management of opera or concert houses, another subdivision of the vocal category has been used, since singers of one classification could not cover all repertoires inside a voice classification. There are very different efforts and tasks associated with the specific repertoire. As an example, within the tenor repertoire, it appears unfeasible for a tenor to sing both the role of Tamino in Mozart's opera *Die Zauberflöte* and Tristan in Wagner's opera *Tristan und Isolde*. The same holds true for soprano voices singing *the title role* in Bellini's opera *Norma* who are not able to cover all the three Brünnhilden of the $3\frac{1}{2}$ operas of Wagner's *Der Ring des Nibelungen*.

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Such differences within a vocal category are often also found in the English language, denoted by the German term "Fach." Herein, terms like "lyric, spinto, dramatic, Helden, etc." are used (Kloiber *et al.*, 2002). In the singer's reality, very often contracts are made between the singer and opera houses with regard to the specific singer's Fach (Ling, 2007). There are overlapping scopes concerning the Fach. For example, some singers singing *Tristan* [considered as Heldenfach (Kloiber *et al.*, 2002)] could also often perform *Lohengrin* [considered as young dramatic (Kloiber *et al.*, 2002)]. However, even inside a vocal Fach, it could make a difference to sing the *Susanna* or the *Contessa* in Mozart's *Le nozze Di Figaro* [both considered as lyric soprano (Kloiber *et al.*, 2002)]. The two poles of a vocal category concerning Fach are represented by the terms "lyric" and "dramatic," with many shades in between: i.e., lyrico spinto, young dramatic, etc. This also concerns the so-called "voice weight," which implies quantitative gradual changes between the terms "light" (lyric) and "heavy" (dramatic).

The placement in a specific repertoire is dependent on many individual factors, like the anatomy of the voice production system or the singer's age, psyche, hydration, and many other factors. From a clinical point of view, it is often not recommended to perform dramatic repertoire at a young age. In fact, singing within a too dramatic Fach is considered as one important reason for dysphonia in professional singers due to overuse (Richter, 2013), possibly leading to a need for phonomicrosurgery (Wang *et al.*, 2023). Furthermore, psychological aspects should be taken into account for the choice of a specific singer's Fach. Also important are aspects of vocal technique. In this respect, it was shown for some tenor cases that the differences between falsetto and stage voice regarding vocal tract articulatory data were stronger for the relatively heavier dramatic voices (Echternach *et al.*, 2014).

It has been found that voices performing dramatic repertoire show higher energies at higher spectrum partials which are relevant for the voice timbre than voices performing lyric repertoire (Stone and Erickson, 2023). Also, dramatic voices exhibit a high vibrato frequency (Erickson, 2020; Stone and Erickson, 2023) and for tenor and soprano voices a high vibrato amplitude (Müller *et al.*, 2021). In contrast, dramatic baritones in a study by Müller and coworkers exhibited a low vibrato amplitude (Müller *et al.*, 2021). All of these studies are based on a comparison after the assignment of the subjects into the groups of dramatic or lyric by external experts. However, these terms are not well defined. Furthermore, independent of the general assignment to a specific Fach, even the same singer could cover an individual range from a more lyric to a more dramatic way of singing.

Even though singers tend to sing in their specific Fach, most of them have an opinion on what singing in either a lyric or in a dramatic way would mean. Furthermore, the acoustical and articulatory differences of such terms have not been understood in detail so far. This study aims to analyze the acoustical and articulatory differences that can be found when professional singers sing in the ways they personally assume as being either lyric or dramatic.

II. MATERIALS AND METHODS

A. Subjects and tasks

After approval from the local ethical committee (Freiburg University Hospital Ethical Committee, No. 206/09), nine professional singers of different categories and Fach were included. At the time of the experiment, none of them complained about any vocal symptoms and vocal pathologies were excluded by clinical examination by an experienced phoniatrician and laryngologist via videostroboscopy or high-speed digital imaging, respectively. The taxonomy according to Bunch and Chapman (2000) and the singers' repertoires at the time of the measurements are provided in Table I.

In order to assign the singers' repertoire by its weight to the continuum between lyrical and dramatic repertoire, Table I was presented to 14 experts, all of whom were professors for singing or academic singing teachers at German Music universities/conservatories, for a rating. These experts were asked to rate all subjects from 0 (most lyric repertoire) up to 10 (most dramatic repertoire). The raters had no access to the audio files or any recordings by the subjects. The results are provided in Fig. 1. In the following, subjects with values lower than 5 were arbitrarily (in order to have 3 subjects in each group) considered lyric ("lyr" in the figures; small dotted lines), those between 5 and 8 lyric/dramatic ("lyr/dram"; large dotted lines), and those greater than 8 dramatic ("dram"; solid lines).

All subjects were asked to sing an ascending diatonic scale on the vowel /a/ at approximately 60 beats per minute (bpm). For the soprano and mezzo-soprano voices, the range from A4 (fundamental frequency [f_o] ca. 440 Hz) to A5 (f_o ca. 880 Hz) was performed, and for the baritones, the range from G3 (f_o ca. 196 Hz) to E4 (f_o ca. 330 Hz) was performed. One mezzo-soprano subject (Mezzo 2) chose a different range from F4 (f_o 349 Hz) to F5 (f_o 699 Hz). In the first task, the subjects were asked to sing this scale in what they considered as "lyric" and in a second task what they considered as "dramatic." There was no explanation of these terms given by the examiners.

B. MRI of the vocal tract

The magnetic resonance imaging (MRI) recordings of the vocal tract were performed with the 3.0 T TIM TRIO (Siemens, Munich, Germany) MRI device in a supine position at 25 frames/s, resolution 128×128 pixels, and field of view 210×210 mm, as described previously (Burdumy *et al.*, 2015; Burk *et al.*, 2023; Echternach *et al.*, 2015; Echternach *et al.*, 2016b). The images were recorded in the midsagittal plane. In keeping with previous studies (Echternach *et al.*, 2010b), the subjects were provided with the audio signal over headphones as an acoustic feedback. The audio signal was recorded with an optical microphone system (CONFON HP-SI 01; MR confon GmbH,

TABLE I. Classification, taxonomy according to Bunch and Chapman (2000), typical repertoire, and opera houses the subjects performed at the time of the experiments.

Classification	Taxonomy	Repertoire	Performing	Opera houses
Soprano 1	2.1/2.4	Donna Elvira (Mozart: *Don Giovanni*), Contessa (Mozart: *Figaro*), Pamina (Mozart: *Zauberflöte*)	International	Zürich, Salzburg, New York (Met), Paris
Mezzo 1	2.1/2.4	Cherubino (Mozart: *Figaro*), Dorabella (Mozart: *Cosi*)	International	Dijon, Luxembourg
Mezzo 2	2.1/2.4	Brangäne (Wagner: *Tristan*), Kundry (Wagner: *Parsifal*), Waltraute (Wagner: *Walküre*), 3. Magd (Strauss: *Elektra*)	International	Köln, Paris, Milano (Scala)
Mezzo 3	2.1/2.4	Magdalena (Wagner: *Meistersinger*), 1. Norn und Floßhilde (Wagner: *Götterdämmerung*), Suzuki (Puccini: *Butterfly*), Mary (Wagner: *Holländer*), Emilia (Verdi: *Otello*)	International	Munich, Bayreuth (Festspielhaus), Milano (Scala), Frankfurt
Mezzo 4	3.1a	Oktavian (Strauss: *Rosenkavalier*), Charlotte (Massenet: *Werther*), Brangäne (Wagner: *Tristan*), Suzuki (Puccini: *Butterfly*), Carmen (Bizet: *Carmen*)	International	Bayreuth (Wagner) Valencia, Firenze (Maggio)
Mezzo 5	2.1/2.4	Klytämnestra (Strauss: *Elektra*), Fricka (Wagner: *Walküre*),	International	Düsseldorf, Stuttgart, Milano (Scala)
Baritone 1	3.4/3.15a/3.15b	Masetto (Mozart: *Don Giovanni*)	National	Feldkirch, Fürth
Baritone 2	1.1/2.4	Sachs (Wagner: *Meistersinger*), Wotan and Wanderer (Wagner: *Rheingold*, *Walküre*, and *Siegfried*), Holländer (Wagner: *Holländer*), Scarpia (Puccini: *Tosca*)	International	Munich, Salzburg, London (Royal), New York (Met)
Bass 1	1.1/2.4	Sarastro (Mozart: *Zauberflöte*), Osmin (Mozart: *Entführung*), Hunding (Wagner: *Walküre*), Gurnemanz (Wagner, *Parsifal*), Marke (Wagner: *Tristan*), Rocco (Beethoven: *Fidelio*)	International	Wien (Staatsoper), New York (Met), Paris, Munich

Magdeburg, Germany), including two microphone recordings at the maximum sample frequency for this optical microphone of 8 kHz (one recording vocalizations and background MRI scanner noise [mic 1] and one recording scanner noise only outside the MRI [mic 2]). mic 1was positioned in a distance of approximately 8 cm from the mouth. Cancellation of scanner noise was performed using dedicated software (DIGITAL AUDIO PRESENTATION CENTER, CONFON DAP-CENTER MKII+; MR confon GmbH, Magdeburg, Germany). In cases where the MRI scanner noise was still present, further noise reduction was performed using the ADOBE AUDITION software (CS6; Adobe Systems, San Jose, CA). Here, a part of the audio file was analyzed where only the scanner noise but not the voice was present. The part was marked as reference noise and cancelled throughout the audio file. Details of this analysis and influence on the spectral differences can be found in Echternach *et al.* (2016a).

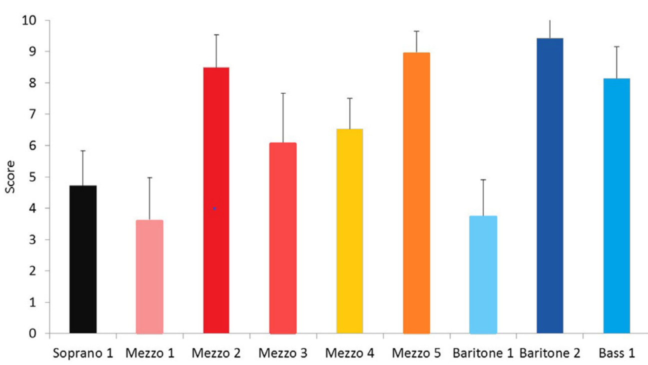

FIG. 1. (Color online) Mean values and standard deviation concerning the rating of 14 experts with respect to the most lyric (0) and most dramatic (10) repertoire for each subject. Black, sopranos; red, mezzo-sopranos; blue, baritones and bass. The color coding of the subjects is consistent with Figs. 3, 4, and 6.

C. Analysis of the noise reduced audio file

Sound pressure level (SPL) and fundamental frequency (f_o) were calculated using the PRAAT software (Boersma and Weenink, 2023). SPL calibration using a SPL meter was not possible due to the magnetic attraction in MRI systems. Lyric and dramatic singing tasks were recorded in a single file, and the noise cancellation was performed under the same filter conditions. Therefore, it was expected that any error should be of a systematic nature. To extract vibrato speed and amplitude, f_o was also extracted using a fast Fourier transform (FFT) of length 2048 together with a Hann (Hanning) window and was tracked over time using MATLAB's pitch() function (window length, 52 ms; overlap, 42 ms; f_o detection: normalized cross-correlation) for each note. The resulting pitch line was analyzed using a continuous wavelet transform (CWT). The CWT was preferred over the standard spectrogram because the CWT has excellent time-frequency localization, is robust to non-stationary frequency content, and makes it possible to capture different vibrato speeds with ease. MATLAB's cwt() function (Morse wavelet, time bandwidth = 20, symmetry parameter gamma = 3) uses L1 normalization, which ensures that oscillatory components with equal amplitude will have equal magnitude in the CWT. The resulting CWT was used to track the strongest frequency between 1 and 15 Hz. The mean frequency value of this vibrato line and its mean magnitude during the path was used to evaluate vibrato frequency and amplitude.

Furthermore, the noise-reduced signals were used to establish a long-time-average spectrum (LTAS) for the entire task using the LTAS function (Hamming, FFT of 512 points) of the WAVESURFER software (Sjölander and Beskow, 2000).

D. Vocal tract resonance frequency estimation from vocal tract MRI images and audio signals

From the two-dimensional (2D) MRI images, resonance estimations were performed using the same procedure, as described in detail previously (Echternach *et al.*, 2016a). For each pitch and task (lyric/dramatic) of each subject, an image representing the temporal midpoint of the note was identified and utilized for further processing. To avoid variations due to the vibrato—present in many subjects—the images were selected at the f_o maximum peak of the vibrato.

After segmentation of the vocal tract and the construction of the vocal tract centerline, the area function was estimated. Finally, an acoustic transmission-line model was simulated in the frequency domain to obtain the transfer function of the acoustic tube corresponding to the discrete area function according to Birkholz and Jackèl (2004). This simulation considered the effects of soft vocal tract walls, viscous friction, and sound radiation. From the resulting transfer function, the first three resonance frequencies (f_{R1-R3}) were extracted by peak-picking.

E. Measurement of articulators

In each frame of the MRI material, a series of measures were taken, as described in previous studies (Burk *et al.*, 2023; Echternach *et al.*, 2016b; Echternach *et al.*, 2023): Lip opening (vertical distance between the lips) and jaw opening (distance between the spina nasalis anterior and the most anterior-inferior point of the bone marrow in the corpus mandibulae), pharynx width (smallest distance between the back of the tongue and the back wall of the oropharynx), larynx position (distance between the tuberculum anterius atlantis and the rectangular projection of the anterior commissura on a line representing the axial direction of the cervical spine), and the jaw protrusion (length of a line from the most anterior-inferior point of the bone marrow in the corpus mandibulae and the point where this line is crossing the line for calculation of the larynx in a right angle). For the larynx position, a higher value indicates a lower larynx position.

F. Statistical analysis

Since only nine subjects were included in the investigation, a detailed statistical analysis was considered not meaningful.

III. RESULTS

For most subjects, differences between their lyric and dramatic way of singing were observed. Figure 2 displays representative midsagittal images for subjects Mezzo 1 and Baritone 2. The corresponding videos for these subjects are provided in Videos 1 and 2, respectively, in the supplementary material.

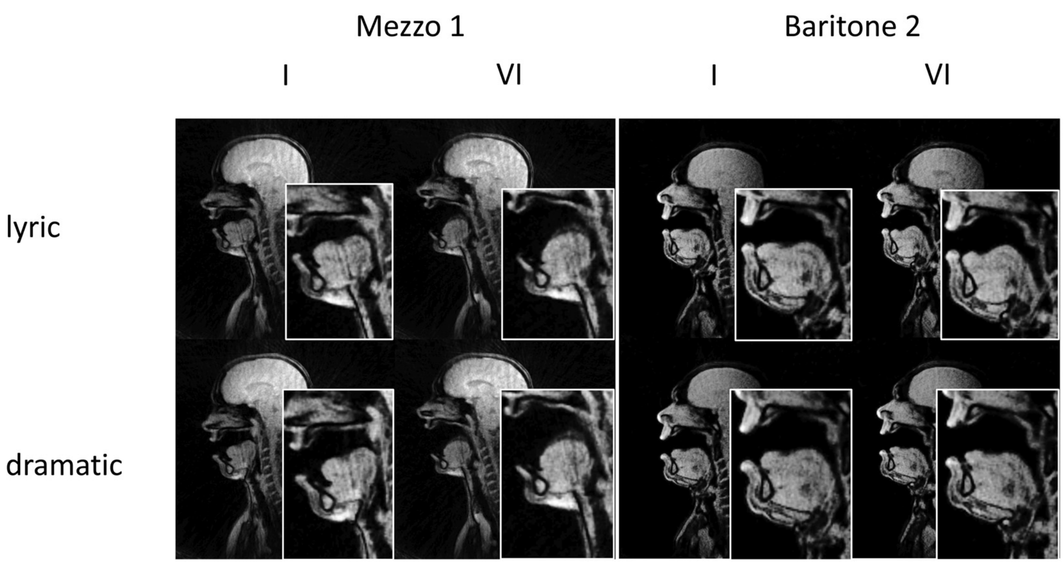

FIG. 2. Representative midsagittal images for lyric (upper row) and dramatic (lower row) singing for pitches I and VI of the scales from subjects Mezzo 1 and Baritone 2, respectively. In each image, a magnification window demonstrates the vocal tract relevant structures.

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In general, the amounts of differences were individual-specific and independent from the classification as either lyric or dramatic as provided in the expert rating (Fig. 1). Additionally, there were no clear tendencies that either classification demonstrated greater or smaller articulatory values for both tasks. For instance, there was no indication that dramatic voices exhibit higher articulatory modifications than lyrical voices across both tasks.

A. SPL

For all subjects, the dramatic way of singing was associated with a higher SPL (Fig. 3). However, in four of the subjects, this difference between both tasks decreased as f_o increased.

B. Vibrato

The dramatic style of singing exhibited, for the majority of subjects, both a higher vibrato amplitude and vibrato frequency, as illustrated in Fig. 4. However, for most subjects there was a noticeable scatter for the different pitches.

C. Articulation

For most subjects, there was a difference concerning articulation between the lyric way and dramatic way of singing. Figure 5 illustrates the mean values categorized by sex, whereas Fig. 6 shows the difference in articulatory data between dramatic and lyric singing for each subject. For the dramatic singing, there was a greater lip opening and a lower larynx position. Among female voices, the jaw opening was larger, while jaw protrusion was not as prominent in the dramatic singing task. No substantial differences were detected for the pharynx width.

D. Spectrum and estimation of resonance frequencies

The subjects exhibited alterations between lyric and dramatic singing in the de-noise-treated audio files of the radiated sound (Fig. 7). For most subjects, there was an

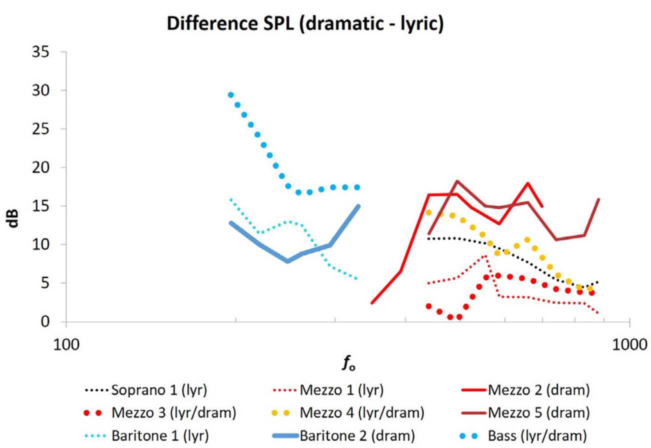

FIG. 3. (Color online) Difference of the sound pressure level (SPL) for the dramatic minus the lyric singing with respect to each fundamental frequency (f_o).

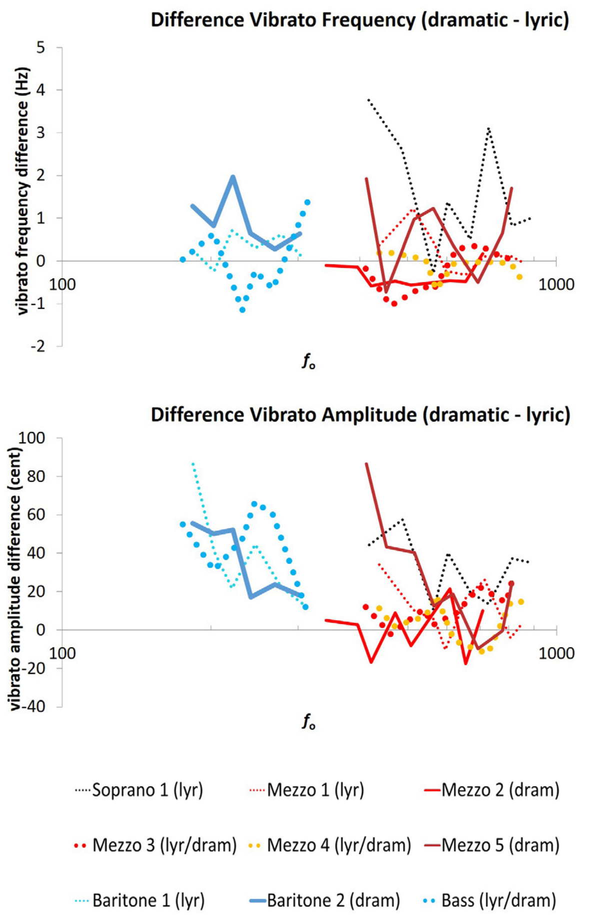

FIG. 4. (Color online) Difference of the vibrato frequency and vibrato amplitude for the dramatic minus the lyric singing with respect to each fundamental frequency (f_o).

increase in energy observed at higher harmonics for the dramatic style of singing. However, some subjects (i.e., Mezzo 1 and 2, Baritone 1, and Bass 1) exhibited almost no differences in this frequency region. Table II shows the mean energy difference between the dramatic task and the lyric task in the frequency band from 2.5 to 3.5 kHz.

The resonance frequencies f_{R1-R3} as calculated from the 2D MRI material were found higher for the lyric way of singing (Fig. 8). Figure 9 presents the ratio of the resonance frequencies for the dramatic and lyric way of singing for each subject. It can be found that the resonatory differences vary not only across subjects but also for different pitches during the experiment.

In general, there was no clear difference among the more lyric, lyric/dramatic, or dramatic voices (see Table I) with respect to SPL, vibrato, resonances, or articulation.

IV. DISCUSSION

This study analyzed the acoustical and articulatory differences between lyric and dramatic singing. In general, it was found that—in comparison to lyric singing—dramatic singing is for many subjects associated with greater SPL, greater vibrato frequency and amplitude, lower resonance frequencies, and greater articulatory changes.

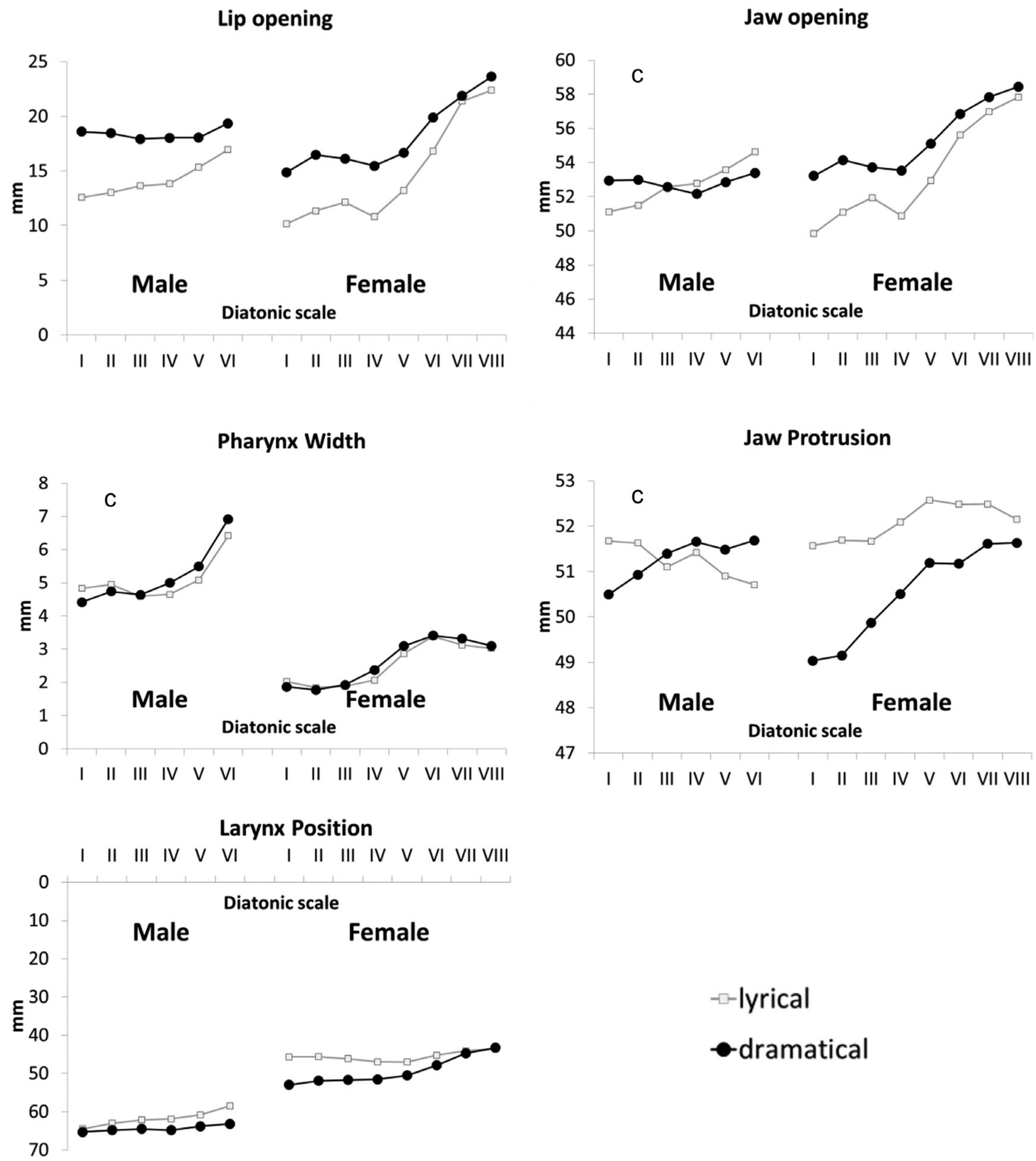

FIG. 5. Articulatory mean distances for dramatic and lyrical singing with respect to sex.

Historically, during the 18th or early 19th century, singers often performed a repertoire that today would be considered lyric. Composers like Mozart, Rossini, Bellini, and others composed numerous arias that fall within the lyric category (Kloiber *et al.*, 2002). During the 19th up to the 20th century, composers such as Wagner, Strauss, and in some cases also Verdi (as in *Otello*) demanded a more dramatic style of singing on opera stages. Associated with the more dramatic way of singing, the number of instrumentalists was increasing, with the consequence of a louder orchestra. Furthermore, the density of orchestration was increased. Therefore, it could be expected that the more dramatic way of singing could be associated with a higher SPL to be heard over a higher orchestra SPL, especially for female voices, who do not frequently use a formant cluster strategy (Sundberg, 1987). Although our study did not incorporate orchestra sound, all subjects demonstrated an increased SPL for the more dramatic way of singing. Since SPL is dependent on subglottic pressure, vocal fold adduction, vocal fold thickness, and the shaping of the resonatory system (Sundberg, 1987; Zhang, 2016), it is plausible that individual morphologic properties play a major role in the question if a voice could stand a dramatic role like Isolde or Brünnhilde. Furthermore, the subglottic pressure increases the stress on the vocal folds with a heightened risk for vocal overuse (Dejonckere and Kob, 2009). Also, in this context, it should be kept in mind that dramatic parts usually are associated with longer effective singing time. All this might be considered in good agreement with the clinical finding that singing a relatively dramatic Fach at an early stage in

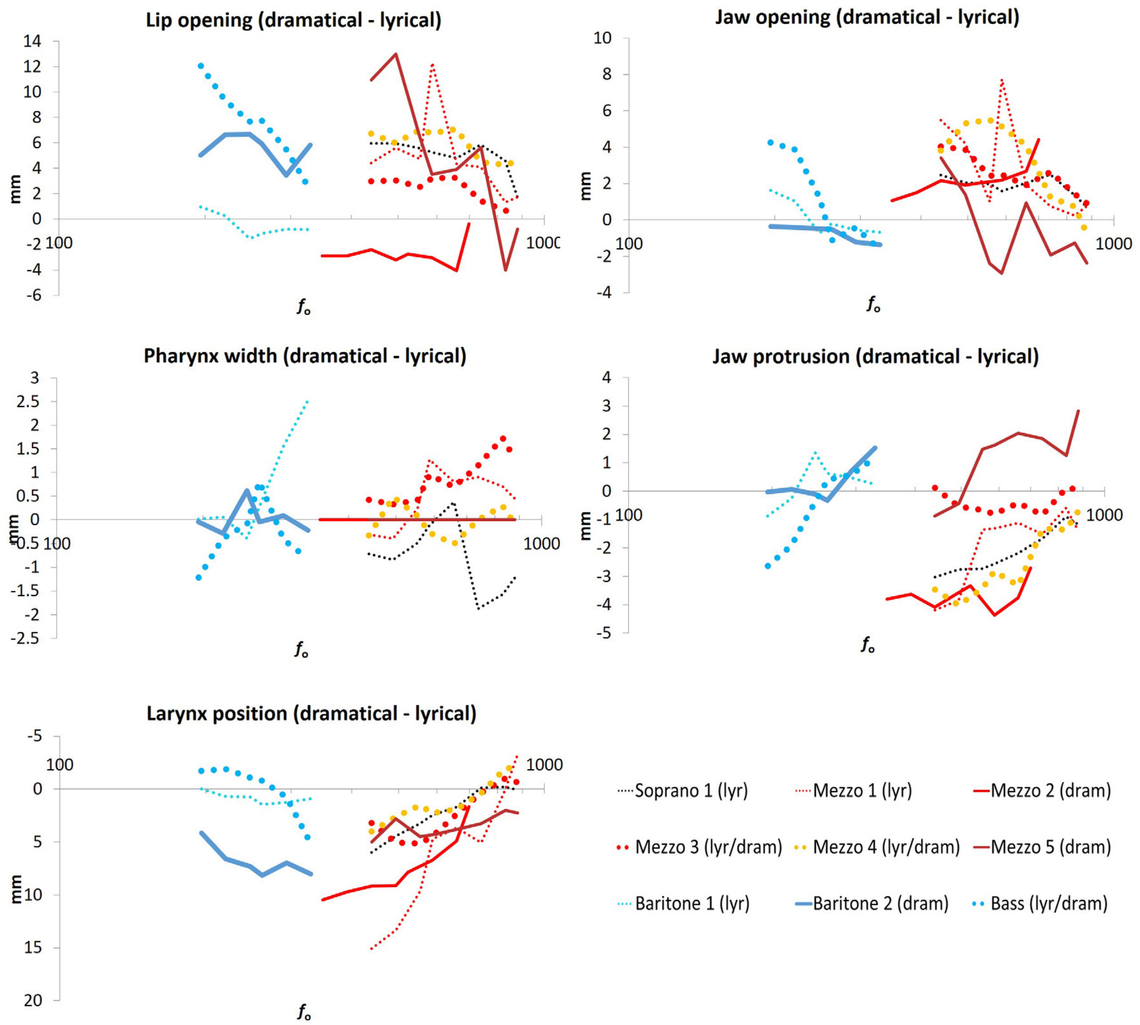

FIG. 6. (Color online) Difference of all articulatory distances for the dramatic minus the lyric singing with respect to each fundamental frequency (f_o).

the singer's career is often considered as a reason for vocal problems in professional singers (Richter, 2013).

It should be noted here that the measurement of SPL in this study has to be interpreted with caution because of the applied noise cancellation process in the audio files, which was necessary due to the noisy MRI environment. Furthermore, due to MRI technology, there was no possibility of valid SPL calibration. Therefore, an inter-subject comparison of the absolute values remains problematic. However, since the same noise filter was used for both tasks (i.e., lyric and dramatic singing), this error could still be considered to be of a systematic nature for the comparison of lyric and dramatic singing. Thus, a comparison of the differences should be considered reasonable.

The difference between dramatic and lyric SPL decreased for rising pitch. This could be explained by the general need of higher subglottic pressures for rising pitch due to the increase in vocal fold stiffness. However, it seems noteworthy that the differentiation of lyric and dramatic singing—and consecutively singers' Fach—might be problematic if only high pitches are presented to an audience. Such problems were also reported in a recent study regarding singers' Fach by Stone and Erickson, who showed differences with relation to pitch (Stone and Erickson, 2023). The same study by Stone and Erickson strengthened the impression that timbre differences contribute to Fach differences when singers of different Fach were compared. For the same singer, the dramatic style of singing was for many subjects associated with changes of the radiated sound spectrum showing higher energy at higher partials, as also shown in Table II for the frequency band of 2.5 to 3.5 kHz. Such finding is also in agreement with Sjölander and Sundberg (2004) who showed that with rising subglottic pressure—which is a major component of SPL management (Sundberg, 1987)—the spectral slope for partials showed a less steep slope.

In a recent database analysis, Müller *et al.* report that spectral differences might contribute to an assignment not only to a voice classification but also to lyric or dramatic repertoire among singers (Müller *et al.*, 2022). The data of the presented study revealed that even within one singer, such spectral differences are of relevance concerning the dramatic or lyric repertoire. However, the spectral analysis in the presented experiment might be problematic due to the

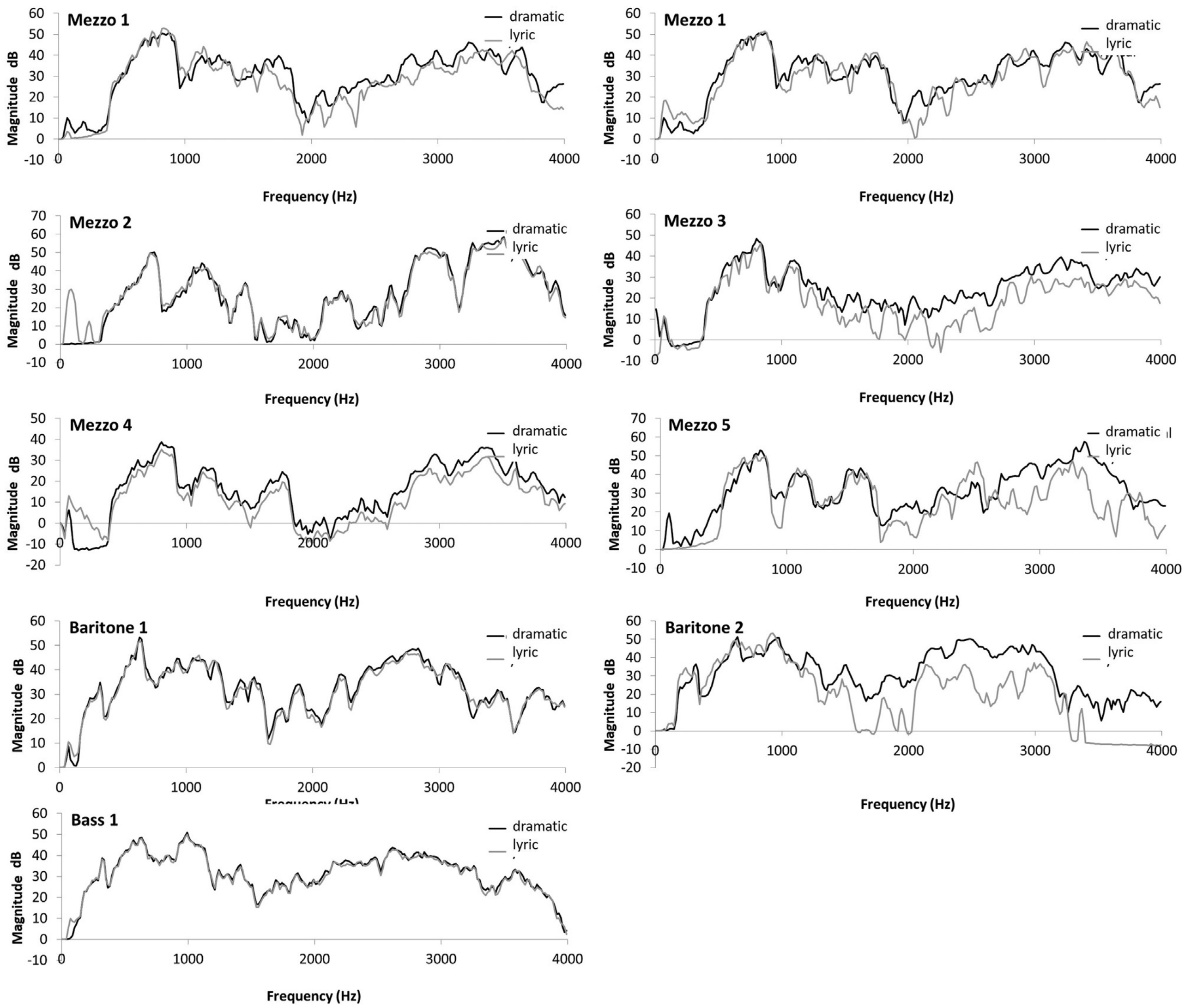

FIG. 7. Spectra for dramatic (black) and lyric (gray) singing as LTAS across all pitches for each subject.

noise cancellation and a recording sampling rate of 8 kHz (which was the highest sample rate of the only optical microphone system allowed in MRI machines in Germany at the time of the experiment) with a rather low Nyquist frequency. The latter could be associated with aliasing phenomena which could affect the data, especially in the higher frequency region.

TABLE II. Mean energy difference (dramatic minus lyric) for each subject in the frequency band from 2.5 to 3.5 kHz.

Classification	dB
Soprano 1	3.83
Mezzo 1	1.46
Mezzo 2	1.56
Mezzo 3	8.78
Mezzo 4	5.57
Mezzo 5	10.71
Baritone 1	0.72
Baritone 2	17.01
Bass 1	0.74

The described spectral differences could not only be dependent on the voice source—as described before—but also on vocal tract resonances. The estimation of resonances from the 2D MRI derived area functions show a lowering of f_{R1-R3} for most of the subjects' dramatic way of singing. Such phenomenon has often been denoted as *covered voice*, *voix sombrée*, or *gedecktes Singen*. This phenomenon of lower f_{R1} in combination with higher SPL is of interest because for speech it has been shown that a lower f_{R1} is associated with lower SPL (Stevens, 1998). Therefore, it could be expected that the rise of SPL for the dramatic way of singing is more a consequence of voice source production rather than vocal tract resonances.

Since resonances are strictly dependent on articulation, it seems of relevance to analyze the articulatory data. In this respect, it was found that most subjects widened both their jaw and their lips for the dramatic voice. However, two subjects showed a contrasting behavior. One showed a greater

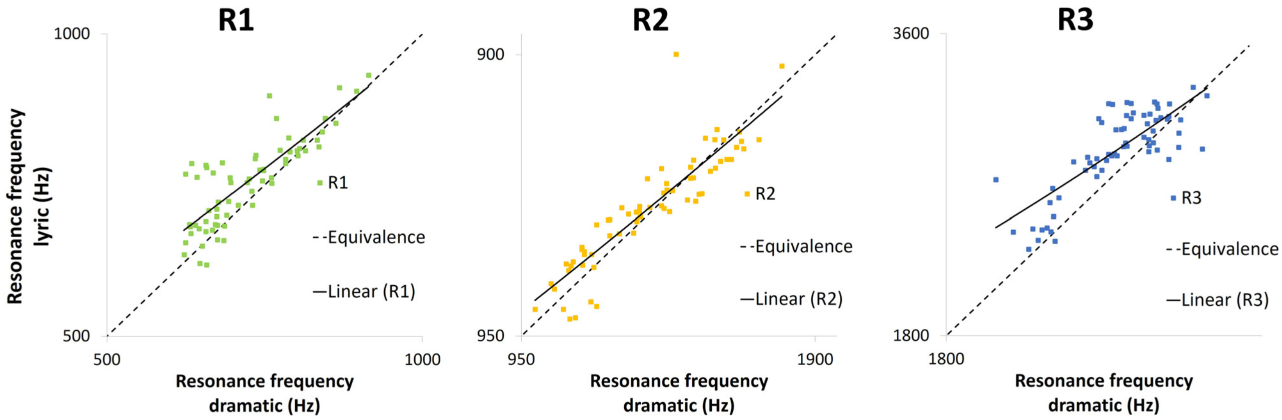

FIG. 8. (Color online) Resonance frequencies R1, R2, and R3 for dramatic versus lyric singing. The dashed lines refer to the equivalence and the solid lines to the trendlines.

and one a substantially smaller lip opening for a given jaw opening difference for the dramatic voice. The first might help in elongating the vocal tract and therefore should help to produce a *covered voice*; the latter remains unclear to the authors. The tongue position and pharynx width were not greatly different between both tasks—the lyric and dramatic ways of singing, respectively. The *covered voice* might be also produced by lowering the larynx. Indeed, a lower larynx position was found for most parts of the dramatic singing. Interestingly, this difference was decreasing with increasing f_o. For the highest f_o, no great difference was found any more for the dramatic and the lyric singing tasks. Because increased f_o is associated with greater tensional muscle activity (Titze, 1994), it might be that difference was minor (i.e., that larynx positions for dramatic and lyric singing were comparable). Furthermore, the gap of difference was more pronounced in female voices. Due to the need of an f_o/f_{R1} tuning situation (Garnier *et al.*, 2010; Joliveau *et al.*, 2004; Köberlein *et al.*, 2021; Sundberg, 1975), it could be expected that the larynx height would rise in order to increase f_{R1}.

It should be mentioned, however, that some articulators (especially in the mouth region, which also would need for example a coronal or axial plane for detection of the lateral opening of the mouth cavity) are not well represented in a midsagittal 2D plane, which could have an effect on the calculation of resonance frequencies, as in the algorithms used by Birkholz and Jackèl (2004). However, since both the dramatic and lyric tasks were performed under the same conditions, such error should be of systematic character. Finally, the articulatory differences among the lyric and dramatic way of singing could be associated with the increased SPL discussed above. In previous studies, it was found that a louder voice was associated with a greater lip opening and jaw opening (Echternach *et al.*, 2016b; Xue *et al.*, 2021). Furthermore, there was lower larynx position associated with louder phonation tasks for the singing voice (Echternach *et al.*, 2016b).

The dramatic way of singing was found to be associated with a higher vibrato frequency. Stone and Erickson (2023) and Erickson (2020) showed in perception experiments that voices are considered more dramatic when the vibrato frequency was higher.

In summary of the experiments, it could be stated that singers serve the expectations of the listener: When it should be more dramatic, the vibrato frequency is raised.

Further, Müller and colleagues (Müller *et al.*, 2021) found in their database analysis that the vibrato amplitude was higher for dramatic compared to the lyric voices for soprano and tenor voices. However, baritones showed a contrasting behavior (Müller *et al.*, 2021). The presented data showed a higher vibrato amplitude for the dramatic task for

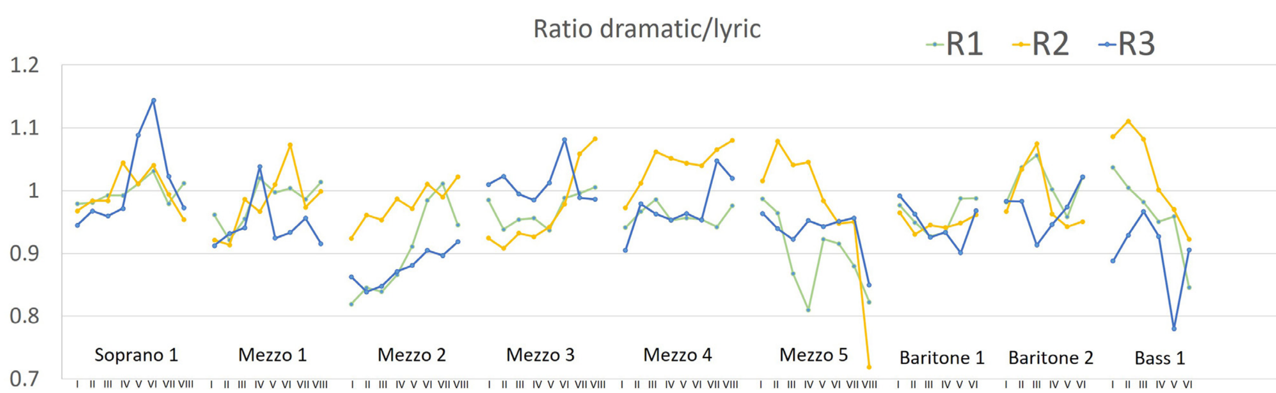

FIG. 9. (Color online) Ratio of dramatic to lyric with respect to resonance frequencies R1 (green), R2 (yellow), and R3 (blue) for all subjects and pitches.

all tested classifications, including the baritones. The reason for this difference remains unclear. However, it should be mentioned that the studies by Müller *et al*. (2021) analyzed differences among different singers before they were assigned to lyric or dramatic. The presented study, in contrast, showed intra-individual differences.

A. Limitations

Several further notable limitations should be mentioned regarding this study. Due to the extensive experimental setup, a rather small number of subjects were included, preventing detailed statistical analysis. It would be desirable to include more subjects for such an investigation. However, due to the inclusion of high-quality singers (refer to taxonomy), it appears unrealistic to include many more of such subjects within a reasonable amount of time. Additionally, in the current investigation, no tenors have been included. Tenor singing is particularly unique and challenging, i.e., with respect to bridging the passaggio (Echternach *et al*., 2016c; Echternach *et al*., 2021; Echternach *et al*., 2011a; Echternach *et al*., 2010b). Further, tenors performing very dramatic repertoire (*Heldentenors*) are very rare. Due to the special adjustments needed throughout the passaggio, it cannot be excluded that Heldentenors would exhibit different results.

This study was performed on the vowel /a/, only. It cannot be excluded that other effects would be found for other vowel conditions or consonant-vowel combinations. Concerning the latter, especially for the Wagner repertoire, pronunciation played a major role for the composer himself. Therefore, it should be mentioned that the dramatic way of singing should not be reduced to sustained phonation but also singing associated speech. This was also the reason not to perform a perceptual rating of the recorded audio files by singing teachers because it could be expected that—besides the manipulation of the audio signal by means of denoising—many other factors have to match the expectation of a dramatic voice that are difficult to fulfil in such an experimental setup.

Not all the subjects used all three strategies (SPL, vibrato, covered voice) at the same time. Some utilized only one. Our data revealed no clear effect that singers performing a dramatic repertoire differed from those singing a more lyric repertoire. In other words: The question what dramatic singing would be was not answered differently by singers performing a dramatic or lyric repertoire.

V. CONCLUSIONS

The presented data delineate three primary differences between dramatic and lyric singing: Dramatic singing was associated with greater SPL and increased vibrato amplitude and frequency as well as lower resonance frequencies. The articulatory differences included a greater lip and jaw opening as well as a lower larynx position. However, all of these strategies exhibited a considerable individual variability. The specific vocal Fach that the analysed singers perform on stage exhibited no important factor for the observed extents of differences. In further research, a comparable experiment should be performed in soundproofed rooms and with more vowel qualities in order to estimate the influences in the higher spectrum regions. Furthermore, it should be clarified how much the consonant-vowel combination might be related to an assignment to a dramatic and lyric voice, respectively.

SUPPLEMENTARY MATERIAL

See the supplementary material for MRI videos for subjects Mezzo 1 and Baritone 2, respectively.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

Ethics Approval

This study was approved by the Freiburg University Hospital Ethical Committee (No. 206/09). All subjects gave their written informed consent before inclusion in the study.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to restrictions by the study subjects.

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