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Research Article

Do Flexible Silicone Tubes Immersed in Water Combined With Vocalise Improve the Immediate Effect on Voice?

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AQ1 **Purpose:** This study aimed to analyze the immediate effect on a singer's voice of a flexible silicone tube immersed in water combined with ascending and descending vocalise scales compared with ascending and descending vocalise scales alone.
Method: A pre- and post-intervention quasi-experimental study was conducted. Thirty adult singers between 18 and 45 years old with no laryngeal disorders performed the two techniques for 3 min each on different days. Acoustic measurements of frequency, jitter, shimmer, glottal-to-noise excitation ratio, noise, smoothed cepstral peak prominence (CPPS), maximum phonation time (MPT), voice range profile, and self-perceived vocal effort (Borg Category Ratio 10-BR Scale adapted for vocal effort) were assessed before and after performing the techniques.
Results: The results indicated an increase in singers' CPPS and MPT values and a decrease in shimmer and noise when performing with a flexible silicone tube immersed in water combined with vocalise. The singers reported a perception of decreased vocal effort after both methods. However, the diminished perceived vocal effort became more pronounced with the tube phonation technique combined with vocalise.
Conclusions: Phonation in tubes combined with vocalise improved the vocal acoustic parameters (including cepstral measurements), increased MPT, and diminished perceived vocal effort. Although using vocalise alone diminished perceived vocal effort, this decrease was more pronounced in the tube phonation technique combined with vocalise.

In order to improve vocal performance through increased reach and flexibility, most singers perform voice warm-up exercises (Hoch & Sandage, 2018; Portillo et al., 2018; Titze, 2001). Although some exercises promote greater control of the phonatory system, many singers and vocal trainers use informally acquired experience-based knowledge, despite the lack of evidence regarding the physiological effects of such exercises (Gill & Herbst, 2016; Gish et al., 2012; Loiola & Silva, 2010; Portillo et al., 2018). Moreover, long and detailed warm-up routines may cause vocal fatigue, a decrease in motivation, and a lack of discipline in singers (Fadel et al., 2016).

Insufficient vocal care routines and inappropriate vocal techniques can negatively affect a singer's voice. Therefore, an understanding of acoustic and physiological vocal production principles and techniques is crucial (Fadel et al., 2016; Gill & Herbst, 2016; Gish et al., 2012).

A common vocal warm-up technique among singers and singing teachers uses vocal exercises that consist of singing a vowel or a series of notes. "Vocalises" are often used in singing lessons and in individual and collective projects, such as choirs and theater groups. Through ascending and/or descending scales or melodies that are built from interval relations and produced repeatedly, vocalises assist in the perception of the melody in musical memory and raise awareness of vocal dynamics and production. The singer is aware of the reproduction of sounds that the auditory system perceives, involving the auditory and vocal

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aspects in singing (Gaborim Moreira & Egg, 2018; Santos, 2019). Therefore, vocalises are used to facilitate vocal flexibility and stimulate better tuning control (Gaborim Moreira & Egg, 2018; Gava Júnior et al., 2010; Gish et al., 2012). In addition, vocalises have been used in clinical speech therapy for individuals with vocal disorders or those seeking vocal improvement (Chaves, 2012).

Semi-occluded vocal tract exercises (SOVTEs), which are commonly used in voice clinics and are known to produce positive results, have also been utilized by many singers, prompting numerous studies of their effect on the singing voice (Cielo, Lima, et al., 2013; Fadel et al., 2016; Portillo et al., 2018; Ramos & Gama, 2017). One variant uses different types of tubes to reduce the impact on the vocal folds, balance the sub- and supraglottic pressure, and allow for more economical and comfortable phonation with reduced effort, preventing vocal hyperfunction (Cielo, Lima, AQ3 et al., 2013; Guzmán et al., 2011; Hampala et al., 2015; Manternach et al., 2017; Manternach & Daugherty, 2019; Portillo et al., 2018).

Silicone tubes have been used for vocal training, as they allow for increased voice control and reduce excessive tension during phonation (D. M. D. R. Gonçalves et al., 2019). Some studies have reported that water resistance therapy improves function, phonatory comfort, and vocal extension profile; decreases tension and glottal-to-noise excitation ratio (GNE); and increases frequency (fundamental frequency [f0]), mobility of the free edge of the vocal folds, and glottal closure (Cardoso et al., 2020; Enflo et al., 2013; Fadel et al., 2016; D. M. D. R. Gonçalves et al., 2019; Guzmán et al., 2016, 2018; Saldías et al., 2020). Tubes can be immersed in water at different depths based on the vocal and laryngeal diagnosis and proposed objectives (Rossa et al., 2019).

In order to produce increasingly satisfactory results, the frequency and intensity of the exercise must be sufficient for muscle adaptations to occur. The overload principle states that muscles must be worked at an intensity or frequency above that to which they are accustomed in order to achieve morphological, metabolic, and neurological changes. This principle remains poorly understood in the context of the voice, partly owing to the fact that the operational definition of vocal overload tasks has not been established to date (Delprado-Aguirre, 2020; Hoch & Sandage, 2018). Loads can be applied considering the intensity, progressive resistance, increased volume and frequency (Delprado-Aguirre, 2020; Hoch & Sandage, 2018), and submersion level of tubes in water (Guzmán et al., 2018).

There are different ways to assess the effect of a technique, such as self-perception, auditory perceptual judgment, and acoustic measures. Instrumental assessment allows for objective quantification of vocal production, with acoustic analysis being the main form of assessment for voice (Roy et al., 2013).

Acoustic analysis and auditory–perceptual assessment of voice are used in speech therapy for vocal characterization. Acoustic analyses provide more objective information and quantitative data than auditory–perceptual evaluations. Acoustic analysis utilizes computational techniques to enable the documentation and monitoring of vocal parameters and verify the results of any technique or treatment (Lopes et al., 2015, 2017). The most common acoustic measures offered by voice laboratories are f0, noise level, GNE, jitter, and shimmer (Vieira et al., 2015). AQ4

Jitter and shimmer indicate cycle-to-cycle frequency and amplitude variability, respectively, of the sound wave of f0 and determine the phonatory system's degree of stability. This changes mainly in situations of reduced glottic resistance and correlates with the presence of noise when phonating (hoarseness) and breathiness. GNE indicates whether a given voice signal originates from vibrations of the vocal folds or from turbulent noise generated in the vocal tract. This parameter quantifies the amount of excitation due to vocal fold oscillations versus the excitation due to turbulent noise. Thus, it is directly related to breathiness and glottal closure (Godino-Llorente et al., 2010; Lopes, Batista Simões, et al., 2017; Lopes, da Silva, et al., 2017; Verde et al., 2018).

Although jitter and shimmer measurements are traditionally common in vocal assessment, currently, acoustic analysis favors cepstral measurements over traditional acoustic parameters (Delgado-Hernández et al., 2018). Smoothed cepstral peak prominence (CPPS) is one of the most common cepstral measures in objective evaluations of voice (Delgado-Hernández et al., 2018; Lopes et al., 2019). Cepstral analysis determines the extent to which f0 harmonics are individualized and stand out in relation to the noise level and is capable of indicating the degree of harmonic organization of voice. Cepstral measurements have been used in several studies, mainly in dysphonic voices with different intensities of vocal deviation (Lopes et al., 2019). However, these measures have not been explored in other populations, such as singers (Balasubramanium et al., 2015).

Moreover, the vocal range profile (VRP), which consists of a graphical representation of the vocal capacity of the larynx based on frequency and intensity measurements, allows for an accurate assessment and understanding of the individual's tonal range and objectively measures the singer's evolution after a vocal training period. If positive changes in the lowest and highest intensity along the frequency range cause a greater VRP area, better control of the entire phonatory mechanism could be expected (Cobeta et al., 2013; Guzman et al., 2020). Thus, VRP enables the evaluation of training to increase vocal extension and intensity and the analysis of the vocal potential of singers and voice professionals, including their possibilities and limitations (Cobeta et al., 2013).

Maximum phonation time (MPT) provides data on glottal efficiency, respiratory function, and laryngeal control (Cielo et al., 2015). Singing more notes and sustaining them for longer periods certainly helps the singer in musical interpretation (Cielo et al., 2015; Cobeta et al., 2013). These measures and objective vocal assessments can help clarify the physical and physiological parameters of vocal production, providing a new perspective for vocal pedagogy.

This study aimed to investigate the combined use of vocalise and SOVTE, including the technique of using tubes immersed in water and its influence on significant vocal production with maximum efficiency and minimum effort. As both techniques have demonstrated several benefits, this study hypothesized that a combined technique will improve vocal acoustic parameters (including cepstral measurements) and MPT, increase vocal extension, and reduce perceived vocal effort. This study proposed that a combined technique will enhance the benefits of vocalise in singers' voices and reduce exercise time, improving singing performance and comfort in voice production. Therefore, the objective of the study was to assess the immediate effect of using a flexible silicone tube immersed in water combined with vocalise on a singer's voice and compare this with the effects of vocalise alone.

AQ5 Method

In this pre- and post-intervention quasi-experimental study, data were collected at the voice laboratory of a public university. The sample comprised 30 adult singers (16 men and 14 women) of different musical styles, 18–45 years old (M_{age} = 25.87 ± 5.64 years), with no structural or functional laryngeal damage as assessed with videostroboscopy and visual examination of the larynx by an otorhinolaryngologist; the same otorhinolaryngologist examined all participants. In addition to visualizing the anatomy of the larynx to check for possible structural disorders through the rigid fiber, vocal productions in low and high tones were acquired for functional assessment of phonation.

The 18–45 years age group was selected to exclude voice disorders during adolescence and aging (Costa et al., 2006; Rocha et al., 2007). The exclusion criteria were behavioral or organic dysphonia; alterations observed through video laryngoscopy; smoking habits; and signs and symptoms of laryngeal, pharyngeal, or respiratory diseases at the time of data collection.

Participants were recruited in person, by phone, and through social media using nonprobabilistic "snowball sampling" selected by convenience. All participants signed the informed consent form and were informed of the research
F1 objectives and procedures. Figure 1 shows the sample selection flowchart, whereas the sample characteristics are de-
T1 scribed in Table 1.

Ten of the participants reported complaints regarding singing performance, such as difficulty with treble, breathing control, sustaining notes, and throat clearing. Seven participants had previously undergone voice therapy for vocal improvement or because of dysphonia; however, none of the participants were undergoing voice therapy at the time of the study. The vocal warm-ups practiced by the singers, as described in the identification questionnaire, are shown
F2 in Figure 2.

Technique Selection

Data were collected in two conditions on separate days to prevent interference of methods. The technique to be performed first was selected randomly. The second recording was scheduled according to the participants' availability. Thus, as there was no control over the time interval between the first and second recordings, the interval varied considerably, with the average being 34.50 (47.29) days. The participants underwent the entire pretechnical evaluation protocol during both conditions.

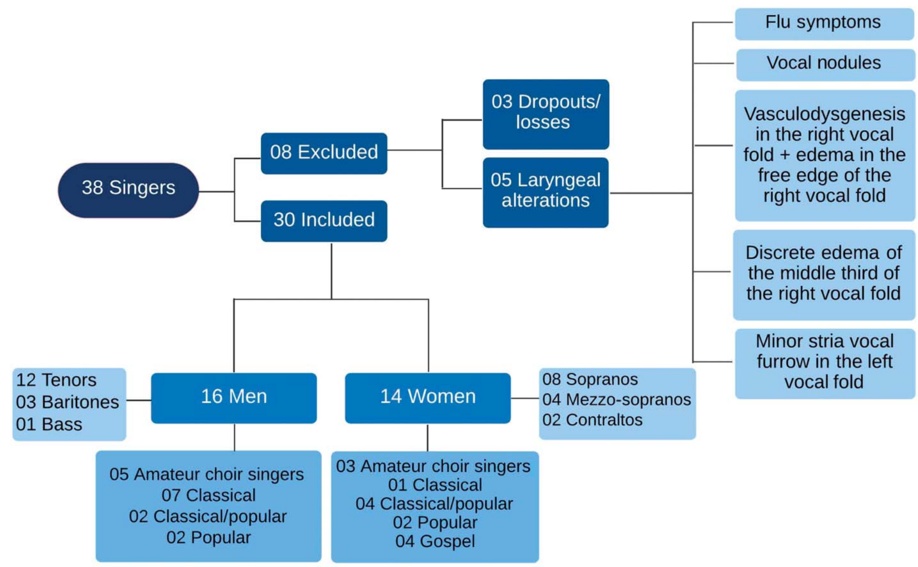
Data Collection and Recording

The vocal records were collected in an isolated, air-conditioned, silent room. The voices were recorded on an Intel Core i3-2348M notebook computer, using the Andrea Pure Audio USB-SA adapter for noise filtering and a Karsect HT-2 headset microphone, which was kept 4 cm away from the singer's mouth at an angle of approximately 45°. The sampling range was 44,100 Hz, and quantization was performed at 16 bits. Voices were recorded with Vocalgrama and VoxMetria software, manufactured by CTS, Inc.

Figure 3 shows the data collection and recording F3
procedure. The procedure involved the following steps:

1. Signing the informed consent form.
2. Videostroboscopy examination of the larynx.
3. Administering the questionnaire related to the participants' background, such as age, singing and training history, weekly singing hours, training in singing and musical style, and vocal complaints.
4. Recording of natural vocal productions of the vowel /ɛ/. Each participant produced the vowel /ɛ/ in the usual tone and volume for 5 s.
   This vowel was chosen because, in clinical practice of vowel spectrography in Brazilian Portuguese, /ɛ/ is considered to be less influenced by changes in the vocal tract and has significantly less harmonic attenuation for men and women, better representing the spectrum of the glottal source (D. M. D. R. Gonçalves et al., 2019). Furthermore, this vowel was suggested by the acoustic analysis program used in this study (CTS Informática, 2020a, 2020b).
5. VRP recording before performing the techniques, with participants producing the vowel /ɛ/ in ascending (from low to high) and descending (from high to low) orders with weak and strong intensities. As the participant produced the vowel /ɛ/ in ascending and descending glissando, the graph was marked with dots that corresponded to the frequency (abscissa) and intensity (ordinate) of the vocal productions. Figure 4 demonstrates the observations, F4
   with the light blue curve showing weak vocal signals (at the lowest possible volume) and the dark blue curve showing loud sounds (vocal signals at the most vigorous possible volume). The participants were asked to emit the loudest possible tone during the vocal productions of glissando. VRP vocal productions were extracted 3 times in order to choose the

Figure 1. Sample selection flowchart.



best VRP curve. Recordings were made, and the falsetto register was included in the vocal productions of glissando. Considering the possible unfamiliarity of the chorister with this type of vocal production, the recording was made twice to ensure reliable results. Therefore, the best VRP curve was considered for pretechnique values, according to the graph quality.

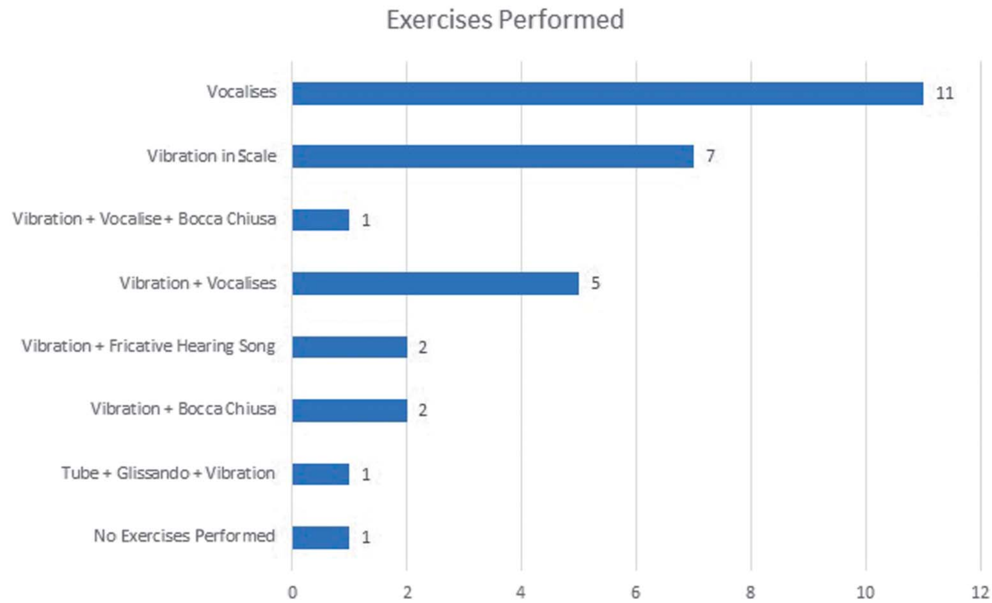
Table 1. Sample characterization based on the identification questionnaire (*n* = 30).

Information	***n***	**%**
Has had formal musical training	10	33
Has taken singing classes	21	70
Musical style	8	27
Amateur choir singers	8	27
Classical	6	20
Classical/popular	4	13
Popular	4	13
Gospel		
Performs vocal warm-up	13	44
Always	15	50
Sometimes	1	3
Rarely	1	3
No		
Has been advised concerning voice care	27	90
Has done voice therapy	7	23
Has voice-related complaints	10	33
Performs vocal cool-down	0	0
	***M* (*SD*)**	**Minimum–maximum values**
How long has been singing? (years)	10.63 (5.9)	1–25
Singing load (hours/week)	7 (7.46)	1–40

6. MPT registration. Participants were asked to produce a single prolonged vowel /ɛ/ to the maximum extent of their lungs.
7. Recording a song in VoxMetria (voice analysis). Participants were asked to choose a difficult song from their repertoire and sing it for 1 min. The degree of difficulty was at the singers' discretion, including difficulties in sustaining notes, producing treble or bass, and controlling their breath.
8. Random selection to determine the first technique to be used.
9. Performance of the technique for 3 min.
10. Posttechnique recording of participants' voices, as described in Items 4 through 7.
11. Applying the Borg Category Ratio 10-BR (CR 10-BR) Scale adapted for vocal effort (Camargo et al., 2019). Participants marked the perceived magnitude of effort made when singing the song they chose before and after the technique.

In order to obtain a satisfactory VRP, semitone vocal productions (note by note) require 30 min on average, which can be a lengthy and exhausting procedure. Therefore, glissando was used instead of semitone vocal productions. Glissando requires sliding the notes in comfortable high- and low-tone volumes and pitch for 3 min on average. Although the semitone vocal production procedure reflects the person's maximum vocal performance more accurately than a glissando, both produce similar results with acceptable differences among researchers and clinicians, with glissando resulting in less fatigue (Barrett et al., 2020; Hallin et al., 2012; Zraick et al., 2000).

Figure 2. Exercises most used by the singers in this study who perform vocal warm-up.



The second data collection condition comprised the following steps:

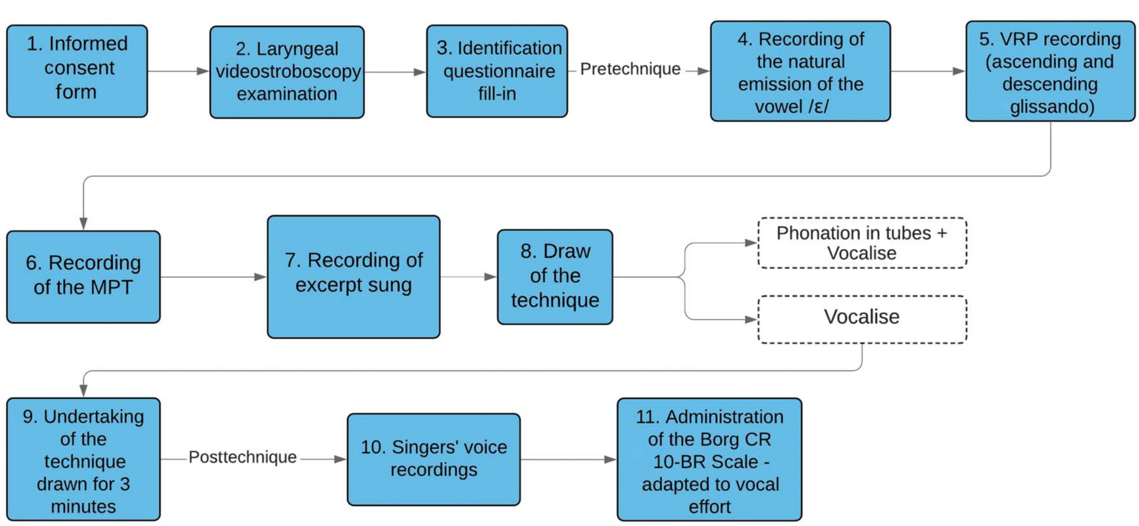
1. Voice recording, as described in Items 4 through 7 (pretechnique).
2. Performing the technique randomly selected for the second condition for 3 min.
3. Voice recording, as described in Items 4 through 7 (posttechnique).
4. Applying the Borg CR 10-BR Scale adapted for vocal effort (Camargo et al., 2019). Participants sang the same song in the same tone as in the previous recording.

Following this, the pretechnique application condition was recorded.

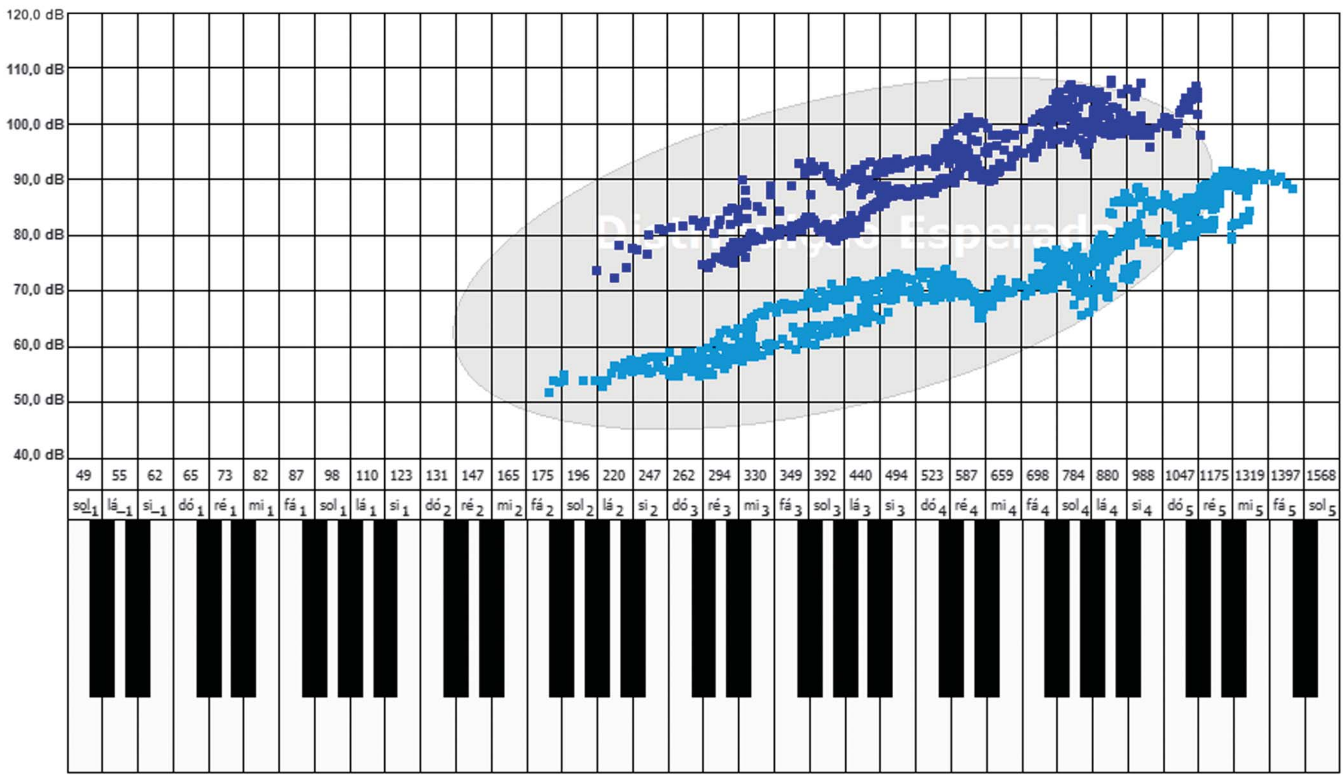
Vocalises

Participants produced the vowel /u/ for 3 min in pre-established melodic tonal variations, as described in Table 2. T2 Some methods suggest that singers should use open vowels in vocalise, as they favor a lighter vocal tone (Chaves, 2012).

Figure 3. Data collection procedure. VRP = vocal range profile; MPT = maximum phonation time; Borg CR 10-BR Scale = Borg Category Ratio 10-BR Scale.



AQ6 **Figure 4.** Graph obtained in Vocalgrama, with high-intensity (dark blue) and low-intensity (light blue) emissions.



However, /u/ was selected in this study, as it is more similar to the articulation posture of the exercise with the tube.

Tube Phonation

In the tube technique, the singer produced the vowel /u/ in ascending and descending vocalise, while avoiding inflating the cheeks during the performance and being visually controlled by the researcher. The silicone tube used in this technique was 35 cm long, 1 cm in diameter, and 2 mm thick. The tube was immersed in a plastic bottle containing water. The bottles had markings for water and tube immersion limits. The distal end of the tube was 7 cm from
F5 the surface of the water (see Figure 5). The tube technique was performed with the overload principle (Borg, 1982; Guzmán et al., 2016, 2018; Tyrmi & Laukkanen, 2017; Vayano & Badaró, 2010), utilizing the principle of increased
AQ8 force with the tube immersed deep into the water.

Table 2. Tone ranges and the corresponding voice types (adapted
AQ7 from Cobeta et al., 2013).

Sequence	Voice type	Range
1	Soprano	G2–E5
2	Mezzo-soprano	E2–A4
3	Contralto	C2–G4
4	Tenor	G1–C4
5	Baritone	E1–A3
6	Bass	C1–F3

Execution of Techniques

The melodic sequence of the vocalise scales was the same for the two conditions (with and without phonation in tubes). To this end, six piano sequences were prerecorded (one for each voice type: soprano, mezzo-soprano, contralto, tenor, baritone, and bass; see Appendixes A–G), as shown AQ9
in Table 2. Each participant's sequence was determined according to their voice type as established by their conductor or singing teacher.

Therefore, each participant performed the exercises with one of the sequences for 3 min for each condition. The 3-min time was indicated by previous SOVTE studies as the minimum time required for exercises (Azevedo et al., 2010; Menezes et al., 2005, 2011; Moreira & Gama, 2017).

All exercises were performed according to the participants' comfort level. Although participants were instructed to stop the exercise should they notice any signs of discomfort, none found this necessary. No control over the voice register used was exercised; hence, it varied based on each participant's vocal range, including falsetto registers. Voice was always produced in legato.

Figure 6 shows Measures 1–7 of the mezzo-soprano F6
vocalise score as an example. Participants performed short phonations (in blue) in three ascending and three descending tones, rising a semitone at a time, as shown in the example, until reaching the maximum note established for their voice type. Following this, they reversed the sequence, descending a semitone at a time, until they reached the

Figure 5. Implementation of tube exercises and tube depth in the water.

A = Performing exercises with flexible tube in water
B = Immersion of the tube to the marked lower limit
1 = Water limit
2 = Distal portion of the tube

lowest limit set for their case. The part of the measure marked in red was for participants to pause briefly and breathe before resuming vocal productions in the following measure, one semitone above the previous vocal productions, as shown in the score. Each measure was performed for approximately 2 s, whereas the pause lasted approximately 1 s. Altogether, the sequences lasted 3 min. Therefore, each participant performed a single sequence corresponding to their voice type for 3 min.

Data Analysis

All recordings were analyzed in Vocalgrama and VoxMetria. Vocalgrama was used for minimum and maximum f0, f0 extension, semitone extension, minimum and maximum intensity, VRP, and MPT. VoxMetria was used for f0, standard deviation of f0 (SDf0), jitter, shimmer, GNE, and noise. The sustained vowel audios recorded in VoxMetria were extracted and imported into the Praat program to calculate the CPPS. The values were tabulated in an Excel spreadsheet to calculate the means and standard deviations.

The normality of the groups was analyzed with the Shapiro–Wilk test, rejecting the hypothesis of normal distribution for $p < .05$. The repeated-measures analysis of variance (ANOVA) was used, with two factors: technique (tube and scale) and time (pre- and postapplication of the technique). Owing to the nonnormality of all data, normality transformations were conducted so that the assumptions of the repeated-measures ANOVA were adequate for the data. The significance level was 5% ($p \leq .05$).

Results

Tables 3–5 show the results of the repeated-measures ANOVA. The dependent variables were f0, SDf0, jitter, shimmer, GNE, and noise (see Table 3); MPT, Borg CR 10-BR score, and CPPS (see Table 4); and minimum f0, maximum f0, extension f0, extension in semitones, minimum intensity, maximum intensity, and area (see Table 5). The factors were technique (T1 = tube technique combined with vocalise; T2 = vocalise alone) and time (pre- and posttechnique). In this study, we evaluated the relationship between the vocal techniques (T1 and T2), analyzing the periods before and after their application. T3 T4 T5

Table 3 shows the results of the acoustic evaluation using the VoxMetria program, with sustained vocal production values before and after performing each technique. Figure 7 shows the graphs of the interactions and intervals for the dependent variables complementing the results presented in Table 3. The repeated-measures ANOVA yielded shimmer as a significant variable for the technique factor ($p = .021$); that is, when comparing the acoustic variables, considering only the applied technique, there was a difference in shimmer values between the tube and vocalise conditions. F7

Therefore, based on the knowledge that the mean of shimmer values at T1 was lower than the mean of shimmer values after T2 (see Table 3), it is inferred that T1 promoted better results for this parameter. For the time factor, the variables f0 ($p = .028$), SDf0 ($p = .044$), and jitter ($p = .008$) were significant. In other words, for these variables, considering only the situations before and after application of the technique ("time" factor), there was a difference in postapplication values compared to preapplication values. Considering that the postapplication means were

Figure 6. Cutout of the score measures used in the vocal exercises. In blue: runtime; in red: break time.

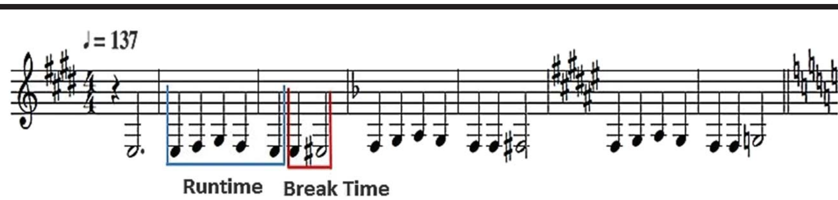


Table 3. Mean (standard deviation) of the sustained emission acoustic measures before and after the two techniques.

	T1 (n = 30)		T2 (n = 30)	
Variable	**Before**	**After**	**Before**	**After**
f0 (Hz)	162.88 (42.77)	170.97 (41.28)	164.84 (46.73)	169.00 (43.52)
SDf0 (Hz)	3.43 (10.29)	1.24 (0.41)	1.43 (0.70)	1.52 (1.76)
Jitter (%)	0.16 (0.07)	0.12 (0.06)	0.20 (0.26)	0.21 (0.35)
Shimmer (%)	2.82 (1.32)	2.18 (0.58)	3.04 (1.10)	3.34 (2.88)
GNE	0.89 (0.10)	0.92 (0.07)	0.90 (0.09)	0.89 (0.11)
Noise	0.71 (0.40)	0.56 (0.31)	0.63 (0.28)	0.69 (0.45)

Note. T1 = tube technique combined with vocalise; T2 = vocalise alone; f0 = fundamental frequency; SDf0 = standard deviation of fundamental frequency; GNE = glottal-to-noise excitation ratio.

better than the preapplication means (see Table 3), it is inferred that the techniques had positive effects on acoustic parameters.

Overall, at T1, there was an increase in f0 and a decrease in SDf0 and jitter. As for the time and technique interaction, shimmer (p = .027) and noise (p = .048) were significant. Table 3 shows that shimmer and noise decreased after applying this technique.

Figure 7 depicts the interaction graph with variable intervals, complementing the results shown in Table 3. The interactions are interpreted as follows: The less parallel the lines, the greater the interaction. Furthermore, superimposed intervals, that is, one contained within the other, indicate the absence of a significant difference between the conditions of a given factor. As seen in Figure 7, noise and shimmer had a significant association with the interaction between technique and time (pre and post). Thus, both techniques can be considered statistically different. In addition, there was an expressive reduction for the technique with the tube. The ranges did not overlap, confirming that there was a difference between the techniques.

Table 4 presents the results of the MPT assessed by Vocalgrama, Borg CR 10-BR Scale score, and cepstral measurements, and Figure 8 provides graphs of the interactions and intervals for the dependent variables, complementing the results in Table 4. The repeated-measures ANOVA demonstrated the significance of time for the variables CPPS (p = .005) and Borg CR 10-BR Scale score (p = .000) and the significant interaction between time and technique for three variables: Borg CR 10-BR Scale score (p = .002), MPT (p = .028), and CPPS (p = .046). The inference is that, when choosing a specific technique, there will be a significant difference in the value of the variables before and after applying the technique. A decrease in the values of the Borg CR 10-BR Scale and an increase in CPPS after the techniques were observed, along with an increase in the MPT after the technique with tubes. This can be understood based on the difference in the slopes of the lines of the interaction graph (see Figure 8).

F8

Table 5 presents the VRP with the overall summary of the parameters resulting from the ascending and descending glissando found with Vocalgrama. Figure 9 shows the graphs of the interactions and intervals for the dependent variables complementing the results presented in Table 5. An increase was only found in the maximum frequency postexercise (p = .020), with no differences between the techniques. Note that both techniques showed an increase in this parameter. However, singers who used the tube technique had a higher maximum frequency value see.

F9

Discussion

Chromatic (as in this study) and nonchromatic warm-up vocalises with vowels in ascending and descending scales (sequence of notes) assist a singer's technical development and promote stretching (in ascending scales) and contraction (in descending scales) of the vocal folds (Guzman et al., 2020). Phonation performed with tubes immersed in water

AQ10

Table 4. Mean (standard deviation) of maximum phonation time (MPT), Borg score, and smoothed cepstral peak prominence (CPPS) before and after the two techniques.

	T1 (n = 30)		T2 (n = 30)	
Variable	**Before**	**After**	**Before**	**After**
MPT (s)	15.44 (4.29)	16.81 (4.66)	16.07 (3.64)	15.58 (3.99)
Borg	1.70 (1.14)	0.80 (0.94)	1.62 (1.13)	1.25 (1.22)
CPPS	16.74 (1.92)	17.69 (1.97)	16.90 (2.28)	17.06 (2.50)

Note. T1 = tube technique combined with vocalise; T2 = vocalise alone; Borg = Borg CR 10-BR Scale (adapted for vocal effort).

Table 5. Mean (standard deviation) of the voice range profile before and after the two techniques.

	T1 (*n* = 30)		T2 (*n* = 30)	
Variable	**Before**	**After**	**Before**	**After**
Minimum f0 (Hz)	108.58 (29.62)	108.03 (31.07)	108.33 (30.59)	110.49 (28.97)
Maximum f0 (Hz)	918.96 (267.16)	955.55 (256.11)	907.60 (265.28)	909.29 (284.06)
Extension f0 (Hz)	807.37 (245.15)	824.18 (276.204)	797.77 (247.42)	798.80 (269.12)
Extension in St (st)	36.95 (3.74)	37.87 (4.37)	36.75 (4.19)	36.31 (4.56)
Minimum intensity (dB)	61.45 (7.79)	60.83 (7.29)	60.61 (6.91)	59.89 (7.74)
Maximum intensity (dB)	102.64 (6.76)	96.32 (24.82)	102.79 (8.10)	102.32 (7.60)
Area (%)	9.03 (2.52)	9.30 (2.63)	8.95 (2.53)	9.04 (1.87)

Note. T1 = tube technique combined with vocalise; T2 = vocalise alone; f0 = fundamental frequency; St = semitones.

balances the muscles that participate in voice production, promoting a more economical vocal production and modifying the vibratory pattern of the vocal folds through the return of acoustic energy (Portillo et al., 2018; Simberg & Laine, 2007).

The results of this study indicate that vocalise exercise may be enhanced by incorporating a flexible tube immersed in water. It is known that deeper immersion results in greater vocal load (Guzmán et al., 2018; Tyrmi & Laukkanen, 2017). This principle is used to improve a singer's vocal conditioning to facilitate vocal preparation for better performance (Caetano, 2018). The participants in this study did not show signs of hyperfunctionality on laryngeal examination, suggesting that the principle of overload could be used in this group.

This study used the same participants for both techniques to minimize differences between groups. Participants' similarity prior to the exercises was tested to ensure that technique type and interval between the two conditions did not influence the results.

As Table 3 shows, f0 increased with techniques post-exercise. This can be attributed to the range of tones performed at high frequencies (high tones) during vocalises (Maia et al., 2012). In addition to the range of tones, the rise in f0 with T1 can be explained by a possible rise in subglottic pressure, verified after performing phonation with tubes (Tyrmi & Laukkanen, 2017). Figure 7 shows an overlap of intervals in the graphs. Therefore, no difference was found between the techniques for this variable.

Regarding the decreasing SDf0, both techniques can be inferred to promote phonatory stability from a physiological perspective. The SDf0 is directly linked to the neuromuscular condition and the vibratory regularity of the vocal fold cover. Higher SDf0 values may indicate phonatory instability and irregularity of vocal fold vibration, causing a deviation in vocal production (Travieso et al., 2013; Van Houtte et al., 2011). The SDf0 after both techniques was below 2 Hz.

As the participants were singers without laryngeal disorders, the jitter, shimmer, GNE, and noise values were according to the VoxMetria normality standards pre- and

Figure 7. Graph of the interactions and intervals for the dependent variables fundamental frequency (f0), standard deviation of f0 (SDf0), jitter, shimmer, glottal-to-noise excitation ratio (GNE), and noise. T1 = tube technique combined with vocalise; T2 = vocalise alone.

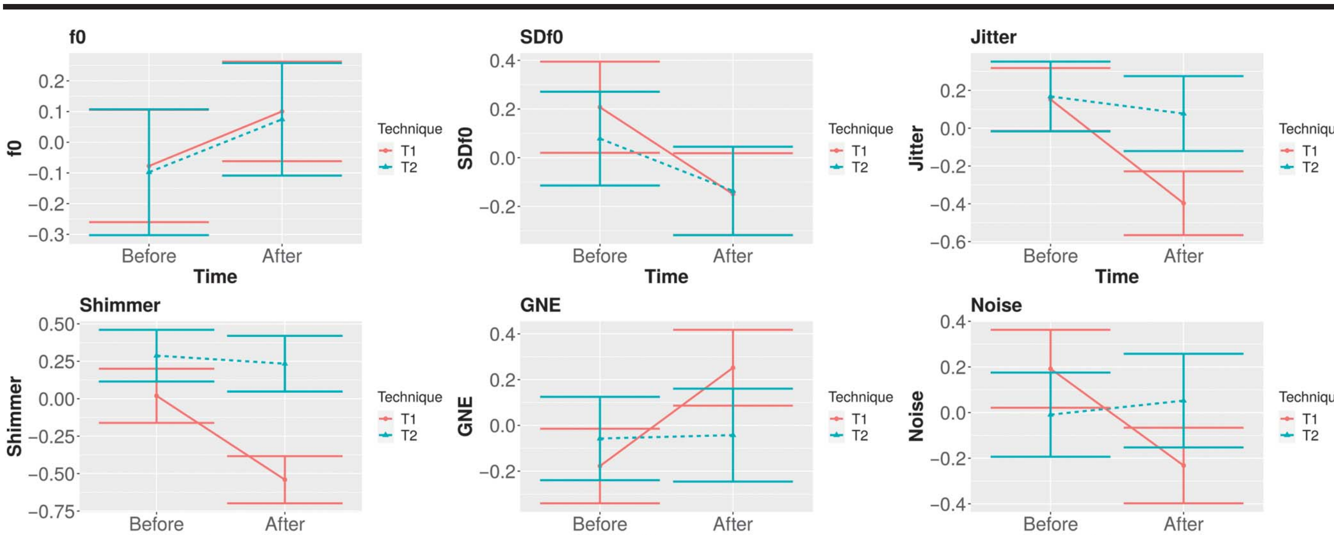
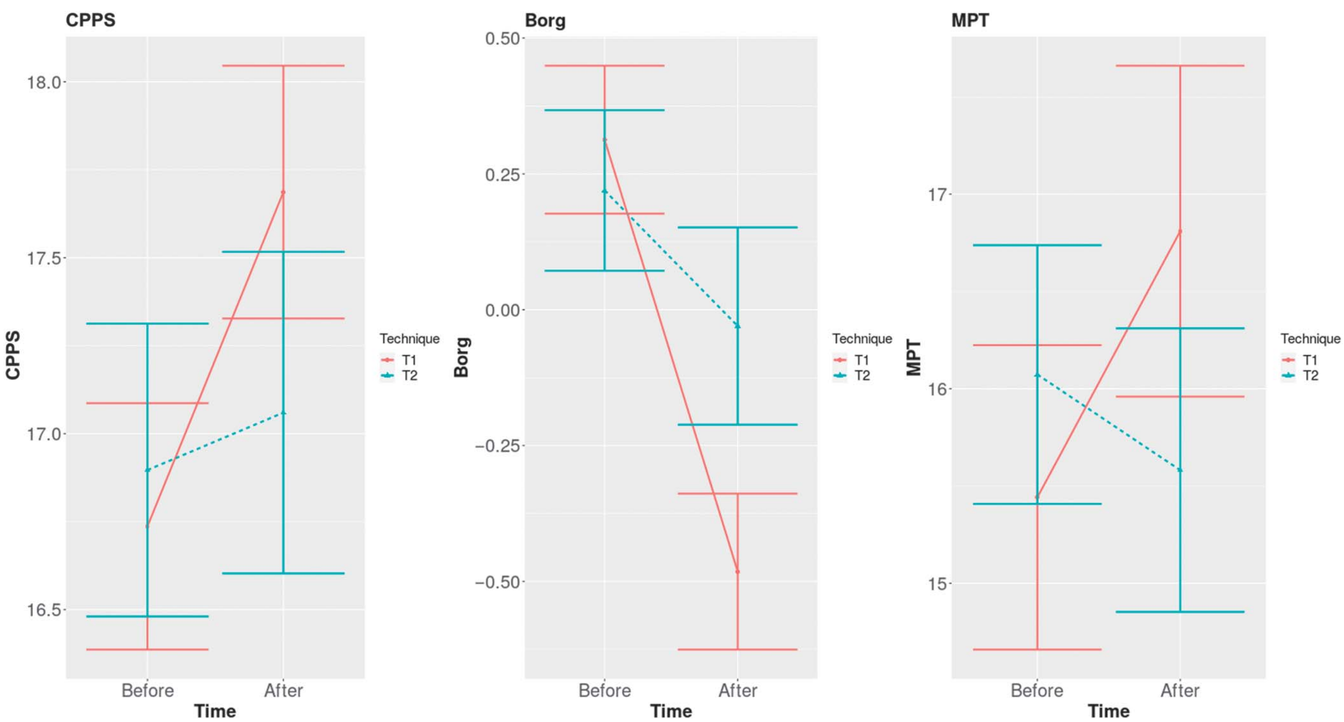
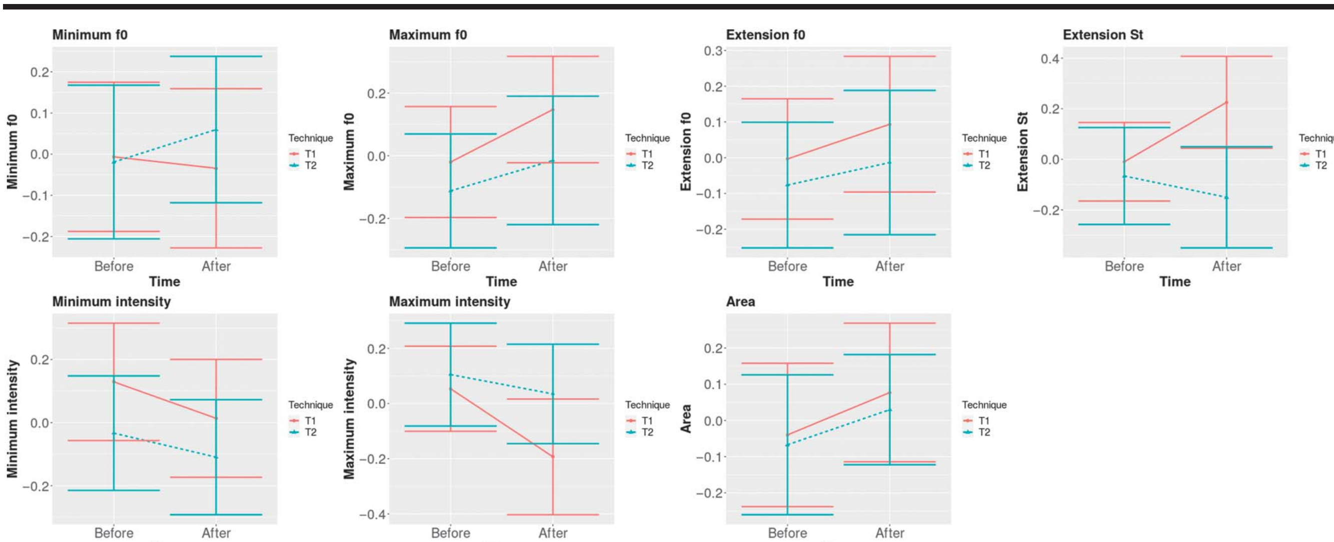


Figure 8. Graph of the interactions and intervals for the dependent variables smoothed cepstral peak prominence (CPPS), Borg score, and maximum phonation time (MPT). T1 = tube technique combined with vocalise; T2 = vocalise alone.



postexercise. A reduction in jitter with Technique 1 indicates a possible improvement in vibratory regularity postexercise (Guzmán et al., 2012). Likewise, a reduction in shimmer after Technique 1 may indicate a potential improvement in glottic adjustment, with an increase in glottic resistance, concerning the approach of the vocal folds (decreasing the excessive passage of air in the form of noise) and the stabilized tension of the vocal muscle (thyroarytenoid). The possible increased activation of the cricothyroid muscle observed with the rise in f0 during ascending exercise

Figure 9. Graph of the interactions and intervals for the dependent variables minimum fundamental frequency (f0), maximum f0, extension f0, extension in semitones (St), minimum intensity, maximum intensity, and area. T1 = tube technique combined with vocalise; T2 = vocalise alone.



likely improved stability rather than increasing vocal stress, as there was an improvement in shimmer and muscle performance favoring the aerodynamics and biomechanics of AQ11 voice production (Corazza et al., 2004; Lopes et al., 2017; Verde et al., 2018).

There were differences between the two techniques postexercise. After Technique 1, participants had lower shimmer and noise values, indicating that phonation with tubes combined with vocalise produced better results than vocalise alone. The benefits of objective measures of acoustic analysis (see Table 3) confirm that phonation with tubes balances the muscles that participate in voice production, aerodynamics, and biodynamics, promoting more economical vocal production, more regular vibration, and more energy (Simberg & Laine, 2007).

As demonstrated in Table 4 and Figure 8, increases in MPT postexercise for Technique 1 were found. MPT is commonly used in speech therapy to determine vocal efficiency and verify the effects of vocal techniques (Cielo, Frigo, & Christmann, 2013). MPT allows ascertainment of the ability of the glottis to remain closed; therefore, an insufficient vocal fold approach can reduce MPT (Galdino & Souza, 2017). Singers generally develop respiratory control for efficient respiratory management, which is related to appropriate vocal productions. Thus, the tube techniques associated with vocalises seem to promote an immediate effect for individuals who frequently train their breathing patterns (Sundberg & Thalén, 2015). This supports the argument that MPT can be improved in healthy populations after performing SOVTE (Brockmann-Bauser et al., 2020; Cielo, Frigo, & Christmann, 2013).

Cepstral analysis, widely used to characterize dysphonic voices at different intensities, proved efficient in comparing pre- and posttechnique performance in healthy voices. CPPS values were higher after both techniques, although Technique 1 showed better results (see Table 4) and a significant time–technique interaction. Therefore, the tube technique improved the harmonic organization of the voice, which stood out in relation to the noise level (Balasubramanium et al., 2015). CPPS is considered the main measure to assess vocal quality and noise quantity (Patel et al., 2018), capable of differentiating individuals with and without vocal quality deviation, with higher values in the latter group (Lopes et al., 2019). This study utilized this analysis on a population with no vocal deviations. The results showed that cepstral research is useful in identifying the effects of vocal techniques in unaltered voices.

A previous study verified the impact of stress on the vocal fold in three cases: /u/ phonation without a tube, phonation with a tube immersed 2 cm into water, and phonation with a tube immersed 10 cm into water. The results showed increased oral and subglottic pressure values. The lowest values were measured for /u/ phonation, whereas the highest values were for phonation with a tube immersed 10 cm into water. Finally, it was concluded that water resistance reduces the impact on the vocal folds, making tube phonation less stressful than ordinary phonation (Horáček et al., 2019). This is in line with the findings of this study. The more economical phonation in tubes was more beneficial to the participants' voices than vocalise phonation of /u/ without a tube.

On the other hand, phonation in immersed tubes may cause fatigue in the adductor muscles if the exercise is excessively long and the water resistance is too high (through a more deeply immersed tube). Therefore, in clinical practice, brief phonations are recommended (Horáček et al., 2019), as in this study.

Each exercise was performed for 3 min. Studies of vocal warm-ups have reported an average exercise time of 5–30 min, depending on a singer's requirements, with 5–10 min being the most common (Aydos & Hanayama, 2004; Gish et al., 2012; Quintela et al., 2008). This suggests that vocalise may require more than 3 min to reach a satisfactory result. The time and type of warm-up and vocal training vary between people and cannot constitute a pre-established routine, requiring constant consideration of a singer's voice. The shorter the performance, the greater the warm-up, and vice versa (Quintela et al., 2008). In contrast, the 3-min phonation exercise with tubes utilizing the overload principle in this study showed a significant improvement in acoustic parameters.

Although the data from this study indicate positive acoustic results, the principle of biological individuality must be considered. Even in a homogeneous group with similar characteristics, individuals have specific muscle needs and abilities (Lussac, 2008). For this reason, the participants answered the Borg CR 10-BR Scale, adapted for vocal effort, to assess their perceptions regarding the proposed exercises.

The participants reported feeling less vocal strain after performing both techniques (see Table 4). Statistical analyses showed a difference between the methods (see Figure 8). After tube phonation combined with vocalise, the singers reported less effort than with vocalise alone. Self-perception assessment is an essential factor because it is difficult for a person to adhere to a method that causes discomfort. The sense of effort is subjective and can be perceived differently from singer to singer (Camargo et al., 2019).

It can be inferred that vocalise promotes efficient voice production but not necessarily vocal economy. Subjective vocal effort data reported by the participants confirmed the objective results. Tube phonation can be useful as both warm-up and vocal training for singers who wish to achieve an efficient vocal system and prepare for demanding vocal performances (Kang et al., 2019; Portillo et al., 2018; Saldías et al., 2020).

Maximum frequency increased for participants who performed the techniques (see Table 5). Therefore, it is possible that when producing the high-pitched sounds of the scale, the cricothyroid muscle, which is responsible for the longitudinal tension of the vocal fold, was more activated. The combination of techniques seems to have facilitated more significant contraction of this muscle, which, in turn, increased the range of high tones (Cardoso et al., 2020; Maia et al., 2012), considering that the highest values were found in Technique 1. Apart from the increase in maximum frequency, no improvements were observed in VRP parameters.

In past studies, singers who performed phonation with tubes at 3 cm below the water surface combined with ascending and descending glissandos for 3 min each, totaling 6 min, showed changes in more VRP parameters in addition to the increase in maximum frequency, such as extension in hertz and semitones and reduction in minimum frequency in men (Cardoso et al., 2020). These results suggest improved vocal flexibility compared with this study.

The other VRP parameters could be related more to longer training with less load compared to training with overload (Baechle & Westcott, 2013; Nasser & Neto, 2017). The most significant gains in both strength and resistance vocal muscle training are predominantly associated with neural and metabolic adaptations (Vayano & Badaró, 2010). Further studies are needed to verify this difference. VRP appears to be a sensitive assessment method to detect improvements in voice after a period of vocal therapy and training. Singers with professional experience had positive effects on the VRP after 10 weeks of training with a functional vocal exercise program (Guzman et al., 2020).

Although the exercises in this study favored strength and resistance more than flexibility, it was observed that there was an increase in the maximum frequency in T1 whereas there was no change in T2. Thus, strength training does not appear to harm flexibility (VRP); considering that resistance is the muscle's ability to generate strength and power over an extended period, strength and resistance training are not mutually exclusive (Wilmore et al., 2010). However, as the overload principle and the types of exercise are not yet fully understood for voice, long-term research is necessary to clarify some concepts (Vayano & Badaró, 2010).

Both warm-ups, the physiological (flexible tube in water) and the artistic, for technical improvement (vocalise) are essential and complementary rather than mutually exclusive. Thus, the two techniques were combined in this study. It was observed that the flexible tube in water combined with vocalise optimized the exercise time, as it promoted better vocal conditions than did the same time performing vocalise alone. As most singers use a longer vocal preparation time, an artistic warm-up for technical improvement should be preceded by a physiological warm-up to prepare the muscles, promote better vocal economy, and avoid fatigue (Behlau et al., 2014; Kang et al., 2019; Portillo et al., 2018).

It is necessary to investigate the magnitude and duration of a given exercise to avoid overloading the phonatory system to the point of generating vocal fatigue. In addition, immediate effects need to be identified in different populations for confident and safe professional use of the vocal techniques to improve or rehabilitate the voice (Caetano, 2018).

The results of this study indicate that a deeply immersed flexible silicone tube combined with vocalise for 3 min improved vibration regularity; increased glottal resistance, vocal energy, and efficiency; improved the harmonic organization of the voice (which stood out in relation to the noise level); and balanced the muscles that participate in voice production, promoting more economical and regular vocal production. In addition, the participants reported less perceived effort after both techniques, although the phonation with tubes caused less perceived vocal effort than vocalise alone.

The participants indicated vocalise as their main vocal warm-up strategy (see Figure 2), which is in line with previous studies (Gish et al., 2012; Lopes de Araújo et al., 2014). However, phonation with tubes combined with vocalise optimized the results within a short performance time. As phonation with tubes produced more immediate results and prepared the phonatory system for better voice production while preventing vocal fatigue, it should be performed before technical/artistic improvement exercises.

Study Limitations

This study had some limitations. First, the study used nonprobabilistic snowball sampling by convenience. However, this study had a quasi-experimental before-and-after design. Quasi-experimental studies, in general, are exploratory in the sense of verifying potential cause-and-effect relationships between an intervention and its effect. These studies are usually followed by a randomized clinical trial (Alsaggaf et al., 2018). We chose a quasi-experimental design in order to increase the ecological validity of the study, approximating real conditions. The study was able to test the hypothesis presented, raise pertinent questions for future research, and highlight considerations for future theoretical arguments on the subject.

Second, the study did not control the interval between recording sessions owing to scheduling limitations. As pre-evaluations were conducted before both recordings and the study focused on the immediate effect, we believe that this limitation is not significant.

Third, the study did not control intensity during the sustained vocal productions of the vowel /ɛ/ measured by a decibel meter. The intensity of vocal productions influences the extracted values, with high intensity achieving better results. Thus, lower intensities, which require better respiratory and laryngeal control, are useful for monitoring clinical evolution. Vocal productions in this study were at the usual loudness, which was subjectively controlled by the evaluator, and all participants were comfortably able to carry them out in a sustained manner. Future studies should evaluate three vocal production intensities: weak (60–70 dB), habitual (70–80 dB), and strong (above 80 dB).

Finally, this study did not examine differences by vocal style and gender. Future research with larger samples should investigate these differences and observe adjustments, vocal demands, and technical standards.

Conclusions

Differences were observed between the two techniques applied. Tube phonation combined with ascending and descending vocalise reduced shimmer and noise and increased CPPS and MPT. In addition, flexible silicone tubes combined with vocalise had better results for maximum f0, SDf0, and CPPS compared to vocalise alone. Furthermore, participants reported reduced perceived effort after performing both techniques, with vocalise combined with tube phonation demanding less perceived vocal effort than vocalise alone.

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Appendix A

Borg Scale CR10-BR Adapted for Vocal Effort

BORG SCALE CR10-BR ADAPTED FOR VOCAL EFFORT

Camargo MRMC, Zambon F, Moreti F, Behlau M. Translation and cross-cultural adaptation of the Brazilian version of the Adapted Borg CR10 for Vocal Effort Ratings CoDAS 2019;31(5):1-5. DOI: 10.1590/2317-1782/20192018112

Adapted from: Baldner, E. F., Doll, E., & van Mersbergen, M. R. (2015). A review of measures of vocal effort with a preliminary study on the establishment of a vocal effort measure. Journal of Voice, 29(5), 530-541. https://doi.org/10.1016/j.jvoice.2014.08.017

Full name:____

D.B.:___/___/___

Date:___/___/___

Check the number that corresponds to the intensity of the voice effort after completing the requested task:

INTENSITY	**SCALE**
No vocal effort at all	0
Very very slight vocal effort (just noticeable)	0,5
Very slight vocal effort	1
Slight vocal effort	2
Moderate vocal effort	3
Somewhat severe vocal effort	4
Severe vocal effort	5
	6
Very severe vocal effort	7
	8
Very very severe vocal effort (almost maximum)	9
Maximum vocal effort	10

Appendix B (p. 1 of 2)

Sequence Baritone

Sequence Baritone

Appendix B (p. 2 of 2)

Sequence Baritone

Appendix C (p. 1 of 2)

Sequence Bass

Sequence Bass

Appendix C (p. 2 of 2)

Sequence Bass

Appendix D (p. 1 of 2)

Sequence Contralto

Sequence Contralto

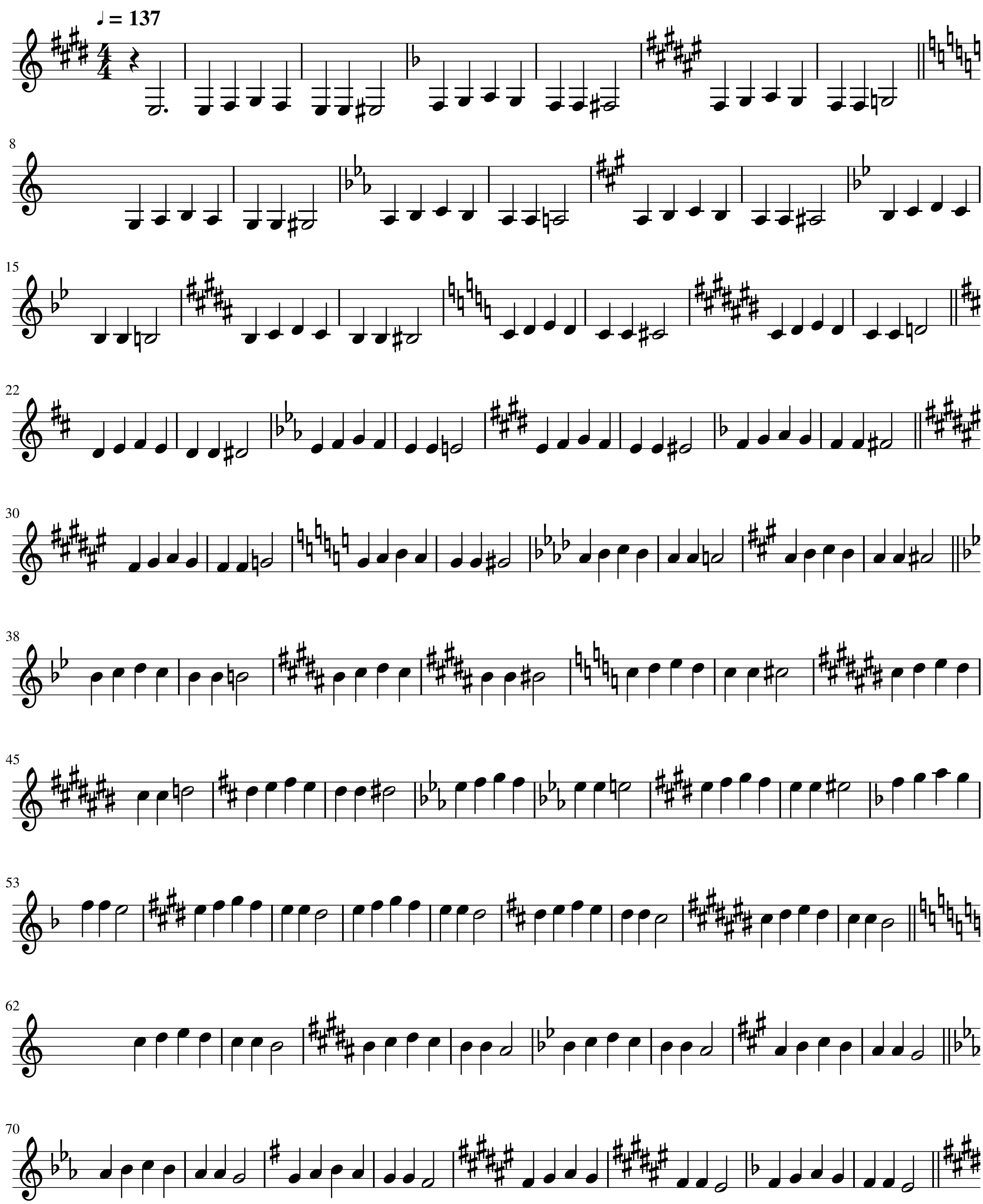
Appendix D (p. 2 of 2)

Sequence Contralto

Appendix E (p. 1 of 2)

Sequence Mezzo-Soprano

Sequence Mezzo-Soprano



Appendix E (p. 2 of 2)

Sequence Mezzo-Soprano

Appendix F (p. 1 of 2)

Sequence Soprano

Sequence Soprano

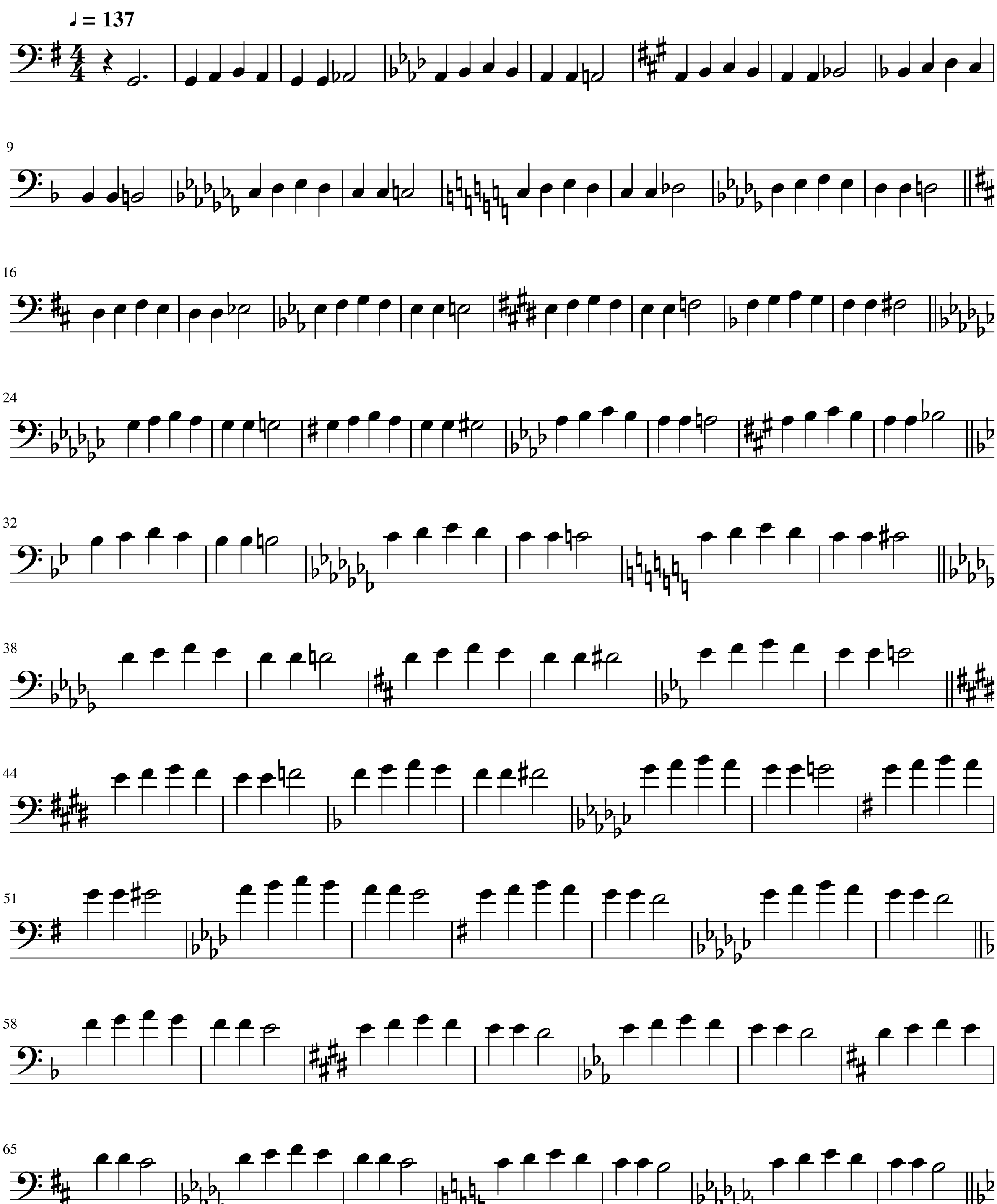
Appendix F (p. 2 of 2)

Sequence Soprano

Appendix G (p. 1 of 2)

Sequence Tenor

Sequence Tenor



Appendix G (p. 2 of 2)

Sequence Tenor

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