How Do Laryngeal and Respiratory Functions Contribute to Differentiate Actors/Actresses and Untrained Voices?

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Summary: Purpose. The present study aimed to compare actors/actresses's voices and vocally trained subjects through aerodynamic and electroglottographic (EGG) analyses. We hypothesized that glottal and breathing functions would reflect technical and physiological differences between vocally trained and untrained subjects.

Methods. Forty participants with normal voices participated in this study (20 professional theater actors and 20 untrained participants). In each group, 10 male and 10 female subjects were assessed. All participants underwent aerodynamic and EGG assessment of voice. From the Phonatory Aerodynamic System, three protocols were used: comfortable sustained phonation with EGG, voice efficiency with EGG, and running speech. Contact quotient was calculated from EGG. All phonatory tasks were produced at three different loudness levels. Mean sound pressure level and fundamental frequency were also assessed. Univariate, multivariate, and correlation statistical analyses were performed.

Results. Main differences between vocally trained and untrained participants were found in the following variables: mean sound pressure level, phonatory airflow, subglottic pressure, inspiratory airflow duration, inspiratory airflow, and inspiratory volume. These variables were greater for trained participants. Mean pitch was found to be lower for trained voices.

Conclusions. The glottal source seemed to have a weak contribution when differentiating the training status in speaking voice. More prominent changes between vocally trained and untrained participants are demonstrated in respiratory-related variables. These findings may be related to better management of breathing function (better breath support).

Key Words: Actors–Actresses–Voice training–Glottal airflow–Subglottic pressure–Contact quotient.

INTRODUCTION

Since the 1980s, research regarding the actor's voice has intensified. Most studies on the actor's voice focused on acoustic and auditory-perceptual analysis of the voice. One of the most common acoustic tools used to study actors' voices has been the long-term average spectrum (LTAS), which is extensively used to assess the so-called actor's formant (AF). The AF is defined as a spectral peak around 3.5 kHz, which is considered a differentiating feature of good voice quality.[1] Leino[1] reported that poor voice quality is different from good voice quality by the steepest spectral slope and suggests that the spectral slope declination has perceptual relevance in the evaluation of voice quality. A gentle spectral slope and a prominent peak at 3 and 4 kHz appear to be the main features, which characterize a good speaking voice.[1–9] The AF has been found in some American and European actors to display a spectral prominence of approximately 3.5 Hz.[1,6–8] Brazilian actors have demonstrated similar results. Master et al aimed to compare actors' and non-actors' voices, the actor's voice showed a smaller difference between low and high harmonics of the spectrum (less spectral tilt), stronger energy level of the AF range, and a higher degree of perceived projection.[9]

The AF is explained physiologically as a resonance phenomenon. Nolan [10] suggested that the AF is accomplished in the same way as the singer's formant according to Sundberg.[11] When the cross-sectional area in the pharynx is at least six times wider than the laryngeal tube opening, the epilarynx acts as an independent resonator. Therefore, an extra formant is added to the vocal tract transfer function (the singer's formant). According to Sundberg,[11] the lowering of the larynx, typical in male classical singing, may explain the ratio between the cross-sectional area of the low pharynx and epilaryngeal tube opening. However, a low vertical laryngeal position is not necessarily desirable in the actor's voice technique. To this regard, earlier studies have demonstrated the presence of a spectral prominence in speaking voice samples to be around 3500 Hz without lowering the larynx. In a magnetic resonance imaging (MRI) and acoustic study, Laukkanen et al[12] found that after vocal exercises using artificial lengthening of the vocal tract in a female subject with a background in speaking voice training, the ratio of the transversal area of the lower pharynx over that of the epilarynx increased. Moreover, acoustic changes showed more energy in the speaker's formant cluster region. Additionally, the distances between the formant frequencies of F3 and F4 and between F4 and F5 decreased. Similar MRI and acoustic findings were observed in another study designed to identify acoustic changes in voice production after a warm-up of two professional voice users.[13] Furthermore, in a study designed to investigate the origin of the speaker's

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formant, authors found that after voice exercises performed by a professional male actor, the strong spectral peak at 3.5 kHz was present in all vowels and formed by the clustering of F4 and F5. The results of computer modeling from the same investigation suggested that a speaker's formant could be obtained with slight narrowing of the epilaryngeal region, widening of oral pharynx, and narrowing of the front part of it.[8] The underlying nature of the AF is still not completely understood, and it is the subject of several speculations.

Regarding auditory perception of voice, most studies carried out with actors have focused on the perception of voice projection. Actors are often required to vocalize with an increased loudness under suboptimal acoustic conditions inherent in most theaters. To accomplish an increased loudness without producing vocal damage, actors are required to learn how to maximize loudness through technical and expressive exercises. Furthermore, the term "vocal projection" does not necessarily have a specific and clear definition, and it usually creates confusion about the exact meaning.[14–20]

Although the term vocal projection seems to be subjective and inaccurate, a previous study determined acoustic and perceptual differences between comfortably projected voices and voices with maximum projection in a group of professional actors.[5] Results showed that spectral energy differences between stronger and weaker regions of specific harmonic frequency ranges (alpha ratio) decreased, and the perception of projection increased with as sound pressure level increased. The authors concluded that LTAS can be a useful tool to evaluate voice quality. Based on this finding, it is possible that the AF would be helpful in producing effective vocal projection during acting. This is essential for performers, making it possible for their voices to be heard with maximum intelligibility by listeners using minimum vocal effort. Additionally, Bele[21,22] conducted a study to develop a valid method for the evaluation of normal-to-good voice quality. This study investigated both normal and supranormal (resonant voice quality) voices in two groups of professional voice users: teachers and actors.

Electroglottgraphy (EGG) has been also used in earlier studies to differentiate vocally trained and untrained voices. Master et al[23] conducted a study aimed to investigate the contribution of the vocal folds to the projected voice, comparing actresses and nonactresses' voices in different levels of intensity. Findings showed no significant differences between groups for EGG quotients. Another study designed to evaluate vocal economy in actresses and nonactresses using an electroglottogram-based voice economy parameter (quasi-output cost ratio) were recently performed. Authors reported no significant differences between groups.[24]

Because theater actors spend several years training their voices, it would be expected that they would have other measurable differences compared with untrained subjects other than the AF. To the best of our knowledge, no previous research has used aerodynamic measures as possible markers to differentiate trained from untrained speaking voices. The present study aimed to compare actors/actresses's voices and nonactor/actresses's voices through aerodynamic and EGG used simultaneously. We hypothesized that glottal and breathing functions should reflect technical and physiological differences between vocally trained and untrained subjects.

METHODS

Participants

A total number of 40 participants were included in this study (20 theater actors and 20 nonactors). The average age of the subject set was 32 years, with a range of 27–47 years of age. In each group, 10 male and 10 female subjects were included. Inclusion criteria for actors and actresses included the following: (1) to be aged between 25 and 50 years, (2) more than 5 years of theater acting experience, (3) at least 3 years of formal vocal training, and (4) no current or past history of a voice disorder based on participant reporting. Inclusion criteria for nonactors and nonactresses included the following: (1) the same age range as trained participants, (2) no current or past history of a voice disorders, (3) no professional use of voice, and (4) no previous voice training or voice therapy. All subjects were asked to attend a single recording lasting about 1 hour. The session obtained audio recordings, aerodynamic, and EGG assessment of voice for both groups.

The present study was conducted with approval from the Institutional Review Board at University of Chile. The nature of the study was explained to each participant before they signed an informed consent.

Equipment

Data were collected in the Voice Research Laboratory at University of Chile. Acoustic, aerodynamic, and EGG signals were captured simultaneously during all phonatory tasks. Aerodynamic data were collected with a Phonatory Aerodynamic System (PAS), KayPENTAX, model 4500 (KayPENTAX, Lincoln Park, NJ). EGG data were obtained with an Electroglottograph, model 6103 (KayPENTAX). Both aerodynamic and EGG systems were connected to a Computerized Speech Lab, Model 4500, which in turn was connected to a desktop computer running a real-time aerodynamic and EGG analysis software, model 6600, version 3.4 (KayPENTAX). To obtain sound pressure level (SPL) and fundamental frequency, acoustic output was measured at a constant microphone-to-mouth distance of 20 cm using a condenser microphone AKG (AKG acoustics, Vienna, Austria) integrated into the PAS. Samples were recorded digitally at a sampling rate of 22 KHz with 16 bits per sample quantization. Acoustic signal was calibrated using a sustained vowel [a:] produced by one of the investigators. The sound level of this reference sound was measured with a sound level meter (Brüel & Kjær, model 2250; Brüel & Kjær Sound & Vibration Measurement, Nærum, Denmark); also positioned 20 cm from the mouth.

At the beginning of the examination, participants were asked to comfortably sit upright in a chair. After this, two surface electrodes were attached over the thyroid cartilage by means of a lightweight elastic band. The electrodes were attached with a Velcro strip, which was comfortably wrapped around the participant's neck as tightly as possible to prevent any movement of electrodes throughout the data collection. Readjustments of the

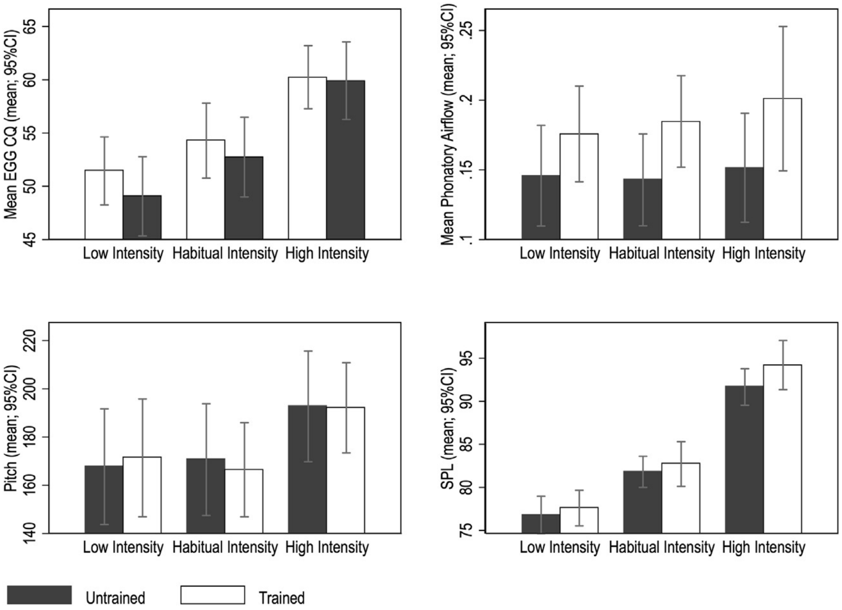

FIGURE 1. Results from univariate analysis for comfortable sustained phonation protocol.

elastic band and electrodes were necessary in some participants until the EGG signal was clearly visualized. After electrode placement, participants were instructed to take the facemask and firmly hold it over the face covering mouth and nose. An adequate seal was required to avoid air leakage during procedures.

Calibration of the airflow rate was performed before every recording session by using a calibration syringe to inject 1 L of air through the airflow head. Air pressure calibration was done automatically before every session. All calibration procedures were carried out according to the manufacturer's instructions.

Phonatory tasks

Participants from both actor and nonactor groups were asked to produce different phonatory tasks depending on the protocol used in PAS. All tasks were produced in three different levels of loudness (habitual, high, and low). Investigators perceptually controlled that subjects really succeed in changing the loudness during recordings.

The software used to capture all signals is task oriented, providing a number of protocols that determine which parameters will be captured and displayed and which statistics will be reported. In the present study, only three protocols were used: comfortable sustained phonation with EGG, voice efficiency with EGG, and running speech.

During comfortable sustained phonation protocol, subjects were required to produce a sustained vowel [a:]. During voice efficiency protocol, an estimate of the subglottic pressure was recorded from the oral pressure during the occlusion of the consonant [p:] during the repetition of the syllable [pa:] (six times approximately). This pressure was captured with a thin plastic and flexible tube inserted into the mouth, extending a few millimeters behind the lips, without touching the tongue or any other oral structure. The remaining aerodynamic variables of this protocol were also calculated from the same phonatory task. During running speech protocol, participants read a phonetically balanced (Spanish version of The Grandfather) text for 60

TABLE 1.
Results From Multivariable Linear Regression Analysis for Comfortable Sustained Phonation Protocol

Independent Variable	Mean SPL (dB)	Mean Pitch (Hz)	Mean Expiratory Airflow (L/s)	Mean EGG Contact Quotient (%)
Gender	−0.12 (–1.88; 1.63); $P = 0.886$	−77.53 (−86.68; −68.38); $P < 0.000$	0.02 (0.0007; 0.058); $P = 0.045$	−2.15 (−4.79; 0.47); $P = 0.107$
Training	1.40 (−0.35; 3.16); $P = 0.115$	−2.40 (−11.55; 6.75); $P = 0.604$	0.041 (0.012; 0.070); $P = 0.006$	−1.47 (−4.11; 1.15); $P = 0.269$
Intensity				
Habitual	Reference	Reference	Reference	Reference
High	10.64 (8.49; 12.79); $P < 0.000$	23.86 (12.66; 35.06); $P < 0.0001$	0.012 (−0.023; 0.047); $P = 0.490$	6.54 (3.32; 9.77); $P < 0.0001$
Low	−5.05 (−7.21; −2.90); $P < 0.0001$	0.92 (−10.27; 12.12); $P = 0.871$	−0.002 (−0.038; 0.032); $P = 0.875$	−3.25 (−6.47; −0.02); $P = 0.048$

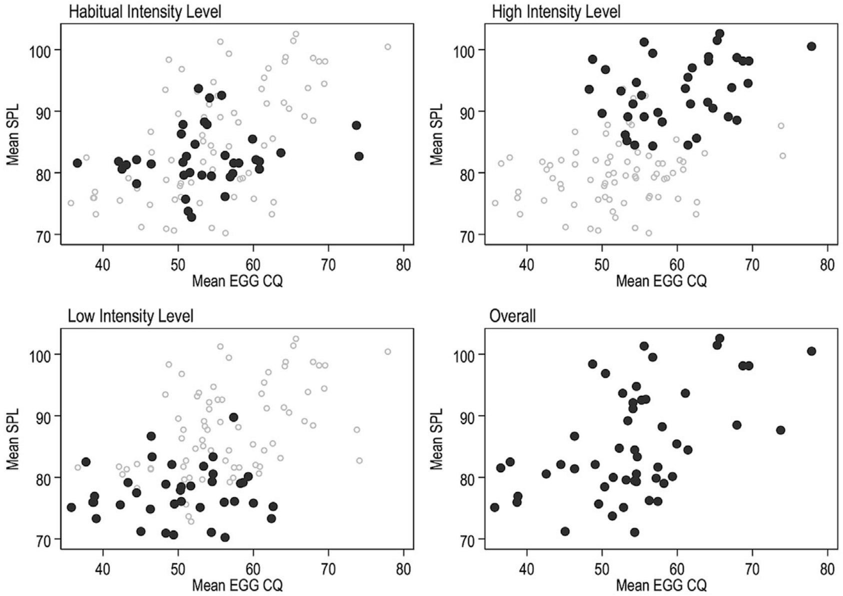

FIGURE 2. Correlation analysis between SPL and CQ throughout loudness levels.

seconds. An average from the entire passage was obtained. All phonatory tasks recorded in the three different protocols were repeated three times by each subject. Researchers demonstrated each phonatory task, and a brief practice was conducted before obtaining samples of voice recordings that best represented the target productions.

Variables

For the EGG, acoustic, and aerodynamic analyses, only the most stable section from the middle part of samples were included. Once the stable sections were selected, the following variables were obtained during the three loudness levels (habitual, high, and low):

1. Acoustic variables: SPL (decibel) and fundamental frequency (F_0) (hertz).
2. EGG variable: mean EGG contact quotient (CQ) (percentage).
3. Aerodynamic variables

Comfortable sustained phonation protocol: mean phonatory airflow (liter per second).

Voice efficiency protocol: mean subglottic pressure (centimeter of water), mean phonatory airflow (liter per second), aerodynamic power (Watt), aerodynamic resistance (centimeter of water per liter per second), aerodynamic efficiency (parts per million).

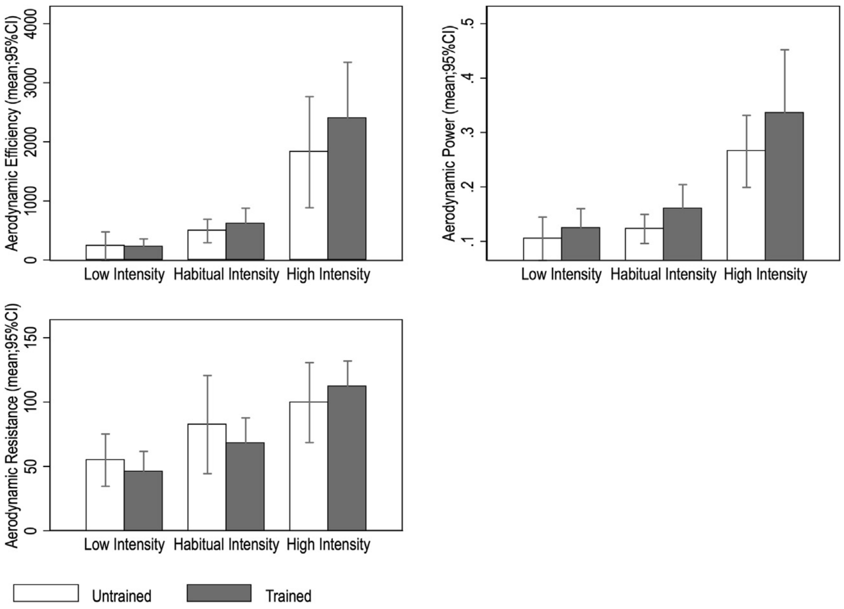

FIGURE 3. Results from univariate analysis for voice efficiency protocol.

TABLE 2.
Results From Multivariable Linear Regression Analysis for Voice Efficiency Protocol

Independent Variable	Mean SPL (dB)	Mean Peak Air Pressure (cm H_20)	Mean Expiratory Airflow (L/s)	Aerodynamic Power (W)	Aerodynamic Resistance cm H_2O/(L/s)	Aerodynamic Efficiency (ppm)	Mean EGG Contact Quotient (%)
Gender	−0.32 (−1.82; 1.16); $P = 0.664$	0.11 (1.05; 1.27); $P = 0.850$	0.03 (0.00; 0.06); $P = 0.039$	0.046 (−0.00; 0.09); $P = 0.051$	−0.27 (−19.89; 19.33); $P = 0.978$	−483.07 (−919.42; −46.72); $P = 0.030$	−2.86 (5.71; −0.00); $P = 0.050$
Training	1.69 (0.19; 3.19); $P = 0.027$	1.42 (0.25; 2.59); $P = 0.017$	0.014 (−0.015; 0.044); $P = 0.341$	0.043 (−0.0038; 0.090); $P = 0.071$	−3.40 (−23.00; 16.19); $P = 0.731$	221.53 (−214.61; 657.69); $P = 0.316$	1.51 (−1.33; 4.37); $P = 0.294$
Intensity							
Habitual	Reference	Reference	Reference	Reference	Reference	Reference	Reference
High	8.97 (−7.13; 10.80); $P < 0.000$	7.01 (5.58; 8.4); $P < 0.000$	0.027 (−0.009; 0.063); $P = 0.139$	0.15 (0.10; 0.21); $P < 0.0001$	30.56 (6.50; 54.62); $P = 0.013$	1565 (1030.024; 2100.50); $P < 0.0001$	4.17 (0.67; 7.66); $P = 0.020$
Low	−6.21 (−8.04; −4.37); $P < 0.0001$	−2.48 (−3.91; −1.05); $P = 0.001$	0.017 (−0.018; 0.054); $P = 0.337$	−0.027 (−0.085; 0.030); $P = 0.347$	−24.65 (−48.71; −0.59); $P = 0.045$	−313.17 (−848.417; 222.05); $P = 0.249$	−2.74 (−6.24; 0.75); $P = 0.123$

Running speech: inspiratory airflow duration (seconds), mean phonatory airflow (liter per second), mean inspiratory airflow (liter per second), inspiratory volume (liters).

Statistical analysis

Results are presented as mean ± standard deviation for continuous variables and as percentages for categorical data. Differences in acoustical, aerodynamical and EGG variables by training status were univariated assessed using Wilcoxon signed-rank test and *t* test (used to compare two groups, either normally or asymmetrically distributed). Then, three different multivariable linear regression models (one per phonatory task) with acoustical, aerodynamic and EGG parameters as dependent variables, and sex, training status, loudness level and its interactions with other variables (if these were statistically significant) as independent variables were fitted, to assess their joint influence (as predictors) over acoustic, aerodynamic and EGG parameters. Finally, Pearson correlation coefficient (r) to asses correlation between acoustical, aerodynamic and EGG variables was used. A P value < 0.05 was considered to be statistically significant and all reported P values were two sided. Stata 13.1 (StataCorp LP, College Station, TX) statistical software was used for analysis.

RESULTS

Results are grouped into the three different protocols used in this study: comfortable sustained phonation, voice efficiency, and running speech. Each protocol includes the univariate analysis, multivariable linear regression analysis, and correlation analysis.

Comfortable sustained phonation protocol

Results from univariate analysis are displayed in Figure 1. No significant statistical differences were found for any variable when trained and untrained subjects were compared by intensity level.

Results from multivariable linear regression analysis are summarized in Table 1. When gender was compared, only mean F_0 and mean phonatory airflow demonstrated significant differences. Mean phonatory airflow was the only variable showing significant differences between training status. Mean SPL and mean F_0 evidenced differences when habitual and high loudness levels were compared. Mean SPL and CQ were found to be different comparing habitual and low loudness productions.

Correlation analysis evidenced no strong correlations for any combination of variables in this protocol. The highest correlation was observed for mean SPL versus mean CQ ($r = 0.4959$; $P < 0.0001$; Figure 2).

Voice efficiency protocol

Results from univariate analysis are displayed in Figures 3 and 4. No significant statistical differences were found for most variables when trained and untrained subjects were compared by intensity level. Significant differences were found only for mean SPL ($P = 0.0264$) and for mean subglottic pressure ($P = 0.0287$), both at high loudness level.

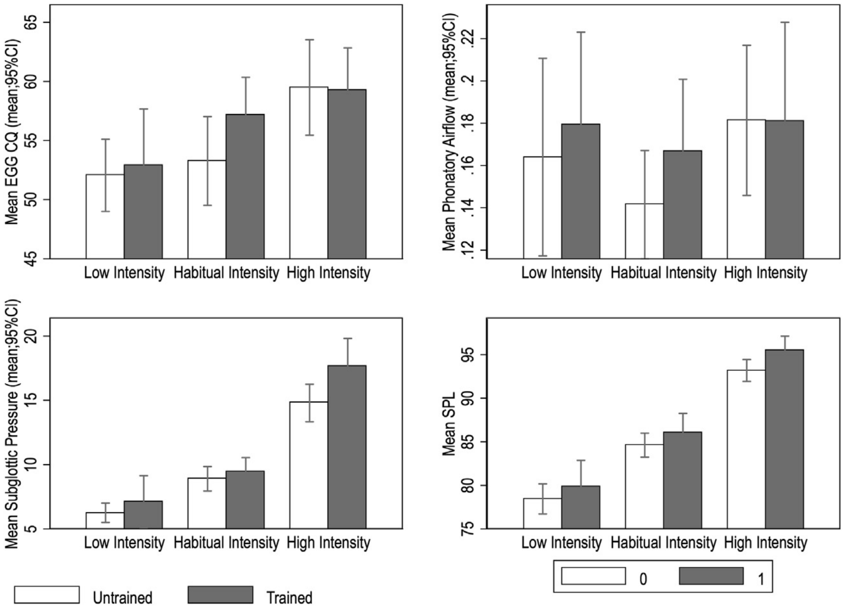

FIGURE 4. Results from univariate analysis for running speech protocol.

Results from multivariable linear regression analysis are summarized in Table 2. Gender differences were observed for mean phonatory airflow, aerodynamic efficiency, and CQ. Training status differences were shown for mean SPL and mean subglottic pressure. All variables except mean phonatory airflow were significantly different between groups for habitual and high loudness levels. Only mean SPL, mean subglottic pressure, and aerodynamic resistance demonstrated significant differences when comparing habitual and low loudness productions.

Correlation analysis evidenced strong correlations only for mean SPL versus mean subglottic pressure ($r = 0.8612$; $P < 0.0001$; Figure 5); mean SPL versus aerodynamic power ($r = 0.6004$; $P < 0.0001$; Figure 6); and mean SPL versus aerodynamic efficiency ($r = 0.6503$; $P < 0.0001$; Figure 7). The rest of combinations were as follow: mean SPL versus mean phonatory airflow ($r = 0.1670$; $P = 0.0719$); mean SPL versus aerodynamic resistance ($r = 0.4059$; $P < 0.0001$); CQ versus mean subglottic pressure ($r = 0.4227$; $P < 0.0001$); CQ versus mean phonatory airflow ($r = -0.2685$; $P = 0.0039$); CQ versus aerodynamic power ($r = 0.0790$; $P = 0.4058$); CQ versus aerodynamic resistance ($r = 0.3595$; $P = 0.0001$); CQ versus aerodynamic efficiency ($r = 0.3193$; $P = 0.0006$); mean SPL versus CQ ($r = 0.3576$; $P = 0.0001$).

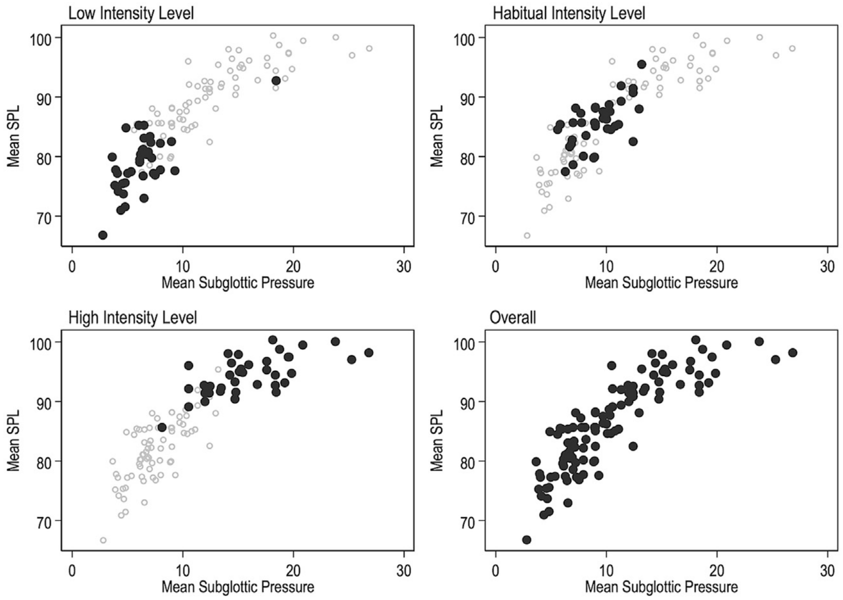

FIGURE 5. Correlation analysis between SPL and subglottic pressure throughout loudness levels.

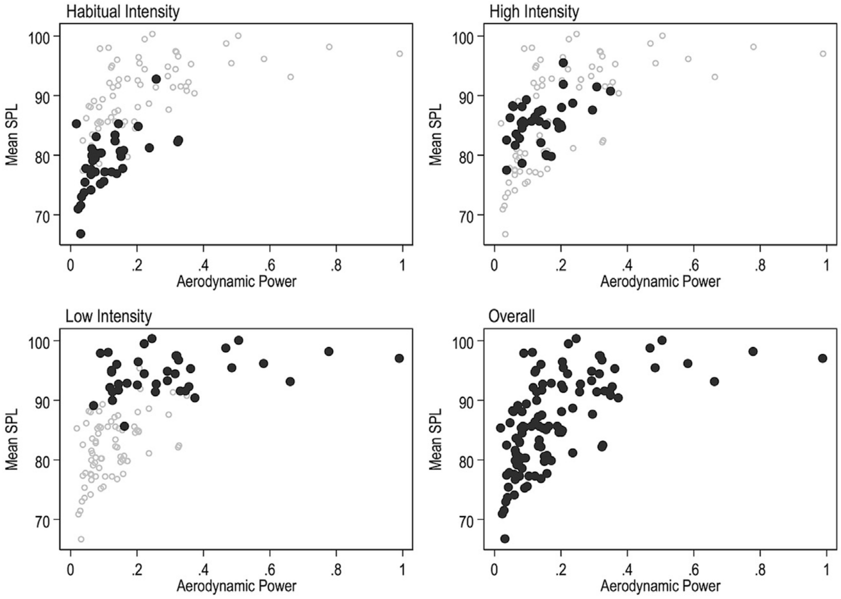

FIGURE 6. Correlation analysis between SPL and aerodynamic power throughout loudness levels.

Running speech protocol

Results from univariate analysis are displayed in Figure 8. When trained and untrained subjects were compared by intensity level, significant differences were found for mean SPL ($P = 0.0051$) at high loudness level; inspiratory airflow duration ($P = 0.0154$) at low loudness level; mean phonatory airflow at high loudness level ($P = 0.0013$) and low loudness level ($P = 0.0073$); mean inspiratory airflow ($P = 0.0122$) at high loudness level; and inspiratory volume at high loudness ($P = 0.0004$) and at low loudness productions ($P = 0.0181$).

Results from multivariable linear regression analysis are summarized in Table 3. Gender differences were observed for all variables except inspiratory airflow duration. Training status differences were observed for all parameters. When comparing habitual and high loudness level, all variables showed significant differences. Only mean SPL, mean F_0 demonstrated significant differences when habitual and low loudness productions were compared.

Correlation analysis

Correlation analysis evidenced good correlations only for: mean SPL versus mean phonatory airflow ($r = 0.6859$, $P < 0.0001$; Figure 9); mean SPL versus mean inspiratory airflow ($r = -0.6367$, $P < 0.0001$; Figure 10); mean SPL versus inspiratory volume ($r = -0.6224$, $P < 0.0001$; Figure 11). The rest of combinations were as follow: mean SPL versus

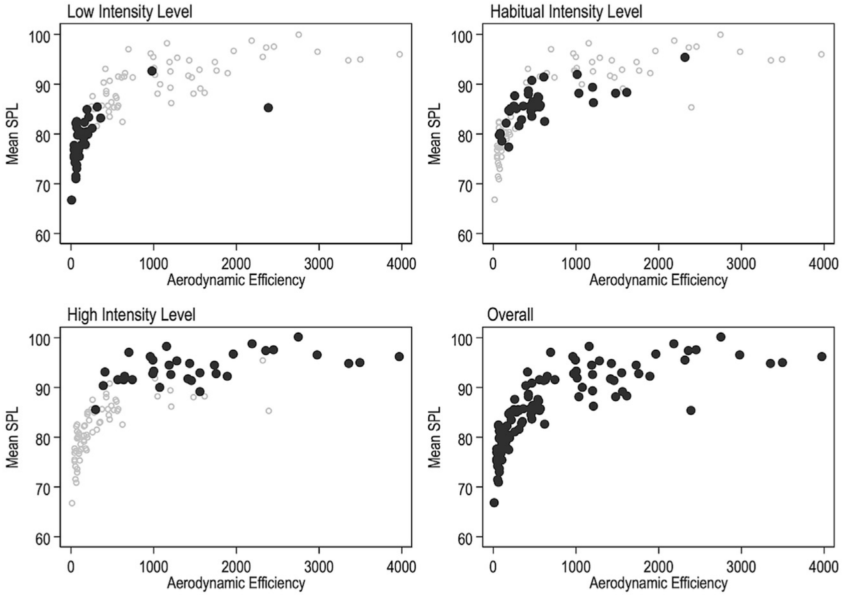

FIGURE 7. Correlation analysis between SPL and aerodynamic efficiency throughout loudness levels.

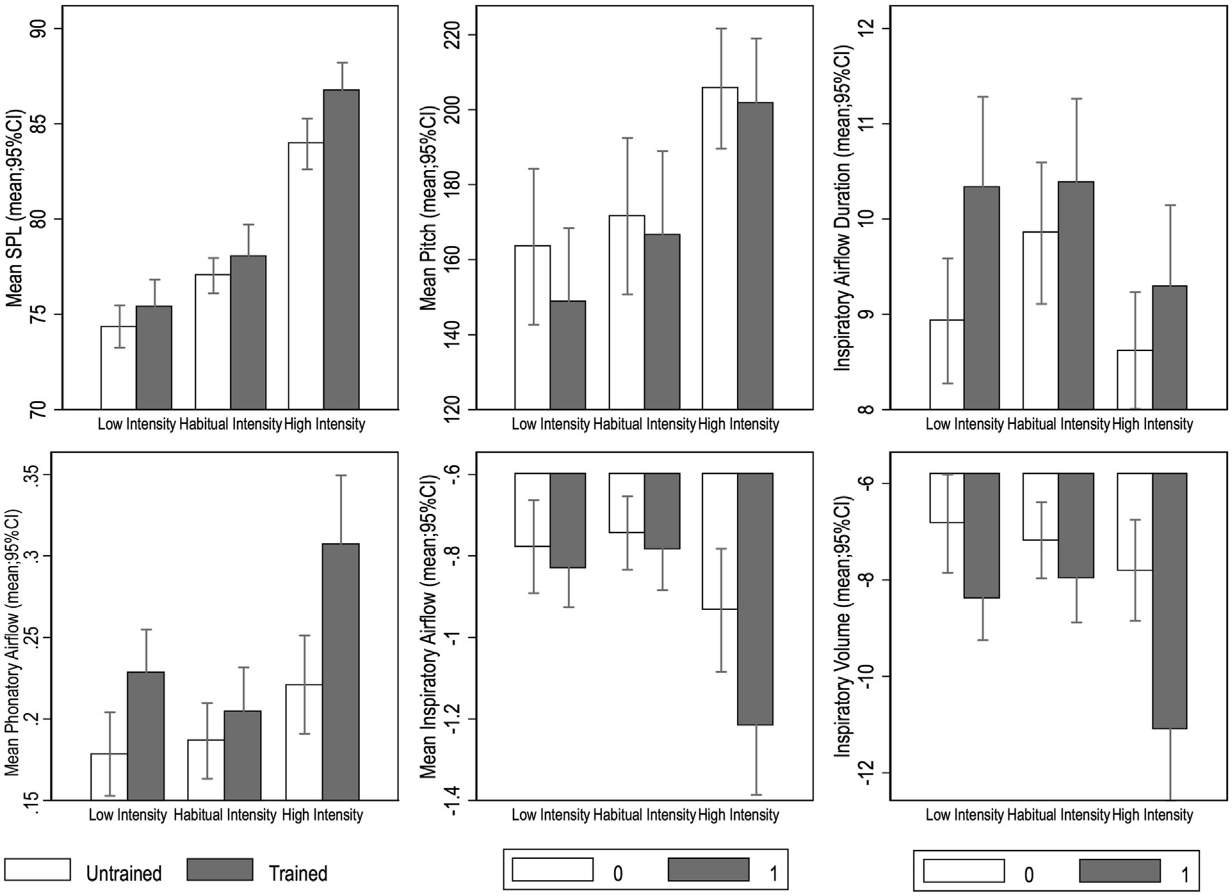

FIGURE 8. Results from univariate analysis for running speech protocol.

inspiratory airflow duration ($r = -0.1112$, $P = 0.2347$); mean F_0 versus inspiratory airflow duration ($r = -0.1485$, $P = 0.1116$); mean F_0 versus mean expiratory airflow ($r = -0.1767$, $P = 0.0577$); mean F0 versus mean inspiratory airflow ($r = 0.0171$, $P = 0.8552$); mean F0 versus inspiratory volume ($r = 0.1236$, $P = 0.1861$).

DISCUSSION

As theater actors and actresses spend several years training their voices, it would be expected that they would have differences compared with untrained subjects. Most earlier investigations regarding actor's voices used acoustic analysis and some differences have been found, being one of the most studied the so-called AF. The purpose of the present study was to compare actors/actresses's voices with untrained voices through aerodynamic and EGG analyses. We hypothesized that glottal and respiratory function should also reflect technical and physiological differences between vocally trained and untrained subjects. Inspection of the results revealed that main differences between groups were found in speech respiratory measures.

Overall, running speech protocol demonstrated more evident differences between groups than the rest of the protocols used in the present study. This was demonstrated in both univariate and multivariable analyses. The latest showed significant differences for all parameters in running speech protocol, whereas the other two protocols showed differences only in few variables. This may suggest that connected speech may be more sensitive than vowel productions when comparing training status. Considering that multivariable analysis is stronger and more reliable, only results obtained from this analysis will be discussed in the following.

Results showed higher values of mean phonatory airflow for vocally trained participants during sustained vowel phonation and running speech. From the aerodynamic point of view, this difference may be explained by a lower glottal resistance and/or a higher subglottic pressure in trained participants. Likely, the higher subglottic pressure demonstrated by actors and actresses compared with untrained participants in this study is the most suitable explanation for glottal flow differences. Moreover, no difference in aerodynamic glottal resistance is concordant to the lack of difference in CQ we found during both comfortable sustained phonation and voice efficiency protocols. These findings were in line with earlier investigations, where no significant differences in CQ were observed when actresses and untrained female voices were compared.[24,25] Furthermore, a study of acoustic analysis by Master et al reported no clear differences throughout varying loudness levels in the difference between the amplitude level of the fundamental frequency (L_0) and amplitude level of the first formant (L_1) between actors and nonactors. L1-L0 is a measure obtained from long-term average spectrum that is associated

TABLE 3.
Results From Multivariable Linear Regression Analysis for Running Speech Protocol

Independent Variable	Mean SPL (dB)	Mean Pitch (Hz)	Inspiratory Airflow Duration (s)	Mean Phonatory Airflow (L/s)	Mean Inspiratory Airflow (L/s)	Inspiratory Volume (L)
Gender	2.13 (1.18; 3.09); $P < 0.000$	−66.76 (−75.07; −58.45); $P < 0.000$	−0.07 (−0.68; 0.53); $P = 0.802$	0.05 (0.03; 0.07); $P < 0.000$	−0.16 (−0.25; −0.07); $P = 0.001$	−1.51 (−2.28; −0.75); $P < 0.0001$
Training	1.66 (0.706; 2.62) $P = 0.001$	−8.92 (−17.23; −0.62); $P = 0.035$	0.86 (0.25; 1.47); $P = 0.006$	0.05 (0.03; 0.07); $P < 0.000$	−0.12 (−0.22; −0.03); $P = 0.006$	−1.91 (−2.68; −1.14); $P < 0.0001$
Intensity						
Habitual	Reference	Reference	Reference	Reference	Reference	Reference
High	7.78 (6.62; 8.95); $P < 0.0001$	34.63 (24.50; 44.75); $P < 0.0001$	−1.16 (−1.91; −0.42); $P = 0.002$	0.06 (0.04; .09); $P < 0.0001$	−0.308 (−0.42; −0.19); $P < 0.0001$	−1.84 (−2.78; −0.90); $P < 0.0001$
Low	−2.62 (−3.80; −1.45); $P < 0.0001$	−13.85 (−24.04; −3.66); $P = 0.008$	−0.49 (−1.24; 0.25); $P = 0.194$	0.008 (−0.017; 0.033); $P = 0.528$	−0.041 (−0.154; 0.071); $P = 0.469$	−0.047 (−0.98; 0.89); $P = 0.921$

with the mode of phonation (degree of vocal folds adduction).[26–28] Based on our findings and earlier works, apparently the glottal source has a weak contribution when differentiating the training status in speaking voice. However, an investigation carried out to compare female vocally trained and untrained subjects, the $L_1 - L_0$ difference was significantly greater for actresses' than nonactresses' voices in both habitual and loud intensity levels.[23] This suggests a stronger F_0 than F_1 in the actresses group, which could reflect less glottal adduction and hence a more flow mode of phonation in the vocally trained participants when compared with the nonactresses.

Because subglottic pressure is positively associated with overall intensity of voice,[29–32] a higher SPL would be expected for trained participants. This, in fact, occurred during the same phonatory tasks that showed higher subglottic pressure. Moreover, a strong positive correlation was observed between SPL and mean subglottic pressure. Additionally, this difference in SPL is concordant to previous investigations.[24,25]

Assuming that actors and actresses used better breath support than untrained participants, our findings could be comparable with earlier investigations carried out in singing voice, where supported and unsupported phonation were compared. Sonninen et al[33] found that supported singing was characterized by a higher subglottic pressure. Results from Griffin et al[34] study showed higher SPL, higher average glottal airflow, and lower open quotient of the glottis in supported singing compared with unsupported singing. The results of another study conducted by Sonninen et al[35] suggest that the difference between supported and unsupported voice is not categorically dualistic, but it is gender and task dependent. In some tasks, subglottic pressure was higher in supported voice, but in others, either no significant correlation existed between subglottic pressure and perceived support or the relationship was polynomial; this indicates that the optimum would be reached at intermediate subglottic pressure values.

Regarding control of subglottic pressure during voice production, Leanderson et al[36] suggested that abdominal muscles may contribute to this. Nevertheless, these findings seems to be in some contrast to data by Watson and Hixon,[37] who concluded that the role of the abdominal musculature is mainly one of posturing the chest wall, whereas subglottic pressure control appears to be the major role of the rib cage.

Normally, when subglottic pressure is increased, SPL is expected to be greater, as well as fundamental frequency. Gramming and Sundberg[38] reported that on average, speakers and singers increase the mean of the speaking F_0 by about 0.4 semitones per 1 dB increase. Nevertheless, our findings showed lower values of fundamental frequency for trained participants in all loudness levels during running speech task. This dissociation between SPL and mean pitch demonstrated for actor and actresses may reflect a better vocal control, ie, subjects with voice training could have the ability to increase overall intensity, but not necessarily with an increment in F_0. Similar results were previously found in a study performed with female participants.[23] A decreased F_0 may be the result of shorter, thicker,

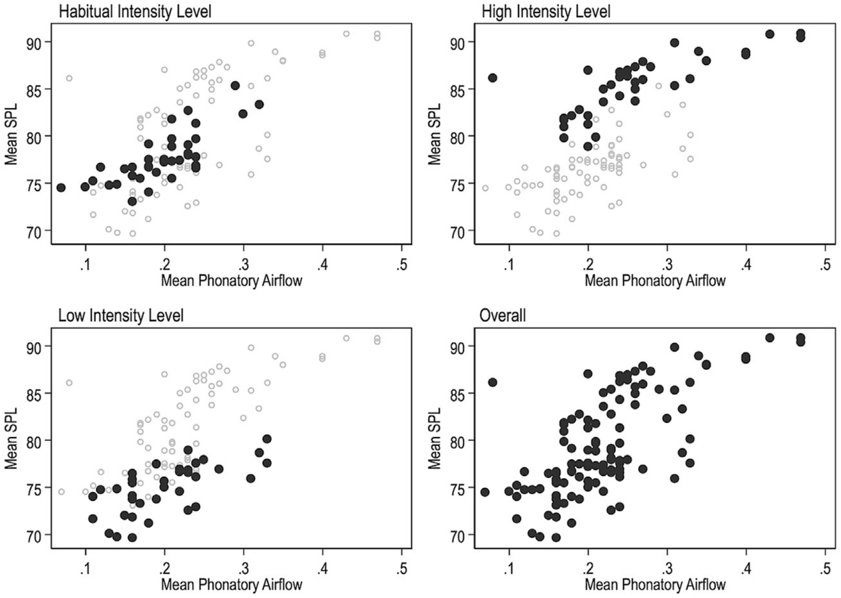

FIGURE 9. Correlation analysis between SPL and mean phonatory airflow throughout loudness levels.

and more relaxed vocal folds, generating less intense glottal adduction.[39] Interestingly, in previous works regarding actors, it was observed that the perception of projection and good voice quality was negatively correlated to F_0: lower values F_0 likely represent improved projection.[6,9] No significant differences for F_0 have also been reported when comparing actors and nonactor's voices.[9]

Considering that vocally trained subjects reached higher SPL and subglottic pressure levels than untrained subjects, without increasing glottal adduction (measured through CQ and aerodynamic glottal resistance), it is plausible that the main subsystem participating in the intensity increment in actors is the respiratory system by increasing the breath support (more muscle activity in abdominal and lower ribs areas) and consequently the subglottic pressure.

During running speech protocol, interesting outcomes were evidenced for inspiratory variables. Trained participants demonstrated longer time for inspiration, higher values for mean inspiratory airflow and also higher values for inspiratory volume than untrained subjects. These findings may be related to the better management of breathing function that actors and actresses are supposed have due to years of voice training. This could also be a suitable explanation for results demonstrated in phonatory airflow and subglottic pressure. Recall that both aerodynamic variables showed higher values for vocally trained participants. It seems that respiratory function is the main

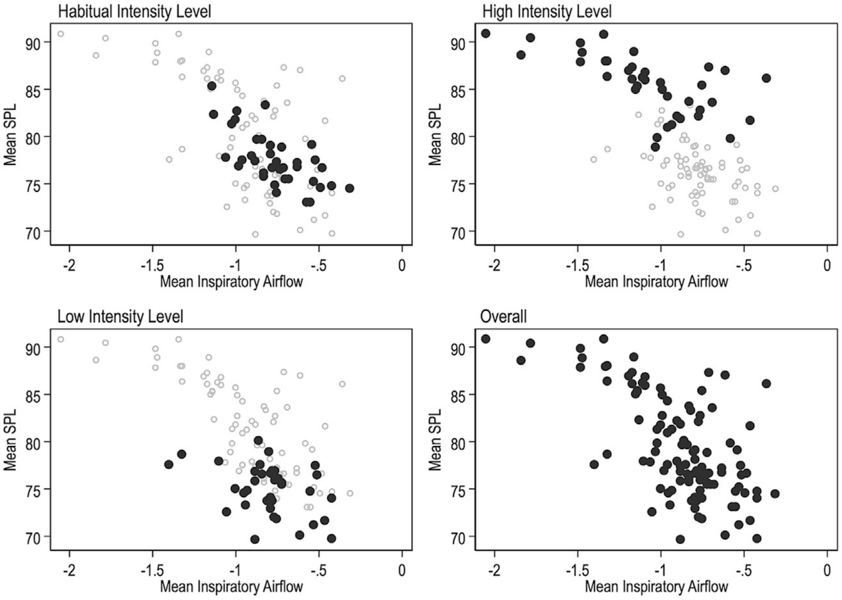

FIGURE 10. Correlation analysis between SPL and mean inspiratory airflow throughout loudness levels.

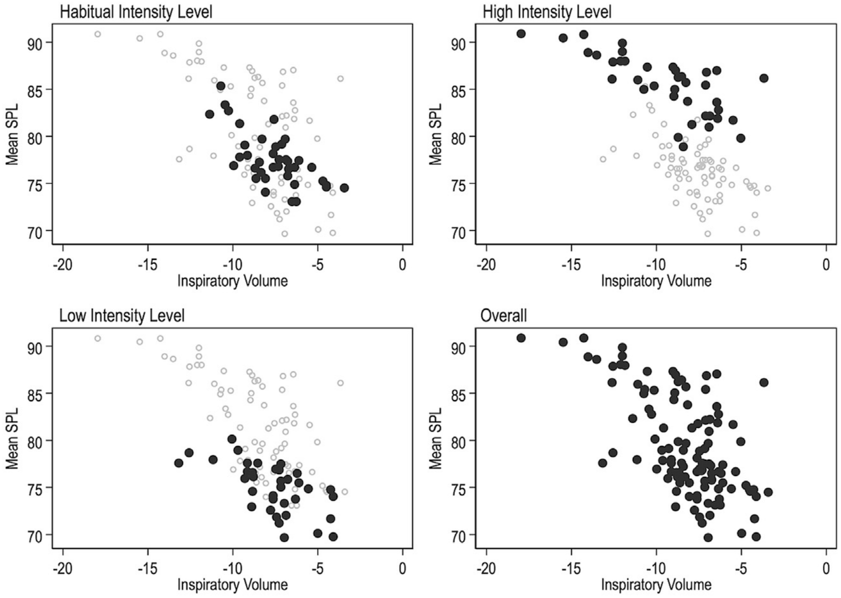

FIGURE 11. Correlation analysis between SPL and mean inspiratory volume throughout loudness levels.

aspect to differentiate the degree of voice training in the present study. Similar to our findings, Iwarsson et al[40] in a study aimed to evaluate lung volume on the glottal voice source, found that with decreasing lung volume, subglottal pressure, and glottal leakage tended to decrease. Moreover, in an investigation of speech breathing kinematics in actors, Watson et al[41] observed that participants used higher lung volumes and greater volume excursions when they were asked to perform monolog performances (projected voice) compared with conversational discourse.

These findings related to inspiratory variables may have also contributed to the higher SPL observed in trained subjects for all loudness levels. In fact, a strong correlation was found between SPL with mean inspiratory airflow and SPL with inspiratory volume. Likely, a longer inspiration time allows a deeper inspiration, greater inspiratory airflow, and greater inspiratory volume. All this, in turn, may help to build a higher subglottic pressure, which may produce a greater SPL in actors and actresses compared with untrained subjects. In addition, a good positive correlation was evidenced between SPL and aerodynamic power, which is defined as phonatory airflow times subglottic pressure.

Regarding gender differences, it is interesting to note that for all phonatory tasks, male participants demonstrated slight but significantly higher values than females for mean phonatory airflow. Literature in general has reported no consistent findings for phonatory airflow rate. Our results are consistent with a large number of studies, which have reported that males demonstrate significantly greater airflow rates in comparison with females.[42–48] However, no significant differences have been found for this parameter[49–52] and also higher values have been observed for females than males.[53]

In our outcomes, CQ and aerodynamic efficiency were also lower for male participants. From the physiological point of view is concordant that these two variables plus glottal airflow move together. When there is a decreased CQ (glottal adduction), one should expect a higher value of phonatory airflow and lower aerodynamic efficiency.

No significant differences were found for subglottic pressure and glottal resistance when gender was compared. Previous studies comparing aerodynamic characteristics in males and females have reported the same results.[54,55]

In addition, mean inspiratory airflow and inspiratory volume demonstrated higher values for male than female participants. Our results are concordant to previous findings.[55] This would imply a more open glottis during inspiration and more vital capacity for male than female subjects. Earlier studies have demonstrated that men have a greater vital capacity than women.

Significant changes throughout differing loudness levels were demonstrated for mean SPL, subglottic pressure, glottal resistance, CQ, and aerodynamic power. Similarly, Stathopoulos and Sapienza[56] examined several aerodynamic variables during changes in vocal intensity in normal adult male and female speakers with normal voice. Subjects were required to produce phonatory tasks at three intensity levels (soft, comfortable, and loud). Laryngeal airway resistance for both males and females was found to consistently increase as vocal intensity increased.

In a previous investigation aimed to assess patterns of breath support in projection of voice, results revealed that breathing patterns changed little when singers increased the intensity of their voice projection.[57] On the other hand, other studies[56,58,59] have indicated a relationship between the sound intensity of voice and the lung volumes used, in particular that at higher intensities both speakers and singers tend to breath at higher lung volumes.

CONCLUSIONS

Based in our findings and earlier works, apparently, the glottal source has a weak contribution when differentiating the training status in speaking voice. More prominent changes between vocally trained and untrained participants are demonstrated in respiratory-related variables. Specifically, actors and actresses seem to reflect a greater degree of vocal training through higher subglottic pressure, higher phonatory airflow, longer time for inspiration, higher values for mean inspiratory airflow and also higher values for inspiratory volume than untrained subjects. These findings may be related to the better management of breathing function (better breath support) in vocally trained participants.

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