Comparison of Effects Produced by Physiological Versus Traditional Vocal Warm-up in Contemporary Commercial Music Singers

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Summary: Purpose. The present study aimed to observe whether physiological warm-up and traditional singing warm-up differently affect aerodynamic, electroglottographic, acoustic, and self-perceived parameters of voice in Contemporary Commercial Music singers.

Methods. Thirty subjects were asked to perform a 15-minute session of vocal warm-up. They were randomly assigned to one of two types of vocal warm-up: physiological (based on semi-occluded exercises) or traditional (singing warm-up based on open vowel [a:]). Aerodynamic, electroglottographic, acoustic, and self-perceived voice quality assessments were carried out before (pre) and after (post) warm-up.

Results. No significant differences were found when comparing both types of vocal warm-up methods, either in subjective or in objective measures. Furthermore, the main positive effect observed in both groups when comparing pre and post conditions was a better self-reported quality of voice. Additionally, significant differences were observed for sound pressure level (decrease), glottal airflow (increase), and aerodynamic efficiency (decrease) in the traditional warm-up group.

Conclusion. Both traditional and physiological warm-ups produce favorable voice sensations. Moreover, there are no evident differences in aerodynamic and electroglottographic variables when comparing both types of vocal warm-ups. Some changes after traditional warm-up (decreased intensity, increased airflow, and decreased aerodynamic efficiency) could imply an early stage of vocal fatigue.

Key Words: Semi-occluded vocal tract–Tube phonation–Singing voice–Warm-up–Aerodynamics.

INTRODUCTION

Although most singers and singing teachers agree on the importance of vocal warm-up before performing, there is no clear evidence to date regarding objective physiological effects that these voice exercises produce. Moreover, literature provides a wide variety of exercises that can be used as vocal warm-up.

Following Behlau, warm-up exercises can be classified into two different groups: (1) physiological and (2) technical or artistic vocal warm-up.[1] The latter is usually taught by singing teachers, and its purpose is to prepare technical aspects such as voice placement, breath support, and vocal timbre. For purposes of the present study, technical warm-up will be labeled traditional vocal warm-up. On the other hand, physiological warm-up is commonly provided by speech-language pathologists working with professional voice users. The goal of this type of warm-up is to prepare adequate physiological conditions of the phonatory system to avoid vocal fatigue during or after performance.[1] Several voice rehabilitation exercises could be used as physiological warm-up, one of the most commonly implemented being semi-occluded vocal tract exercises (SOVTE).

SOVTE are widely used in voice rehabilitation and voice training. This group of exercises is characterized by postures of vocal tract that include anterior constrictions (eg, lip buzz, lip trills, tongue trills) and artificial lengthening such as tube phonation with the distal end either in the air or into a recipient filled with water. Several benefits have been attributed to this type of exercises, such as an increase in vocal tract inertive reactance,[2–6] which may be favorable to voice production by decreasing the phonation threshold pressure (PTP)[5] and increasing skewing of the glottal flow waveform (faster cessation of the flow).[4,5] Increased skewing strength energy of higher spectral harmonics and, this in turn, should lead to a more resonant and economic voice production. An increased oral pressure and, consequently, an elevation of the intraglottal pressure[7,8] and subglottic pressure (Psub)[9–11] have also been reported during semi-occlusions. Several studies have also reported a change in the relative contact time of the glottis (contact quotient [CQ]) when semi-occlusion is compared with vowel phonation.[11–19] Variations of CQ are dependent on the type of SOVTE.[19] Outcomes related to changes on vocal tract shape as an effect of SOTVE have also been reported in the literature.[20–25]

Previous research has been conducted to compare the acoustic effect of different SOVTE versus traditional vocal warm-up. Most studies have used spectral measures by using long-term average spectrum.[26–28] A recent study aimed to explore the impact of traditional singing vocal warm-up compared with SOVTE (phonation into a plastic drinking straw) on voice spectrum, and perceived phonatory effort showed that warm-up exercises did not significantly affect either spectral characteristics or perceived phonatory effort by subjects.[26] A case-control investigation conducted by Guzman et al[27] compared the

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effect on spectral slope declination of traditional warm-up and vocal function exercises (VFE) (voice exercise program that uses some types of SOVTE) in vocally normal Contemporary Commercial Music (CCM) singers. Significant changes after practice were observed on alpha ratio (increase) and singing power ratio (increase) in speaking voice, and singing power ratio (increase) for VFE group in the singing voice.[27] The traditional vocal warm-up also showed pre-post changes for alpha ratio (increase). Moreover, significant differences between the VFE group and the control group for alpha ratio and singing power ratio were found in speaking voice samples (greater pre-post difference for VFE). Therefore, it is possible to assume that VFE produced a greater positive effect than traditional singing warm-up on the spectral slope declination in speaking voice analysis.[26] Acoustic effect of vocal warm-up with SOVTE in dysphonic teachers has also been assessed. Spectral tilt was measured after straw phonation exercises compared with vocal exercises with open vowel [a:]. The results showed that voice exercises with straw may have positive immediate acoustic effects (Guzman et al).[28]

To date, no studies have been conducted to compare the possible differential effect of traditional versus physiological vocal warm-ups using aerodynamic and electroglottographic (EGG) measures in CCM singers. The question that motivates the present research is "Are there objective and/or subjective differences between physiological vocal warm-up (based on SOVTE) and traditional singing warm-up?" Therefore, the present study aimed to observe whether physiological warm-up using SOVTE and traditional singing warm-up differentially affect the aerodynamic, EGG, acoustic, and self-perceived parameters of voice in CCM singers.

Based on previous studies on SOVT exercises, we hypothesize that physiological vocal warm-up including SOVT exercises should lead to a more economic voice production if compared with traditional vocal warm-up (using an open vocal tract configuration). Specifically, physiological warm-up method should be expected to produce a greater perceived resonant voice quality compared with traditional warm-up. Moreover, objective measures should reflect a more economic voice production after physiological warm-up by increasing acoustic output and decreasing laryngeal effort (eg, lower CQ and lower Psub).

METHODS

Participants

A total number of 30 CCM singers were included in this study. CCM is used to denote nonclassical music. This term was created to include singing styles such as music theater, pop, rock, gospel, R&B, soul, hip-hop, rap, country, folk, experimental music, and any other styles not considered classical.[29]

Subjects were randomly assigned to two groups: an experimental group (n = 15) and a control group (n = 15). The total sample included 18 female participants (nine for each group) and 12 male participants (seven for the experimental group and five for the control group). The average age of the experimental group was 32 years, ranging from 24 to 39 years. The average age of the control group was 34 years, ranging from 27 to 38 years. The average time of singing training for the experimental and the control group was 4.8 and 5.2 years, respectively. Inclusion criteria for participants were as follows: (1) aged between 25 and 45 years, (2) no current or history of major voice problems based on participants' self-report, (3) perceptually normal voice, and (4) at least 3 years of formal singing voice training. Perceptual assessment was conducted by one of the authors of this paper with more than 15 years of experience in voice clinic. The grade of dysphonia, roughness, breathiness, asthenia, strain (GRBAS) scale was used. 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.

Singing vocal warm-up

All participants were required to engage in a 15-minute session of vocal warm-up exercises.

The vocal warm-up program for the experimental group included the same three phonatory tasks used in a previous study by Guzman et al[27]: (1) to phonate a sustained vowel [u:]-like sound using habitual speaking pitch and loudness level, (2) ascending and descending glissandos through a comfortable vocal range (including falsetto), and (3) pitch and loudness accents (rapid fluctuations of pitch and loudness). All phonatory tasks were performed using a commercial plastic stirring straw (5 mm in inner diameter and 25.8 cm in length). Phonation into a straw is considered as a SOVTE. Participants were encouraged to feel vibratory sensations in the front part of the mouth and head. The entire exercise sequence lasted 15 minutes (5 minutes per phonatory task).[27]

Vocal warm-up for the control group consisted of traditional singing exercises using the vowel [a:]. The sequence used in the present study was based on a previous work.[27] Each participant sang a melody based on musical intervals of thirds. Musical pitch ranges were adapted to each participant's voice type (voice classification). For high male and female voices (tenor or soprano), the starting note was E3 and E4, respectively; for middle male and female voices (baritone or mezzo-soprano), the starting note was C3 and C4, respectively; and for low male and female voices (bass or alto), the starting note was A2 and A3, respectively. Voice type was determined from participants' self-report. The melody was repeated changing the musical tonality by semitones in an ascending and a descending manner, through a comfortable vocal range. Participants were encouraged to feel vibratory sensations in the front part of the mouth and head. The entire exercise sequence lasted 15 minutes.

Before data acquisition, explanation and demonstration of all exercises were provided to all participants by trained speech-language pathologists who authored the present study. To standardize demonstrations of exercises, all experimenters participated in a 3-hour training session. No voice rest time was considered between both instrumental voice assessments (pre and post warm-up) and warm-up session. Control of pitch was auditorily monitored by the experimenters using an electronic keyboard.

Equipment and data collection

Aerodynamic, EGG, and acoustic recordings were carried out before and after warm-up. 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 the 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 pre and post warm-up assessments as required from participants. SPL was calibrated using a sustained vowel for further sound level measurements. The equivalent level of this reference sound was measured with a sound level meter (model 2250; Bruel & Kjær Sound & Vibration Measurement, Nærum, Denmark) also positioned at a distance of 30 cm from the mouth.

Aerodynamic and EGG devices were connected to a computer through the Computerized Speech Lab, model 4500 (KayPENTAX). EGG signal was captured with an electroglottograph (model 6103, KayPENTAX). EGG signal quality was monitored using a real-time oscillogram incorporated in the EGG software. A Phonatory Aerodynamic System (model 4500, KayPENTAX) 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 and EGG analysis software (model 6600, version 3.4, KayPENTAX) was used to analyze all samples. From the middle section of each sample, the most stable part was analyzed (5 seconds approximately).

Participants from both groups were asked to produce the same three assessment phonatory tasks before and after the vocal warm-up exercises: (1) a sustained speaking vowel [a:], (2) repetition of the syllable [pa:] (speaking voice quality), and (3) sing the song "Happy Birthday" for 1 minute using a comfortable pitch range. Repetition of the syllable [pa:] was performed to estimate the Psub from the oral pressure during the occlusion of the consonant [p:]. A silicon tube inserted into the mouth was used to acquire oral pressure. Participants were asked not to touch the tube with the tongue or any other oral structure to not block the airflow. To avoid air leakage through the nose, a nose clip was used for all participants during data acquisition. Three repetitions of the two first phonatory tasks were performed by each subject. F0 was required to be the same during pre and post assessments for the sustained vowel and repetition of the syllable [pa:] phonatory tasks.

PTP was also obtained. Participants were asked to produce the same phonatory task that they performed to measure Psub estimated from oral pressure. They were required to produce a sequence of six syllables [pa:] at the softest possible voice without reaching whisper.

Variables

From acoustic, EGG, aerodynamic, and samples acquired before and after warm-up, the following variables were obtained:

(1) F0 (Hz) from acoustic signal. To control for gender differences, this variable was converted to semitones. For each subject, the initial (pre) Hz value was used as the reference value to later on convert the post Hz measure into semitones. Therefore, this variable shows how subjects in each group deviate, on average, from their own initial F0, which for all participants is always zero.
(2) SPL (dB) from acoustic signal.
(3) mean EGG CQ (%) from EGG signal. Criterion level of 25% from the peak-to-peak amplitude of the EGG signal was used for CQ analysis.
(4) Psub (cm H_2O) estimated from the maximum peak of the oral pressure during the occlusion of the consonant [p:] in the syllable [pa:].
(5) PTP (cm H_2O) from aerodynamic signal.
(6) mean phonatory airflow (L/seg) from aerodynamic signal.
(7) aerodynamic power (watt) from aerodynamic signal defined as Psub times glottal airflow.
(8) aerodynamic resistance (cm H_2O/L/seg) from aerodynamic signal, defined as Psub divided by glottal airflow.
(9) aerodynamic efficiency (ppm) from aerodynamic signal, defined as acoustic power divided by aerodynamic power.

Self-assessment

Effects of the two vocal warm-up strategies were also self-assessed. Participants were asked about the perception of resonant voice quality before and after vocal warm-up. Resonant voice quality includes two main aspects: (1) vibratory sensations in the front part of the mouth and head, and (2) sensation of easy voice production. Self-assessment was performed on a 100-mm visual analog scale (where 0 = not resonant at all, 100 = very resonant) while singing the song "Happy Birthday."

Statistical analysis

Data were analyzed and plotted with R software (R Core Team, 2015, Wickham, 2009, Lawrence, 2015). Results are presented for each one of the three implemented tasks and for visual analog scale scores. A 2×2 mixed-factor analysis of variance was conducted on all tasks' variables, with warm-up method as between-group factor and pre-post as within-group factor. When relevant, generalized eta squared is reported as effect size measure. Additionally, two-tailed paired *t* tests were conducted on all variables on each treatment condition. They are reported whenever relevant, along with Cohen d for effect size. *t* Tests were conducted irrespective of the significance of the analyses of variance's interactions or main effects strictly to gauge the extent of change after treatment in each condition. However, no two-sample *t* tests were conducted to inspect between-group difference on the post-treatment measure, given the lack of statistical support for them to be reported.

RESULTS

Figure 1 shows a trellis means plot for all variables inspected during the sustained vowel [a:] phonation task. No significant interactions were observed for any of the variables. However, a trend-wise interaction was observed for mean SPL, with a significant paired *t* test contrast in the traditional group (Table 1).

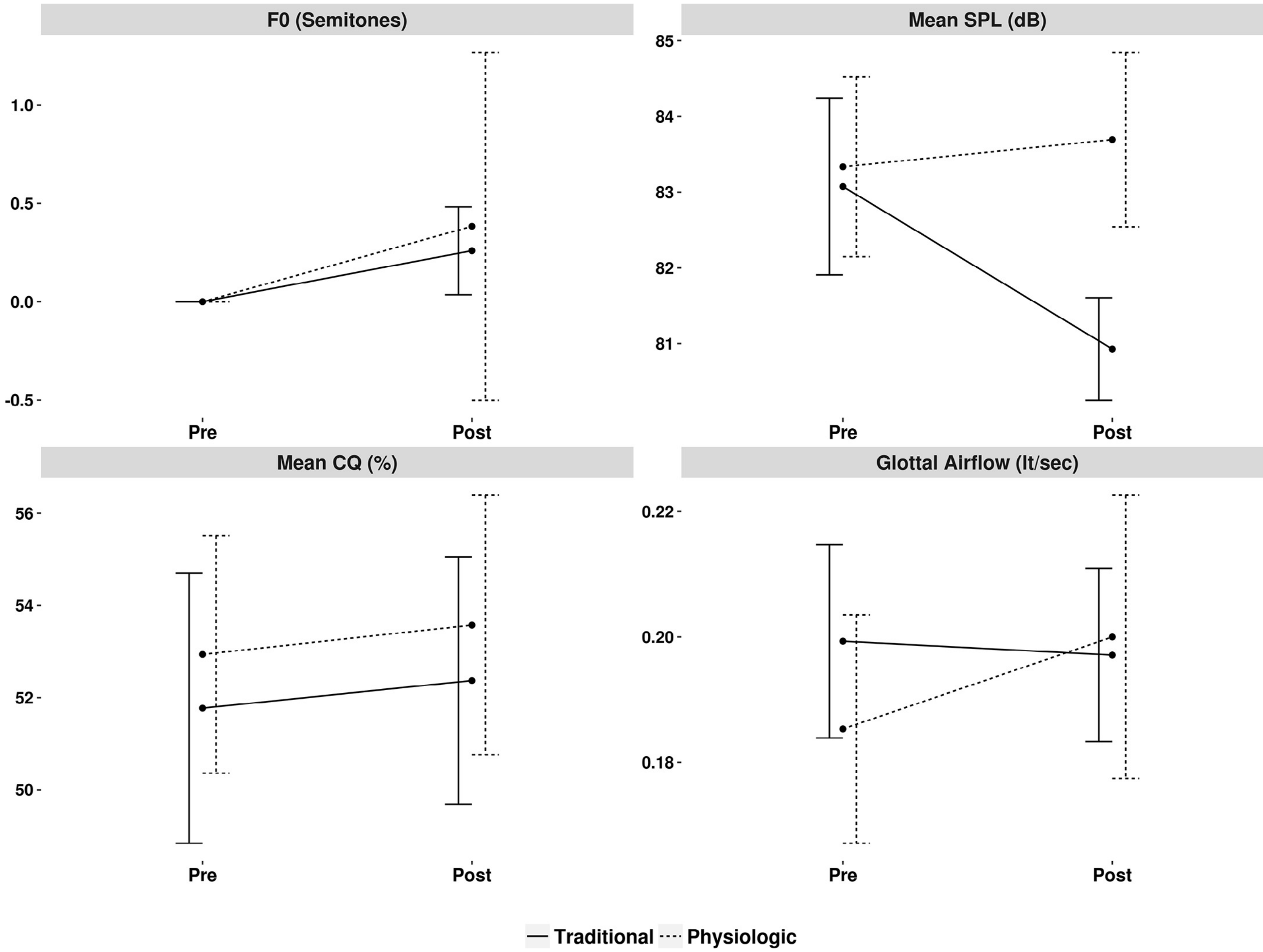

FIGURE 1. Interaction plot for all variables in the sustained vowel [a:] phonation task.

Figure 2 shows a trellis means plot for all variables obtained during the repetition of the syllable [pa:]. No significant interactions were observed for any of the variables. Statistically significant main effects for mean SPL, glottal airflow, and aerodynamic efficiency are presented in Table 2.

Figure 3 shows a trellis means plot for all variables in the song Happy Birthday. No significant interactions or main effects were observed for any of the variables. Also, no significant effects were observed when conducting paired *t* tests on any of the variables in either group.

Figure 4 shows a means plot for self-perceived resonance voice quality, and Table 3 presents associated statistics.

DISCUSSION

The present study aimed to observe whether physiological warm-up using semi-occluded exercises and traditional singing warm-up differently affect aerodynamic, EGG, acoustic, and self-perceived parameters of voice in CCM singers. No significant differences were found when comparing both types of vocal warm-up methods in either subjective or objective measures, as

TABLE 1.
Mixed-factor ANOVA Results, Along With Paired *t* Tests on Both Warm-up Methods for the Sustained Vowel [a:] Phonation Task

	ANOVA (1,28)									Paired *t* Test (14)					
	Pre-Post			Warm-up			Interaction			Traditional			Physiological		
	F	*P*	GES	F	*P*	GES	F	*P*	GES	t	*P*	d	t	*P*	d
Mean SPL	2.02	0.16	0.01	1.21	0.27	0.0034	3.99	0.05	0.024	2.34	0.03	0.83	–0.36	0.7	0.23

Degrees of freedom for tests are provided in parentheses.

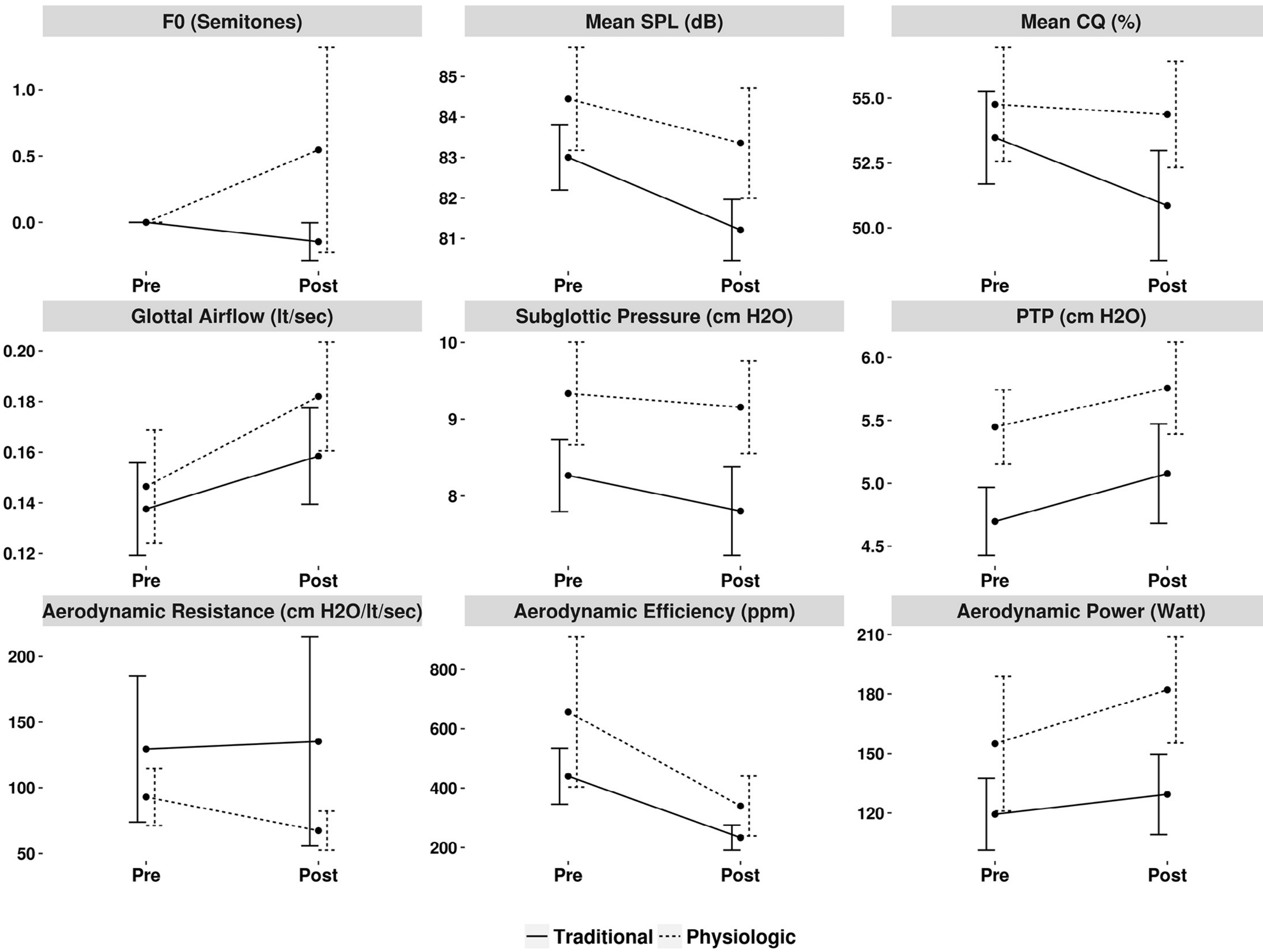

FIGURE 2. Interaction plot for all variables in repetition of the syllable [pa:] phonation task.

reflected by the lack of significant interactions. Furthermore, the main positive effect observed in both groups when comparing pre and post conditions was a better self-reported quality of voice.

Self-perceived Resonance Voice Quality

It is widely accepted among singers and singing teachers that warm-up may improve voice production and promotes an easy phonation. In the present study, self-reported resonant voice quality significantly increased after both physiological and traditional warm-ups. Subjects in both groups reported an easier voice production and more vibratory sensations in the front part of the face immediately after exercises. Moorcroft and Kenny[30] investigated changes perceived by singers and listeners after vocal warm-up, and found that singers perceived their voices with more

TABLE 2.
Mixed-factor ANOVA Results, Along With Paired *t* Tests on Both Warm-up Methods for the Repetition of the Syllable [pa:] Phonation Task

	ANOVA (1,28)									Paired *t* Test (14)					
	Pre-Post			Warm-up			Interaction			Traditional			Physiological		
	F	*P*	GES	F	*P*	GES	F	*P*	GES	t	*P*	d	t	*P*	d
Mean SPL	6.53	0.01	0.03	1.58	0.21	0.046	0.38	0.53	0.001	2.83	0.01	0.96	1.16	0.26	0.51
Glottal airflow	7.95	0.009	0.332	0.36	0.56	0.11	0.53	0.46	0.002	–2.28	0.04	0.81	–2	0.06	0.73
Aerodynamic Efficiency	8.85	0.006	0.054	0.75	0.4	0.021	0.39	0.53	0.002	3.27	0.005	1.08	1.92	0.07	0.72

Degrees of freedom for tests are provided in parentheses.

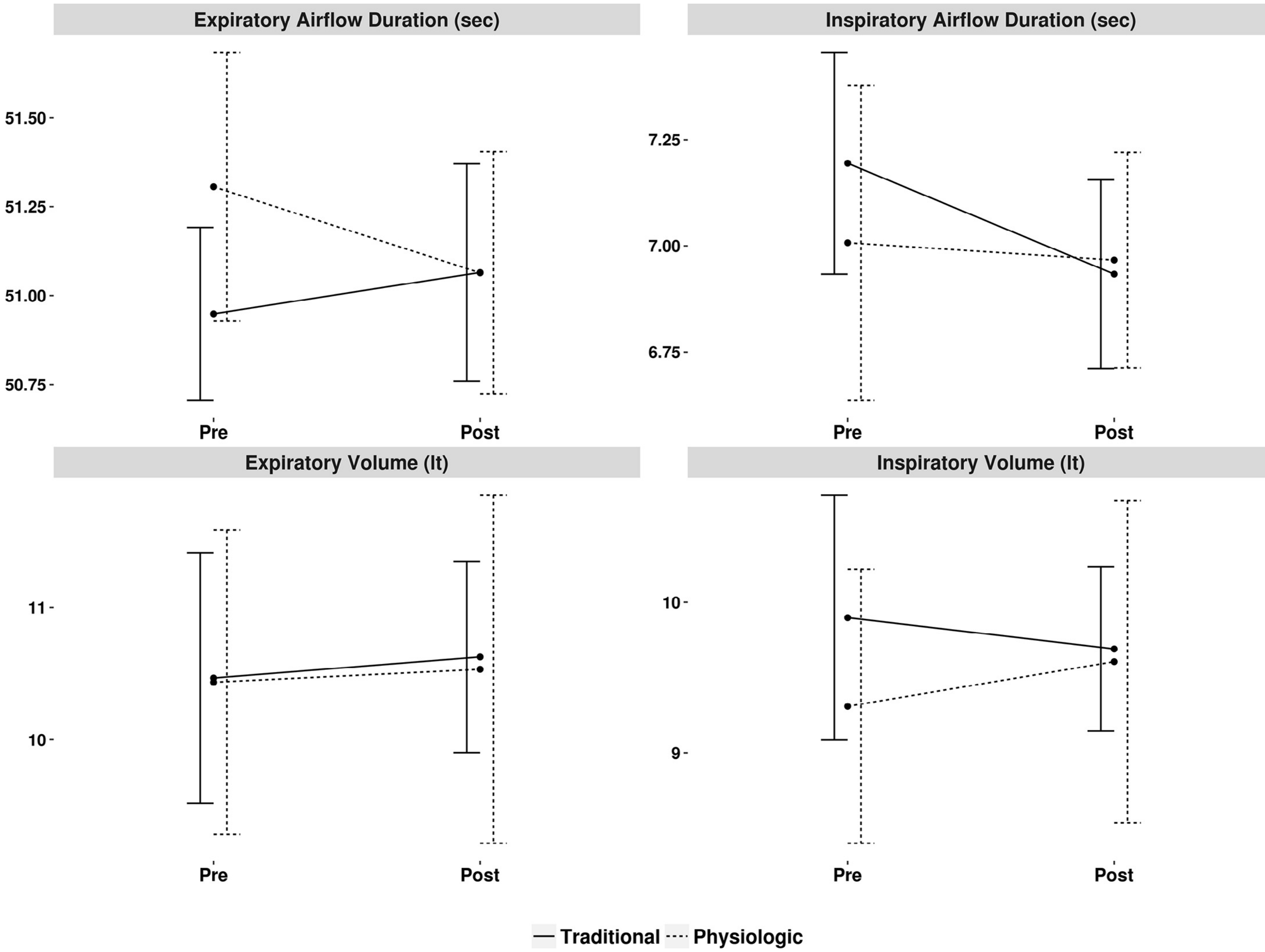

FIGURE 3. Interaction plot for all variables in the song Happy Birthday task.

resonant sensations after exercises. Similarly, Elliot et al[31] reported that amateur singers felt that their voices were in better condition after vocal warm-up. Specifically, subjects reported that singing was easier, particularly at high pitches. McHenry et al[32] investigated the effectiveness of specific versus combined warm-up strategies in a group of actors. The authors found that both warm-up methods decreased the subjectively perceived vocal effort. In a pilot survey conducted by Gish,[33] information about several subjective aspects related to vocal warm-up in singers was obtained. Most (74%) of the surveyed singers stated that their voices were easier and more flexible after warm-up (70%). Likewise, SOVTE are also expected to reduce vocal effort after practice. Paes[34] studied the immediate effects of phonation into traditional Finnish glass tube in a group of teachers diagnosed with behavioral dysphonia. Authors found that most of the subjects (68%) experienced an increased phonatory comfort

TABLE 3.
Mixed-factor ANOVA Results, Along With Paired *t* Tests on Both Warm-up Methods for the Self-perceived Resonance Voice Quality

	ANOVA (1,28)									Paired *t* Test (14)					
	Pre-Post			Warm-up			Interaction			Traditional			Physiological		
	F	*P*	GES	F	*P*	GES	F	*P*	GES	t	*P*	d	t	*P*	d
Resonant voice quality	60.5	<0.001	0.398	0.75	0.39	0.018	0.2	0.65	0.002	8.15	<0.001	2.48	4.24	<0.001	1.35

Degrees of freedom for tests are provided in parentheses.

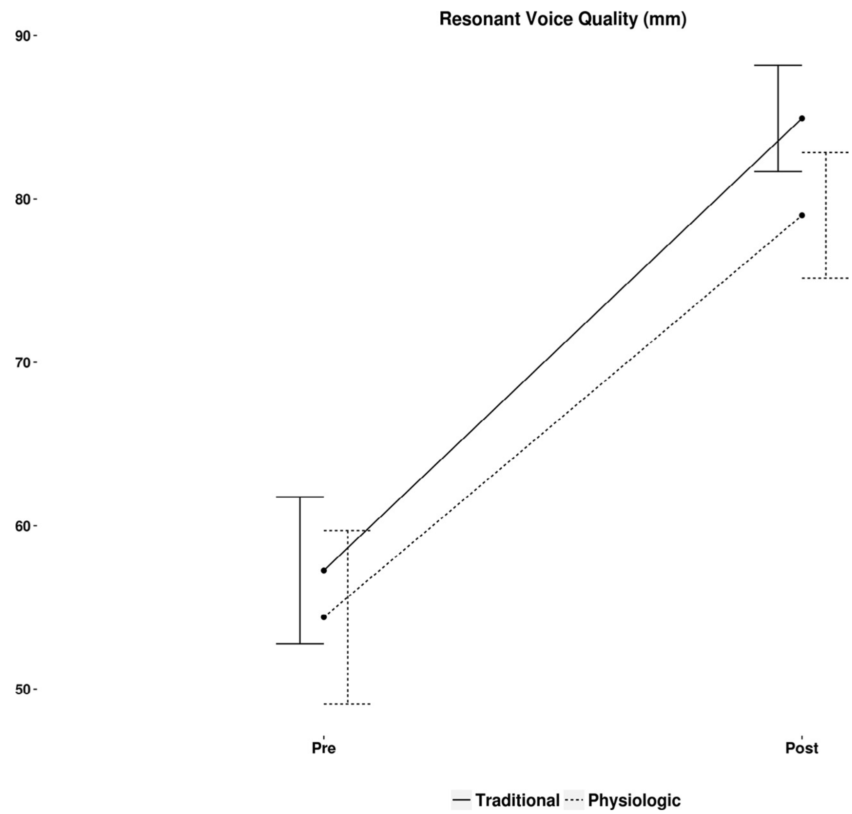

FIGURE 4. Interaction plot for the self-perceived resonant voice quality.

after practice. Overall, there is strong evidence to suggest that warm-up positively affects voice, at least on self-perceived characteristics.

Even though in our study better self-perceived voice quality was observed for both groups, this variable did not differ significantly when comparing both warm-up strategies. Thus, physiological and traditional vocal warm-up did not differentially affect this subjective variable. Similar outcomes were reported by Duke et al[26] in a study aimed at observing the effect of traditional vocal warm-up versus SOVTE in male singers.

Aerodynamics, acoustics, and EGG

Because perceived phonatory effort has been associated with the PTP[35,36] (the minimum Psub needed to barely initiate and sustain phonation), a decrease is expected on this variable after both types of vocal warm-up. However, no significant changes for PTP were found in our data when comparing pre and post warm-up conditions for both groups. Titze and Story[37] stated that PTP is indirectly proportional to the thickness of vocal folds and directly proportional to the tissue viscosity, the velocity of the mucosa wave during phonation, and the prephonatory vocal width. Theoretically, vocal warm-up should increase blood flow to the vocal fold tissues, thus decreasing viscosity, and this, in turn, should decrease the PTP. Earlier studies assessing the effect of vocal warm-up on PTP have shown no consistent results. In some cases, findings are even contrary to what is expected from a theoretical point of view. Vintturi et al[38] and Motel et al[39] found a significant increase of PTP after vocal warm-up; other studies have reported a high variability among participants or no effect.[30,39] Only one study, conducted by McHenry and colleagues (2009), has reported a decrease on PTP after vocal warm-up.

The overall SPL showed a significant decrease after vocal warm-up for the control group (traditional warm-up) during both sustained vowel [a:] and repetition of the syllable [pa:]. This variable remained constant for the experimental group. Because a decrease in vocal projection is one of the most common symptoms associated with vocal fatigue,[36,40–42] it seems plausible to assume that traditional warm-up in the present study may have caused an early stage of vocal fatigue (loading effect). McHenry and Evans[44] also interpreted the decrease of SPL after warm-up as a sign of vocal fatigue in a study performed with classically trained singers. However, one must be cautious when interpreting these data because interactions were not below the 0.5 alpha level traditionally adopted in research. In any case, reported generalized eta squared measures for effect size are not trivial. Also, our findings show that glottal airflow significantly increased after traditional vocal warm-up. From a physiological point of view, glottal airflow could increase owing to an increased Psub or owing to a decreased glottal resistance. In our data, Psub did not show changes when comparing pre and post warm-up conditions. Regarding glottal adduction, videolaryngostroboscopic investigations have reported glottal chinks[44,45] and abnormal closure[44,45] in subjects with vocal fatigue. According to Stemple et al,[45] a bowed edge of the vocal folds (incomplete closure) could be caused by a weakness of the thyroarytenoid muscles due to vocal fatigue. In our experiment, although the CQ from EGG signal and aerodynamic resistance did not show any significant change, an interesting trend was observed in both variables for the traditional warm-up group. There was a decrease after exercises, which could be indicative of a decreased glottal closure. Decrease of laryngeal resistance has also been considered as a potential sign of warm-up by Laukkanen et al.[47] Furthermore, aerodynamic efficiency showed a significant decrease after traditional vocal warm-up. Aerodynamic efficiency is defined as the acoustic power divided by aerodynamic power (glottal airflow × Psub). Because total SPL (acoustic power) decreased, glottal airflow increased, and Psub remained constant after warm-up for the control group, the decrease in aerodynamic efficiency is expected.

Even though previous data may support the idea that the changes observed after traditional warm-up could be related to vocal fatigue (showing a hypofunctional-like glottal behavior), earlier investigations regarding vocal fatigue after loading tests have demonstrated different outcomes. Higher values of F0 and SPL have been reported after vocal loading. Additionally, alpha ratio (spectral tilt) has been found to be lower after vocal loading tasks.[47–50] These acoustic results may be indicative of a compensatory hyperfunctional behavior and vocal effort related to fatigue. Considering that these previous investigations have been carried out using a loading period longer than 15 minutes (as it was used in the present study as warm-up), it could be suitable to state that the vocal loading time could have an effect on vocal behavior. However, Laukkanen et al,[21] in a study exploring the effect of two different warm-ups on vocal tract configuration and acoustic characteristics of voice, found an increased total SPL after only few minutes of practicing.

If a decreased SPL, increased glottal airflow, and decreased aerodynamic efficiency really are signs of an earlier stage of vocal fatigue in the present study, this should be concordant to what participants subjectively felt after warm-up. Current definitions of vocal fatigue include the sensation of increased vocal effort that become greater over time with voice use.[40] Differently, as mentioned above, participants from the control group reported an easier voice production after exercises. Therefore, self-reported information seems to not support the idea of a possible vocal fatigue after traditional warm-up. Nevertheless, it is also possible that self-perceived voice characteristics could be deceptive. Barr[52] questioned whether effects of warm-up in singers are really related to physiology or are more psychological or placebo. The author suggested that a placebo effect may be present when the warm-up has no physiological basis. However, the singer has some benefits, and likely because he or she feels mentally ready to perform.

CONCLUSION

Both traditional and physiological (the latter based on semi-occluded exercises) warm-ups produce favorable sensations (easy phonation and vibrations on the front part of the face and mouth) after exercises. Moreover, there are no evident differences on aerodynamic and EGG variables when comparing both types of vocal warm-ups. Some changes after traditional warm-up (decreased SPL, increased glottal airflow, and decreased aerodynamic efficiency) could imply an early stage of vocal fatigue. However, these signs are not concordant to subjective sensations of improved voice after exercises reported by singers. CCM singers should consider what type of vocal warm-up works the best for their voices regarding subjective sensations, especially sensations related to a more economic voice production.

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