

Aerodynamic Characteristics of Growl Voice and Reinforced Falsetto in Metal Singing

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Summary: Objectives. The present study aimed to assess the aerodynamic characteristics of vocally healthy metal singers when producing growl voice or reinforced falsetto.

Methods. Fifty-four participants (metal singers) were initially enrolled in this study, with 23 meeting the inclusion criteria. Sixteen participants performed growl voice and seven performed reinforced falsetto as a voice resource during metal singing. All participants were asked to undergo rigid laryngeal videostroboscopy to confirm the absence of laryngeal pathology. Then, subjects were aerodynamically assessed while performing growl voice or reinforced falsetto.

Results. Higher glottal airflow rate, sound pressure level, and subglottic pressure (P_{sub}) for growl voice samples compared to vowel production without growl voice (keeping the same fundamental frequency [F0]) were found. Higher P_{sub} , sound pressure level, and glottal resistance for high-pitched reinforced falsetto compared to naïve falsetto (keeping the same F0) were found. No differences for F0 were found for neither growl voice nor reinforced falsetto.

Conclusions. It seems that growl voice is produced by decreasing vocal folds adduction and increasing P_{sub} , which in turn, promotes an increased airflow rate. Reinforced falsetto is characterized by an increased vocal fold adduction and an increased P_{sub} . A proper resonance strategy in reinforced falsetto and a decreased glottal adduction in growl voice might probably be the factors that contribute to prevent voice problems in singers who use these vocal resources, classically labeled as vocal abuse.

Key Words: Subglottic pressure—Glottal airflow—Glottal resistance—Singing voice—Supraglottic compression.

INTRODUCTION

The present study is a continuation of a line of research whose general objective is to explore supraglottic constriction and the underlying physiology of different types of vocal sounds in singing and speaking voice.

Certain contemporary commercial music (CCM) singing styles commonly include vocal sounds that could be considered as harmful and detrimental for voice. Some of these vocal sounds are produced by narrowing of epilaryngeal and/or other vocal tract structures, causing a distorted and auditorily perceptual pressed sound. Growl voice is one of these vocal resources, being frequently used in jazz, blues, pop, gospel, and metal singing among others.^{1,2} Some ethnic singing from Brazil, Japan, and South Africa also include similar voice productions.³ In metal singing (eg, dead metal, black metal, and metalcore), growl voice can be also called as death growl, death metal vocals, guttural vocals, grunting, unclean vocals, and harsh vocals.⁴ Caffier et al⁵ stated that grunting singing is stylistically suited to reproduce gloomy or brutal lyrics. It has a devilish sound and can express anger and despair.⁵

Few previous studies have been addressed to explore the underlying physiology of growl voice. In a laryngeal endoscopic study, Sakakibara et al⁶ showed that growl voice is produced through the simultaneous vibration of the vocal folds and laryngeal supraglottic structures. The vocal folds vibrate periodically and the aryepiglottic folds generate subharmonics. The presence of subharmonics during growl voice production has also been found in other studies.^{7–9} Vibration of aryepiglottic folds was also reported in a radiologic study.⁶ Additionally, authors showed that during growl voice production, the larynx rose to the fourth vertebra and there was a large anterior-posterior (A-P) laryngeal constriction.⁶ Recently, Caffier et al found that during growl voice production, glottal closed phase is decreased because the vocal folds vibrate decoupled due to reduced contact.⁵

Other vocal resource that metal singers (especially in heavy metal) use as part of their vocal technique is the reinforced falsetto. This type of falsetto has been described as a voice production that uses a greater vocal folds adduction compared to naïve falsetto (nontrained falsetto).^{10,11} The greater adduction during reinforced falsetto production results in loud and bright sound. Acoustically, the perceptual differences between naïve and reinforced falsetto are caused by an increment of harmonic energy in the high spectral region (2–5 kHz) in the latter.¹¹ Reinforced falsetto may be used in CCM musical styles such as blues, glam rock, epic metal, heavy metal, soul, etc.

Guzman et al¹¹ conducted a study aimed to determine the resonance strategies of metal singers when singing high pitches with reinforced falsetto. Authors suggested that this type of voice production is associated with a shortening of the vocal tract and a very open mouth configuration. High first and second formants values in all of the participants seem to reflect articulatory characteristics, such as a wider jaw opening, a

Accepted for publication April 30, 2018.

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Journal of Voice, Vol. 33, No. 5, pp. 803.e7–803.e13

0892-1997

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<https://doi.org/10.1016/j.jvoice.2018.04.022>

narrower pharynx, spread lips, and high vertical laryngeal position.¹¹

Because growl voice and reinforced falsetto seem to perceptually be a pressed and laryngeal hyperfunctional voice, it is not unreasonable to think that long-term use of these voice productions may cause voice disorders. However, some metal singers and singing teachers maintain that long-term use of these techniques will not cause harm to the voice if produced in a healthy manner. In a study aimed to assess a group of metal singers who engage in growl voice and/or reinforced falsetto, Guzman et al¹² found that these techniques do not seem to contribute to laryngeal disorders. Perceptual, acoustic, functional, and laryngoscopic assessment showed no major alterations in most of the participants. Moreover, no significant differences in voice and laryngeal evaluation were found when comparing these metal singers with other CCM singers who do not use neither growl voice nor reinforced falsetto.¹² Recently, in a study conducted to multidimensionally investigate common vocal effects in experienced professional CCM singers, laryngeal structures of all singers were found to be healthy in spite of using vocal effects such as growl voice and vocal distortion over many years.⁵ To the best of our knowledge, no more studies have been addressed to assess voice condition in metal singers.

The present study aimed to assess aerodynamic characteristics of vocally healthy metal singers during production of growl voice or reinforced falsetto. We hypothesized that aerodynamic characteristic during growl voice and reinforced falsetto productions would reflect a low phonatory effort even if these techniques sound like vocally stressful behaviors.

METHODS

Participants

Fifty-four participants (metal singers) were initially enrolled in this study. Only 23 met the inclusion criteria. Sixteen of them performed growl voice and seven subjects performed reinforced falsetto as a voice resource during metal singing. Mean age of growl voice group was 26 years, ranging from 21 to 32. Mean age of the reinforced falsetto group was 27 years, ranging from 22 to 35. Inclusion criteria for participants were: (1) at least 1 year of experience singing growl voice or reinforced falsetto, (2) no current or past history of major voice problems during last year, (3) perceptually normal voice, (4) absence of any structural or functional vocal fold disorders, (5) self-reported normal hearing, and (6) technically appropriate singing voice technique (growl voice or reinforced falsetto) assessed by a singing teacher who teaches these types of voice techniques for metal singers (co-author of the present paper). Perceptual assessment was conducted by one of the authors of this paper, using GRBAS (grade, roughness, breathiness, asthenia, strain) scale. Participants in both groups were native speakers of Spanish and reported no hearing problems. The present study was approved by the institutional review board at University of Chile and all participants signed informed consent.

Laryngoscopic assessment

Once subjects passed auditory perceptual assessment and singing voice technique evaluation, they were asked to undergo rigid laryngeal videostroboscopy (digital videostroboscopy system; Atmos Strobo 21 Led; ATMOS MedizinTechnik, Lenzkirch, Germany) to confirm the absence of laryngeal pathology. Laryngoscopic examinations were performed by one experienced voice pathologist who is co-author of the present study. No topical anesthesia was used during endoscopic procedure.

Equipment and data collection

Aerodynamic and acoustic measures were captured for each participant during growl voice or reinforced falsetto productions. All samples were recorded digitally at a sampling rate of 22.1 KHz with 16 bits/sample quantization. Acoustic signal was recorded using the incorporated condenser microphone AKG CK 77 (AKG Acoustics, Vienna, Austria) that Phonatory Aerodynamic System provides (KayPENTAX, Lincoln Park, NJ). A constant microphone-to-mouth distance of 20 cm was used. Acoustic samples were captured to obtain mean fundamental frequency (F0) and mean sound pressure level (SPL). F0 was obtained to ensure that this variable was kept constant between repetitions as required to participants.

Aerodynamic device was connected to a computer through a Computerized Speech Lab, model 4500 (KayPENTAX, Lincoln Park, NJ). A Phonatory Aerodynamic System, model 4500 (KayPENTAX, Lincoln Park, NJ) was used to collect aerodynamic data. Calibration of the air pressure and airflow signals was performed before data acquisition according to the manufacturer's instructions. A real-time *aerodynamic analysis software*, model 6600, version 3.4 (KayPENTAX, Lincoln Park, NJ) was used to analyze all samples. From the middle section of each sample, the most stable part was analyzed.

Phonatory tasks

Phonatory tasks required to participants were not the same in both groups. The following are the phonatory tasks for growl voice group: (1) a sustained vowel [a:] producing growl voice at a comfortable and usual pitch, (2) a sustained vowel [a:] without growl voice keeping the same F0 as task 1, (3) repetition of the syllable [pa:] producing growl voice at a comfortable and usual pitch, and (4) repetition of the syllable [pa:] without growl voice keeping the same F0 as task 3. The following are the phonatory tasks for reinforced falsetto group: (1) a sustained vowel [a:] producing reinforced falsetto at a high and comfortable pitch, (2) a sustained vowel [a:] producing naïve falsetto keeping the same F0 as task 1, (3) repetition of the syllable [pa:] producing reinforced falsetto at a high and comfortable pitch, and (4) repetition of the syllable [pa:] producing naïve falsetto keeping the same F0 as task 3. Repetition of the syllable [pa:] was asked to obtain the subglottic pressure (Psub) from the oral pressure (Poral) during the occlusion of the consonant [p:]. A silicon tube inserted into the mouth was used to acquire Poral. Participants were asked not to touch the tube with their tongue or with any other oral structure so as to not block the airflow.

Three repetitions of all phonatory tasks were performed by each subject. F0 was required to be the same during all phonatory tasks.

Variables

From acoustic and aerodynamic samples acquired, the following variables were obtained:

- (1) F0 (Hz) from acoustic signal.
- (2) SPL (dB) from acoustic signal.
- (3) Psub (cm H2O) estimated from the maximum peak of the Poral during the occlusion of the consonant [p:] in the syllable [pa:].
- (4) Mean glottal airflow (L/seg) from aerodynamic signal.
- (5) Glottal resistance (cm H2O/L/seg) from aerodynamic signal, defined as Psub divided by glottal airflow.

Statistical analysis

Data were processed with *R software* (version 3.4.4, The R Foundation for Statistical Computing, Vienna, Austria).^{13,14} Because of limited sample size, differences between singing styles were explored by means of a nonparametric test (paired-sample Wilcoxon test). Moreover, because small sample sizes are known to impact both *P*-values and effect size, a more

robust measure of differences was obtained by calculating confidence intervals (CIs) for each contrast, based on the median of the differences between the two measures. Thus, only CIs not including zero were considered as significant and are here reported.¹⁵

RESULTS

Figures 1 and 2 show results from phonatory tasks (sustained vowel [a:] and repetition of the syllable [pa:]) performed during growl voice production and voice production without growl voice. During sustained vowel [a:] (Figure 1), significant differences were found for mean SPL (CI 5.176, 11.635, $P < 0.001$) and glottal airflow (CI 0.585, 1.205, $P < 0.001$) when comparing growl voice production and vowel production without growling. No differences were detected for F0 (-28.226 , 23.036 , $P = 0.52$). During repetition of the syllable [pa:] (Figure 2), significant differences were found for mean SPL (CI 5.961, 10.618, $P < 0.001$), glottal airflow (CI 0.666, 1.258, $P < 0.001$), Psub (CI 14.811, 35.654, $P < 0.001$), and glottal resistance (CI -187.033 , -15.233 , $P < 0.001$). No differences were detected for F0 (-21.605 , 39.678 , $P = 0.52$).

Figures 3 and 4 display results from phonatory tasks (sustained vowel [a:] and repetition of the syllable [pa:]) performed with reinforced falsetto and naïve falsetto. During sustained vowel [a:] (Figure 3), significant differences were found only

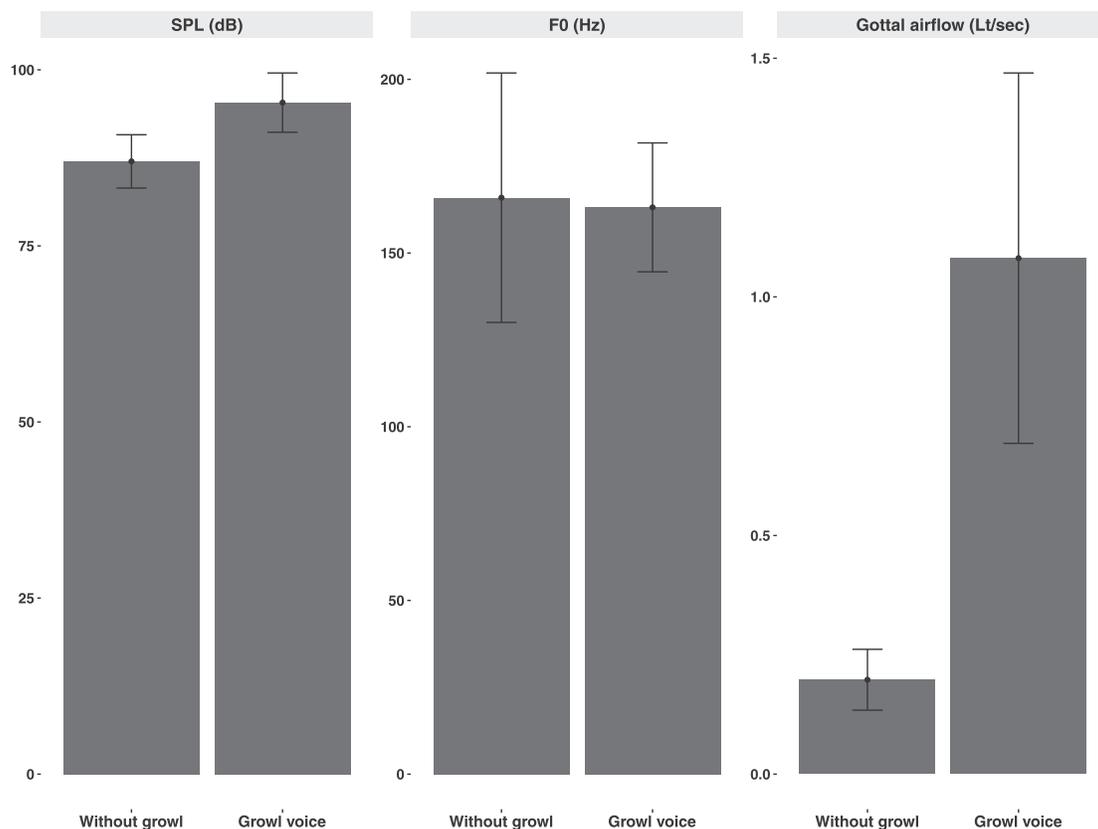


FIGURE 1. Results from sustained vowel [a:] performed during growl voice production and voice production without growl voice. Error bars represent 95% CI for the means of each variable for each condition. Nonoverlapping or slightly overlapping error bars are to be interpreted in terms of significant differences between conditions. Widely overlapping error bars translate into nonsignificant differences.

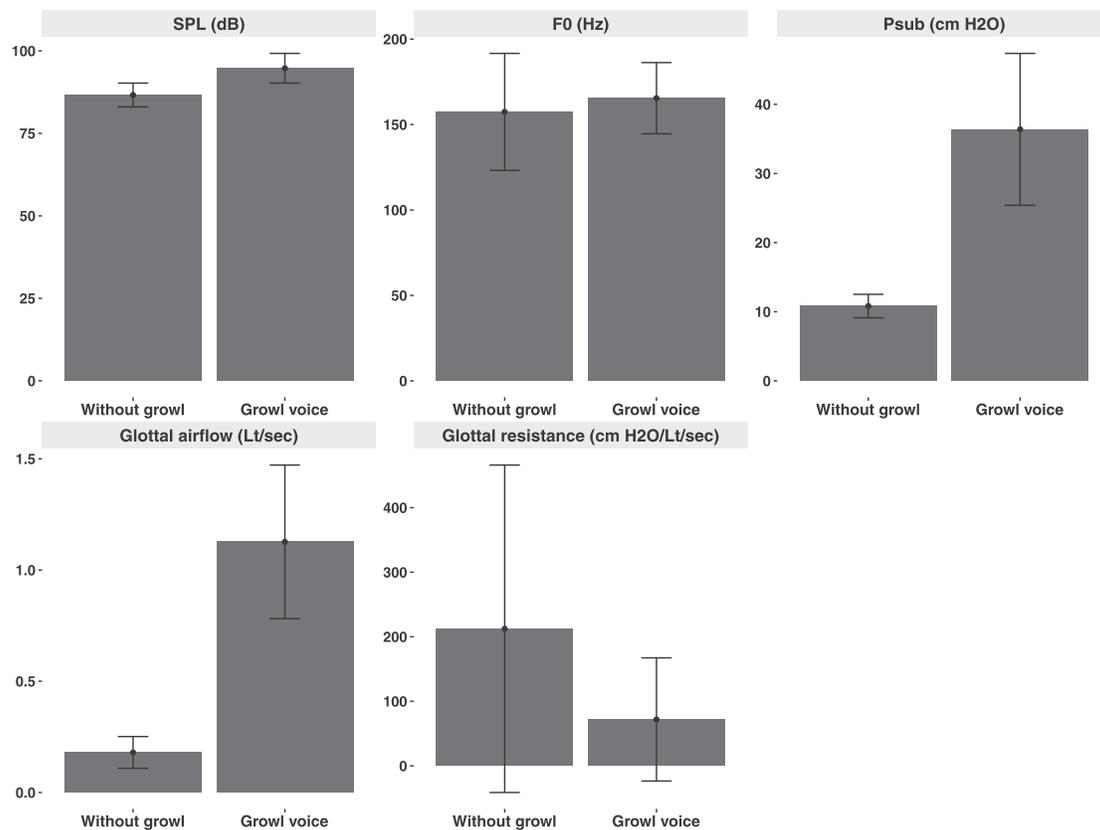


FIGURE 2. Results from repetition of the syllable [pa:] performed during growl voice production and voice production without growl voice. Error bars represent 95% CI for the means of each variable for each condition. Nonoverlapping or slightly overlapping error bars are to be interpreted in terms of significant differences between conditions. Widely overlapping error bars translate into nonsignificant differences.

for mean SPL (CI $-12.591, -3.853, P=0.01$). No differences were evidenced neither for F0 (CI $-16.308, 1.961, P=0.1$) or for glottal airflow (CI $-0.0100, 0.2033, P=0.15$). During repetition of the syllable [pa:] (Figure 4), significant differences for Psub (CI $-23.903, -9.441, P=0.02$) were observed. No differences were detected for the rest of dependent variables (F0 $-12.74, 5.16, P=0.93$; glottal airflow $-0.0916, 0.138, P=0.27$; glottal resistance $-228.248, 12.916, P=0.07$).

The lack of significant differences in F0 during all phonatory tasks are expected and desired because all participants were required to keep the same pitch during voice production and repetitions of growl voice and reinforced falsetto.

DISCUSSION

Previous studies on vocal resources commonly used in metal singing (growl voice and reinforced falsetto) have explored underlying physiology through endoscopic assessment, radiologic examination, and acoustic analysis.⁵⁻⁹ To the best of our knowledge, no research has been conducted to describe aerodynamic behaviors of these techniques. Therefore, the purpose of the present study was to assess aerodynamic characteristics of vocally healthy metal singers during productions of growl voice and reinforced falsetto. Based on our previous published data and earlier studies by other researchers, we expected

aerodynamic characteristics during growl voice and reinforced falsetto productions to reflect a low phonatory effort, even though these techniques sound like vocally stressful behaviors.

Inspection of results revealed that some aerodynamic characteristics of vowel production with growl voice might correlate with nonphonotraumatic phonatory practice. Glottal airflow and Psub were higher during growl voice production as compared to voice production without growl. In addition, a lower glottal resistance was observed during growl voice production. Because glottal airflow is defined as the ratio between Psub and glottal resistance, it seems natural to think that higher airflow found in the present study during growl voice production was caused by decreased vocal folds adduction and also a high Psub. A low glottal closure (to allow a high airflow rate) clearly would decrease the probability of phonotrauma during growling. Caffier et al,⁵ through endoscopic imaging and electroglottography, reported that during production of some vocal resources commonly used in rock (eg, grunting and rattle), the closed phase of the glottis is decreased because the vocal folds vibrate decoupled due to reduced contact. Caffier et al mentioned that there is no real oscillation cycle but rather tonal noise.⁵ Although a high Psub has been associated to a high phonatory effort, data from the present study would

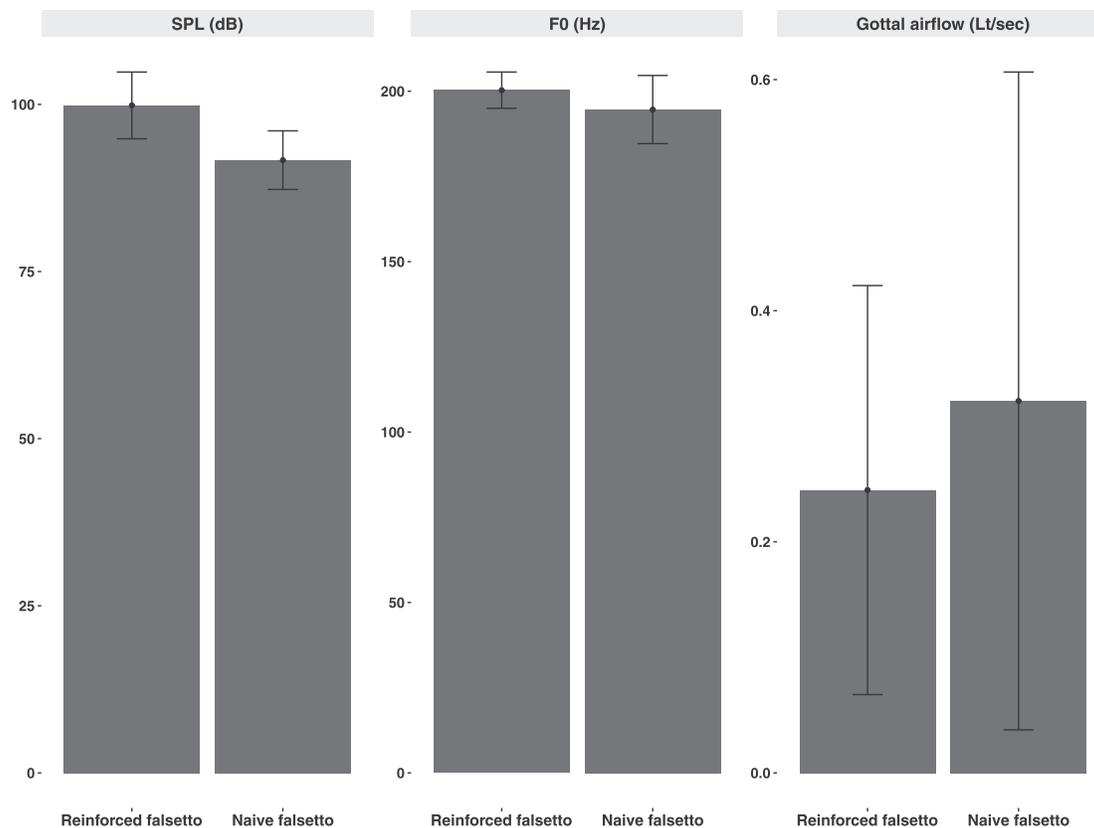


FIGURE 3. Results from sustained vowel [a:] performed during production of reinforced falsetto and naïve falsetto. Error bars represent 95% CI for the means of each variable for each condition. Nonoverlapping or slightly overlapping error bars are to be interpreted in terms of significant differences between conditions. Widely overlapping error bars translate into nonsignificant differences.

allow to speculate that high P_{sub} was likely used as aerodynamic strategy to produce vibration of supraglottic structures rather than vocal folds oscillation. If vocal folds adduction would not be low during growl voice production, a high glottal airflow would not be possible, making unlikely the vibration of supraglottic structures as described in earlier studies.^{6,7,16}

Activity of supraglottic structures during growl voice production seems to be one of the most relevant aspects during this technique. Results by Guzman *et al*¹² revealed that growl voice is characterized by supraglottic compression, pharyngeal constriction, and changes in vertical laryngeal position. Guzman *et al* suggested that the rough and raspy perceptual quality of growl voice production is likely produced by the vibration of the supraglottic structures involved in the observed laryngeal compression.¹² Similarly, Borch *et al*¹⁶ found significant supraglottic activity including the aryepiglottic folds, anterior part of the mucosa covering the arytenoids, and ventricular folds (medial compression). Additionally, high-speed digital imaging (fiberscope inserted into the nose cavity) revealed that growl voice production presented simultaneous vibration of laryngeal supraglottic structures (likely caused by high airflow rate).⁷ Recently, Caffier *et al*⁵ reported that during production of rattle (a vocal resource used in rock) the aryepiglottic folds play an important role in producing crackling sound, the supraglottic anteroposterior constriction is clearly visible, and the vocal

folds vibrate relatively relaxed. Even if growl voice possesses a quality that may sound pressed or constricted, the major work may not be performed by the vocal folds, but by the increased activity of laryngeal supraglottic structures and aerodynamic behavior (high glottal airflow and P_{sub}).

Results from falsetto analysis indicated that significant higher values of both P_{sub} and glottal resistance were found for reinforced falsetto when compared to naïve falsetto's. At the first glance, it seems that reinforced falsetto may involve a more phonotraumatic voice production than naïve falsetto, as both high P_{sub} and gottal resistance are associated to phonatory effort. However, in a previous study performed with metal singers who regularly use this technique, no major vocal folds disorders were reported. The use of proper resonance strategies (vocal tract shape) to prevent excessive vocal folds muscle efforts during high-pitched reinforced falsetto might explain lack of voice damage. Resonance strategies during reinforced falsetto production were previously assessed through acoustical analysis in a group of metal singers.¹¹ Results revealed high values of the two first vocal tract formant frequencies (F1 and F2) in all participants. Data from the present study showed higher values for total SPL during reinforced falsetto production compared to naïve falsetto production.¹¹ An adequate resonance strategy might also be the cause for this increase. In fact, in the previously cited resonance strategy study,¹¹ a clear increase of the spectral energy in one or two harmonics due to

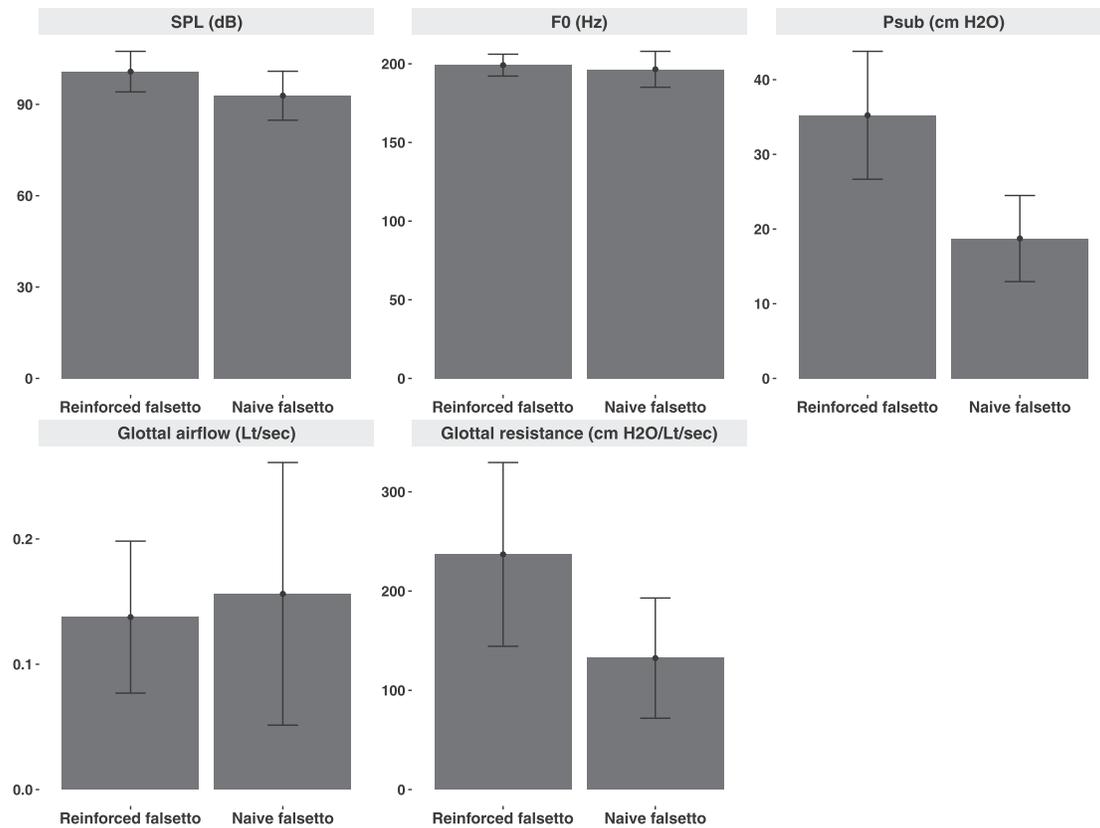


FIGURE 4. Results from repetition of the syllable [pa:] performed during production of reinforced falsetto and naïve falsetto. Error bars represent 95% CI for the means of each variable for each condition. Nonoverlapping or slightly overlapping error bars are to be interpreted in terms of significant differences between conditions. Widely overlapping error bars translate into nonsignificant differences.

the coincidence or proximity with one or two first formants was shown for all singers. These outcomes suggest that the total SPL during reinforced falsetto production may not be mainly supported by increasing vocal effort (high glottal resistance and high Psub), but also by an adequate vocal tract configuration strategy.

As for acoustic analysis during high-pitched voice production, similar results were reported by Borch et al in a group of rock singers.¹³ They claimed that high values of formant frequencies reflected a relatively high larynx position and open mouth configuration. Guzman et al¹¹ found that all assessed metal singers spontaneously used the vowel /a/ (open vocal tract configuration) during the production of reinforced falsetto in high pitches. Earlier studies have shown that a similar vocal tract configuration is classically displayed by sopranos during production of high pitches to avoid laryngeal muscle effort.^{17–19}

High activity and compression of supraglottic structures previously reported in growl voice^{7,12,16} and reinforced falsetto productions,^{11,12} have been also found in other singing styles and in speaking voice. Medial and A-P laryngeal compression have commonly been described as endoscopic signs of vocal hyperfunction.^{20,21} Previous studies, however, have shown that an increased supraglottic activity may also be a normal and even desirable vocal behavior in subjects diagnosed with normal voice.^{22–27} Medial and A-P laryngeal supraglottic activity

have been observed in healthy opera singers,^{23,25} CCM singers,^{21,23,26} and in professional theater actors.²⁷

CONCLUSION

Growl voice seems to be produced by decreasing vocal folds adduction and increasing Psub, which in turn promotes an increased airflow rate. Reinforced falsetto is characterized by an increased vocal fold adduction and an increased Psub. Likely, a proper resonance strategy in reinforced falsetto and a decreased glottal adduction in growl voice could be the factors that contribute to the avoidance of voice problems in singers who use these vocal resources that could be classically labeled as vocal abuse.

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