Electroglottographic Analysis of Actresses and Nonactresses' Voices in Different Levels of Intensity

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Summary: Background. Previous studies with long-term average spectrum (LTAS) showed the importance of the glottal source for understanding the projected voices of actresses. In this study, electroglottographic (EGG) analysis was used to investigate the contribution of the glottal source to the projected voice, comparing actresses and nonactresses' voices, in different levels of intensity.

Method. Thirty actresses and 30 nonactresses sustained vowels in habitual, moderate, and loud intensity levels. The EGG variables were contact quotient (CQ), closing quotient (QCQ), and opening quotient (QOQ). Other variables were sound pressure level (SPL) and fundamental frequency (F_0). A KayPENTAX EGG was used. Variables were inputted in a general linear model.

Results/Discussion. Actresses showed significantly higher values for SPL, in all levels, and both groups increased SPL significantly while changing from habitual to moderate and further to loud. There were no significant differences between groups for EGG quotients. There were significant differences between the levels only for F_0 and CQ for both groups.

Conclusion. SPL was significantly higher among actresses in all intensity levels, but in the EGG analysis, no differences were found. This apparently weak contribution of the glottal source in the supposedly projected voices of actresses, contrary to previous LTAS studies, might be because of a higher subglottal pressure or perhaps greater vocal tract contribution in SPL. Results from the present study suggest that trained subjects did not produce a significant higher SPL than untrained individuals by increasing the cost in terms of higher vocal fold collision and hence more impact stress. Future researches should explore the difference between trained and nontrained voices by aerodynamic measurements to evaluate the relationship between physiologic findings and the acoustic and EGG data. Moreover, further studies should consider both types of vocal tasks, sustained vowel and running speech, for both EGG and LTAS analysis.

Key Words: Actresses–Actors–EGG–Sound level–Contact quotient–Closing quotient–Opening quotient.

INTRODUCTION

Several perceptual and acoustics differences between the actor's voice and the regular speaking voice have been reported. Most of these vocal characteristics are related to the performance requirements that actors and actresses need to accomplish during acting. They are needed for effective vocal projection, having the ability to produce a voice that is loud enough to hear in various performance spaces while using minimum vocal effort.[1] Moreover, other vocal features such as the mean pitch, intonation, and timbre features are also changed during performance to express different emotions to play a specific character.[2–4]

Researchers have tried to objectively describe what a good voice quality in performers is. One of the most important attributes that characterizes a well trained and, hence, a good actor's voice quality, is the so-called "resonant voice." According to Titze,[5] resonant voice is defined as a voice production that is both easy to produce and vibrant in the facial tissues, particularly on the alveolar ridge and adjacent facial plates. The perception of "ease" and "vibrancy" belongs primarily to the person producing the sound, but listeners can have similar perceptions. Moreover, it has been described as a voice that projects well[6] and is characterized by large harmonic content in the high part of the spectrum.[5] Therefore, resonant voice should be considered a goal in voice training for performers, and in fact it has been an important component in vocal pedagogy for a long time.

Although this concept is commonly used among voice trainers and professional voice users, the biomechanics, aerodynamics, and acoustic nature of resonant voice are not completely understood. Resonant voice could be the result of three main factors: (1) vocal tract changes, (2) changes of laryngeal adduction, and (3) an interaction between the voice source and filter.

Vocal tract changes cause the formant frequencies to shift. These changes in the vocal tract formants might produce a voice that projects well and has good harmonic content. In this regard, the "actor's" or "speaker's formant" has been widely linked to the concept of resonant voice in performers. Leino,[7] using a long-term average spectrum, found a peak around 3.5 kHz as a differentiating feature of good voice quality and named this peak the "actor's formant." The author also reported that poor voice quality was different from good voice quality by the steepest spectral slope. Leino[7] suggested that the spectral slope declination has a perceptual relevance in the evaluation of voice quality. A gentle spectral slope and a prominent peak at 3 and 4 kHz seem to be some of the features often characterizing a good male speaking voice. Nolan[8] suggested that the

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actor's formant is accomplished in the same way as the singer's formant according to Sundberg.[9] That is, when the cross-sectional area of the epilaryngeal tube opening is sufficiently different from the cross-sectional area of the low pharynx. In a study designed to investigate the origin of the "speaker's formant," it was found that after voice exercises were performed by a professional male actor, the strong peak at 3.5 kHz was present in all vowels and it was mainly formed by the clustering of F_4 and F_5. The results of modeling from the same study suggested that a speaker's formant could be obtained through a slight narrowing of the epilaryngeal region, widening of the back of the mouth cavity, and narrowing of the front part of it.[10]

This acoustic feature that characterizes a good voice has not only been observed in performers but also in ordinary speakers with good voice quality. Leino,[11] in a study conducted to seek the voice quality of normal vocally untrained male university students, reported that the good voices differed from the poor voices by having a more prominent peak at 3–4 kHz.

The actor's formant would help the production of effective vocal projection during acting. This is essential for performers, making it possible for their voices to be heard by the listeners with maximum intelligibility and minimum vocal effort. In this regard, Pinczower and Oates[1] pointed out that when comparing the intensity difference between the higher (2–4 kHz) and lower (0–2 kHz) regions of the spectrum in voice samples from the maximal projected condition, LTAS demonstrated increased acoustic energy in the higher region of the spectrum. This characteristic was not as evident in the comfortable projected condition. These outcomes offered some preliminary support for the existence of an actor's formant (prominent peak in the upper part of the spectrum) during maximal projection. Using acoustic and perceptual analyses, Master et al[12] compared male actors and nonactors. Outcomes showed that actor's voices were perceived as louder and better projected than nonactor's voices, even though sound pressure level (SPL) did not differ between the groups. This could suggest that not only SPL influence the perception of voice projection. In fact, they found a stronger peak at about 3.4 kHz (actor's formant) in actors, which might have affected the perception of projected voice. Furthermore, the alpha ratio was also greater in the actors (less step spectral tilt). Master et al,[13] in a similar study performed with actresses, did not find statistical significant differences in the spectral slope declination assessed with alpha ratio. Additionally, there was no evidence of an actor's formant cluster in the actresses' voices. Authors concluded that voice projection for this group of actresses seemed to be mainly a result of a laryngeal setting instead of vocal tract resonances.

A second factor that would contribute to the production and perception of resonant voice quality is the source-filter interaction. It has been proposed that by narrowing the laryngeal vestibule, producing a narrow anterior constriction or an artificial lengthening of the vocal tract induces an increase in vocal tract impedance, specifically resulting in changes in the inertive reactance.[14,15] This in turn would cause more skewing of the glottal airflow, increasing the energy of the higher frequency harmonics, and producing a richer voice quality. Furthermore, the oscillation threshold pressure is reduced by increased vocal tract inertance.[15] Vocal tract impedance appears to impact at least two components of voice source function: (1) glottal flow pulse and (2) vibrational characteristics of the vocal folds. The acoustic pressures propagating in the vocal tract affect the glottal flow pulse shape and hence the overall harmonic energy in the acoustic output signal. The second component is the mechano-acoustic interaction of the vocal tract pressures, which influences the vibrational characteristics of the vocal folds.[14] All these characteristics produce a more perceptually resonant voice quality.

In a study to test the hypothesis that resonant voice is produced by narrowing the laryngeal vestibule and is characterized by first formant tuning and more ample harmonics, Smith et al[16] reported that spectral analysis showed that first formant tuning was exhibited during resonant voice productions and that the degree of harmonic energy in the range of 2.0–3.5 kHz was related to voice quality: nonresonant voice had the least amount of energy in this range, a resonant-relaxed voice had more energy, and a resonant-bright voice had the greatest amount of energy. Videoendoscopic data indicated that laryngeal vestibule constriction was not consistently associated with resonant voice production.

Not only vocal tract changes and the source-filter interaction can contribute to a resonant voice quality but also a specific laryngeal configuration (glottal adduction) is an important factor by itself. A barely abducted, or a barely adducted, laryngeal configuration maybe favorable to produce a resonant voice.[17] Specifically, barely abducted vocal folds have been proposed to produce maximum "vocal economy" defined as the maximized ratio between voice output (dB) and intraglottal impact stress (kPa) under constant subglottic pressure and frequency conditions.[18] Previous studies indicated that vocally, healthy, trained subjects produced resonant voice with barely abducted, or barely adducted, vocal folds, and thus a configuration within the range of those producing maximum vocal economy.[19] Verdolini et al[17] conducted a study with vocally trained subjects to observe whether the electroglottographic (EGG) contact quotient (CQ) could be used to noninvasively distinguish resonant from other voice types. Results showed that the average contact quotient distinguished resonant from pressed voice but inconsistently distinguished resonant from breathy voice. Furthermore, no significant difference was found in CQ during resonant and normal productions. In a more recent study, Grillo and Verdolini[20] attempted to determine if pressed, normal, resonant, and breathy voice qualities can be distinguished from one another by laryngeal resistance and/or vocal efficiency in vocally trained subjects. Findings indicated that laryngeal resistance but not vocal efficiency reliably distinguished pressed, normal, and breathy voice. Neither of the measures, however, distinguished normal from resonant voice, which were distinguished perceptually.

Peterson et al[19] assessed several EGG and aerodynamic parameters during pressed, normal, resonant, and breathy vocal productions in vocally trained participants. The results indicate that for the vowel /a/ and /i/ (not for /u/), the contact quotient provides a sensitive tool for distinguishing the voice types in physiologically interpretable directions. Moreover, regarding aerodynamic features, the maximum flow declination rate was greatest in pressed and resonant voice and lowest during normal and breathy voice. In addition, the peak-to-peak amplitude flow (AC) showed higher values for resonant and breathy voice, whereas for normal and pressed voices, it was lower. For minimum flow, pressed, resonant, and normal voice produced low values, whereas high values were obtained in breathy voice productions.

Most of the studies aimed to investigate the differences between actors and nonactors have been performed with male participants. Moreover, most of them have focused on vocal tract changes instead of vocal fold vibration aspects, which could influence the voice quality. Master et al[13] compared actresses' and nonactresses' voices through acoustic analysis. One of the acoustic variables that they sought was the level difference between the F_1 and fundamental frequency (F_0) regions (L1–L0), which provides information on the mode of phonation. Despite the fact that this parameter is not a direct measure of vocal fold behavior, it has been correlated to the degree of glottal adduction.[21–23] The L1–L0 difference was significantly greater for nonactresses' than for actresses' voices in both habitual and loud intensity levels. This suggests a lower and stronger F_0 than F_1 in the actresses group, which could reflect less glottal adduction for the same SPL. It was also found a correlation between speaking F_0 and L1–L0 difference at habitual levels. Authors speculated that decreased phonation frequency values maybe the result of shorter, thicker, and more relaxed vocal folds, generating less intense glottal adduction.

Through glottal contact, closing, and opening quotients, the present study sought to identify a possible contribution of glottal source to the projected voice in different levels of intensity when comparing actresses' and nonactresses' voices. This study is the continuation of the last mentioned investigation carried out with female performers.

METHODS

Participants

Thirty actresses and 30 nonactresses were included in this study. The average age of the subjects was 26 years, with a range of 20–50 years. Inclusion criteria for actresses included: (1) more than 5 years of theater acting experience, (2) at least 1 year of formal vocal training, and (3) no current or past record of voice disorders. Inclusion criteria for nonactresses included: (1) the same age range as actresses, (2) no current or past record of vocal disorders, and (3) no professional use of the voice. Participant from both groups were native Brazilian Portuguese speakers.

Phonatory tasks

Participants from both actresses and nonactresses groups were asked to sustain the vowels /a/, /i/, and /u/ for 5 seconds, in three different levels of intensity (habitual, moderate, and loud). This resulted in a total number of 540 samples (60 subjects × 3 vowels × 3 intensity levels). Actresses were instructed to project their voice during recordings. One of the authors of the present study perceptually controlled that actresses really succeed in projecting the voice during recordings.

Equipment

EGG data were obtained with an EGG, model 6103 (KayPENTAX, Lincoln Park, NJ) connected to a *Computerized Speech Lab* (*CSL*), model 4500, which in turn was connected to a desktop computer running a *Real-Time EGG Analysis* software (KayPENTAX), model 5138. To measure SPL, audio recordings were performed simultaneously with EGG data collection. Acoustic output was measured at a constant microphone-to-mouth distance of 15 cm, using a Shure MS-48 microphone connected to the *CSL* (model 4500) in a sound-treated room. Samples were recorded digitally at a sampling rate of 44 kHZ with 16 bits/sample quantization. Audio signal was calibrated using a 220 Hz tone produced with a sound generator for further sound level measurements. The sound level of this reference sound was measured with a sound level meter (MINIPA MSL 1351C, Pares Electronica, Brazil), also positioned at a distance of 15 cm from the generator. After recordings, the relative sound level values were obtained using the software *Multidimensional Voice Profile* (KayPENTAX, Lincoln Park, NJ).

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 elastic band and electrodes were necessary in some participants until the EGG signal was clearly visualized in the *Real-Time EGG Analysis* software. The quality of the EGG signal was monitored permanently throughout the recordings.

Variables

For the EGG analysis, the first and last second of each sample were excluded. Once the stable sections were selected, the following variables were obtained for the vowels /a/, /i/, and /u/ throughout the three intensity levels (habitual, moderate, and loud):

1) SPL (dB)
2) EGG measurements
    - F_0 (Hz): number of cycles of vocal folds vibration per second.
    - Contact quotient (%): closing quotient plus opening quotient, that is the ratio of the duration of the "contact phase" to the entire glottal cycle period.
    - Opening quotient (%): ratio between opening phase and total time of the glottal cycle. Measured in %.
    - Closing quotient (%): ratio between closing phase and total time of the glottal cycle. Measured in %.

Values obtained from vowels /a/, /i/, and /u/ were added and divided by three to obtain a single mean value.

Statistical analysis

Statistical analysis was performed using the software *Statistical Package for the Social Sciences* (*SPSS*, v.13.0; IBM SPSS Statistics, Armonk, NY). Data were described by mean, median, standard deviation, minimum values, maximum values, and quartiles for each variable. The *t* test was used to compare data between groups considering the interaction effect between two factors: groups (actresses and nonactresses) and intensity level (habitual, moderate, and loud). A *P*-value <0.05 was considered to be significant.

RESULTS

The mean age of the actresses group was 30 ± 5.8 years, whereas the mean age of nonactresses group was 22 ± 8.7 years. Despite the young population, actresses reported at least 1 year of formal voice training, understanding formal vocal training as regular university courses taught by acting professors and/or speech-language pathology specialist in performing voice technique. Some of the actresses also reported other types of voice training during short periods, aimed specifically at the development of theatrical vocal skills.

Table 1 summarize mean values and dispersion measurements of SPL (dB) and F_0 (Hz) for actresses and nonactresses. Actresses showed statistically significant higher values of mean SPL for the three intensity levels: habitual ($P = 0.03$), moderate ($P = 0.02$), and loud ($P = 0.01$). There was also a significant increase of SPL for both groups from habitual to moderate ($P = 0.02$) and from moderate to loud ($P = 0.03$). This indicates that actresses and nonactresses produced a difference when they were asked to increase loudness. There was no statistically significant difference for F_0 values between groups throughout the three intensity levels. On the other hand, there was a significant change in F_0 values across the intensity levels, that is, F_0 increased with the intensity, from habitual to moderate and moderate to loud for both groups ($P = 0.00$).

Mean values and dispersion measurements of EGG (%) variables in three intensity levels by group are shown in Table 2. There was no significant difference between groups for contact quotient. CQ increased significantly with the intensity level only from habitual to loud for both actresses and nonactresses groups. Moreover, there was no significant difference between groups and intensities for closing and opening quotients.

All *P*-values for the three loudness levels and all variables included in the present study are presented in Table 3 for both groups.

DISCUSSION

The primary goal of this study was to evaluate whether vocal fold vibration has any contribution to the voice quality when comparing projected actresses' voices with nonactresses' voices. Specifically, the question was if actresses' voices demonstrate any difference on EGG parameters as compared with the other group. Participants were asked to produce sustained vowels in three different intensity levels. The data indicated that groups did not differ significantly in any of the EGG variables. Contact, closing, and opening quotients were roughly the same for both groups throughout the different intensity levels. Nevertheless, there was a clear difference in the sound level measurements between groups.

Because actors and actresses usually need to project their voices during performing by increasing the sound level, it is quite important to consider the sound level measurements. Additionally, another reason to take into account the intensity values is because it might influence the others variables included in the present study such as F_0 and EGG quotients. Although, in the literature, there is no consensus about ranges for habitual, moderate, and loud phonations, we consider,

TABLE 1.
Quartiles, Minimum, Maximum, Mean, and SD Values for Acoustic Measures in Habitual, Moderate, and Loud Loudness by Group

		SPL			F_0		
Groups	Frequencies	Habitual (dB)	Moderate (dB)	Loud (dB)	Habitual (Hz)	Moderate (Hz)	Loud (Hz)
Actresses (n = 30)	Minimum	64.76	67.68	75.19	177.52	204.53	222.13
	1st Quartile	72.05	77.73	83.11	212.22	235.45	276.4
	Median	75.30	80.61	86.42	236.54	263.33	303.93
	3rd Quartile	77.55	83.46	88.57	253.92	280.81	329.75
	Maximum	81.43	86.89	91.14	286.88	309.31	393.33
	Mean	74.53	79.9	85.16	233.64	260.36	301.82
	SD	4.41	4.55	4.50	26.95	29.12	39.94
Nonactresses (n = 30)	Minimum	60.97	64.11	67.25	188.01	213.16	213.89
	1st Quartile	67.64	73.74	77.87	223.55	241.37	273.61
	Median	70.77	75.93	81.69	241.74	260.33	302.86
	3rd Quartile	74.88	80.51	83.8	259.74	290.36	323.39
	Maximum	82.77	87.54	95.17	314.62	357.02	446.35
	Mean	71.62	76.82	81.5	241.65	270.01	304.18
	SD	5.33	5.05	5.66	28.08	37.95	51.09

Abbreviation: SD, standard deviation.

TABLE 2.
Quartiles, Minimum, Maximum, Mean, and SD Values for EGG Measures in Habitual, Moderate, and Loud Loudness by Group

		Contact Quotient			Closing Quotient			Opening Quotient		
Groups	Frequencies	Habitual (%)	Moderate (%)	Loud (%)	Habitual (%)	Moderate (%)	Loud (%)	Habitual (%)	Moderate (%)	Loud (%)
Actresses (n = 30)	Minimum	35.09	35.44	34.82	7.44	7.58	6.66	20.93	21.21	22.70
	1st Quartile	40.28	42.07	44.07	9.17	9.21	10.06	28.61	28.66	30.27
	Median	45.68	44.74	46.91	11.67	10.21	11.79	33.83	34.17	34.28
	3rd Quartile	47.11	49.23	51.30	14.12	16.09	18.14	37.03	36.96	38.21
	Maximum	53.40	54.28	56.27	24.01	24.39	36.50	50.83	41.39	49.97
	Mean	44.50	45.42	47.17	12.68	13.06	14.66	32.99	32.96	34.34
	SD	4.95	4.68	4.91	4.47	5.30	7.04	6.13	5.63	6.31
Nonactresses (n = 30)	Minimum	36.61	39.53	38.58	8.81	8.40	8.45	26.35	20.67	16.30
	1st Quartile	42.53	44.54	45.46	11.13	11.12	11.11	29.40	30.01	32.20
	Median	45.83	46.08	48.70	11.90	13.42	12.68	32.51	33.40	35.07
	3rd Quartile	48.54	49.48	52.39	14.02	14.74	15.35	35.22	36.91	38.07
	Maximum	53.86	53.57	55.43	34.23	28.27	26.26	38.78	54.95	58.28
	Mean	45.49	46.74	48.60	14.77	14.46	14.06	32.38	33.92	35.36
	SD	4.07	3.79	4.00	6.65	4.92	4.21	3.43	6.05	7.98

Abbreviation: SD, standard deviation.

according to our clinical experience, that the values obtained in the present study are representative of both actors and nonactors population.

In regards to the sound level, inspection of the results demonstrates that the significant higher SPL values were obtained for actresses than nonactresses across the three intensity levels. Therefore, vocally trained subjects reached higher intensity levels than untrained subjects without producing a higher glottal adduction (measured through CQ) as compared with nonactresses' voices (recall that there was no difference in CQ between groups). From these results, one question comes to mind. If EGG parameters did not contribute to the higher mean of sound level in the actresses group, what could be the possible explanation for these findings?

The total radiate sound level might be influenced by three main systems: the glottal source, respiratory system, and vocal tract. More specifically, several variables contribute to SPL such as glottal adduction, subglottic pressure, F_0, and formant frequencies.[24–26] In regard to the supraglottal cavities, changes cause the formant frequencies to shift. These changes in the vocal tract formants might produce a voice that projects well and has good harmonic content. Related to this, the actor's or speaker's formant has been widely linked to the concept of projected voice in actors.[7,8,11,12] Therefore, it is possible to speculate that some vocal tract adjustments might be a good explanation for the higher SPL found in the actresses group in the present study. Nonetheless, in a previous study conducted by Master et al,[13] the same subject groups were evaluated to observe whether there are any spectral distribution differences between groups during a reading task. The spectral tilt (alpha ratio) and the amplitude and frequency of the actor's formant region were assessed. No significant differences between groups were found for alpha ratio at either level, and there was no evidence of an actor's formant cluster in the actresses' voices. The authors conclude that voice projection does not seem to be mainly a result of vocal tract resonances adjustments in this group of actresses. Considering these outcomes, it is unlikely that vocal tract changes are the explanation for the SPL differences between groups in the present study.

TABLE 3.
***P*-Values for the Three Loudness Levels and All Variables for Both Groups**

	Actresses			Nonactresses		
Variables	HL_ML	ML_LL	HL_LL	HL_ML	ML_LL	HL_LL
SPL	$P = 0.000$	$P = 0.000$	$P = 0.000$	$P = 0.000$	$P = 0.001$	$P = 0.000$
F_0	$P = 0.000$	$P = 0.007$	$P = 0.000$	$P = 0.000$	$P = 0.002$	$P = 0.000$
Contact quotient	$P = 0.465$	$P = 0.225$	$P = 0.041$	$P = 0.163$	$P = 0.070$	$P = 0.004$
Closing quotient	$P = 0.771$	$P = 0.839$	$P = 0.210$	$P = 0.324$	$P = 0.772$	$P = 0.948$
Opening quotient	$P = 0.987$	$P = 0.256$	$P = 0.406$	$P = 0.374$	$P = 0.437$	$P = 0.084$

Abbreviations: HL, habitual level; ML, moderate level; LL, loud level.

Another plausible explanation could also emerge from the outcomes of these two studies. Despite that in both studies, the same subject groups were used, different phonatory tasks were required: a read-aloud task and sustained vowels for the study by Master et al[13] and the present study, respectively. Possibly, during isolated sustained vowels, the vocal tract configuration, articulation, and vocal placement are easier to achieve as compared with the running speech or a reading task. These possible vocal tract adjustments could contribute to the increased sound level for the actresses' voices in the present study. This should be investigated in further studies considering both types of vocal tasks for both EGG and LTAS analysis.

A third possibility to explain the difference in sound level without changes in glottal CQ might be the contribution of the subglottic pressure. Aerodynamic parameters such as subglottic pressure, glottal flow, and glottal resistance are controlled in a coordinated way by all the systems involved in voice production process. Thus, if the degree of vocal fold adduction remains without alterations (no CQ changes), a higher sound level could also be explained by more air pressure below the glottis.

As reported by Bouhuys et al[27] and by Rubin et al,[28] SPL is regulated primarily by means of subglottic pressure. The relation between subglottic pressure and vocal intensity has been widely studied. Titze et al[29,30] indicated that SPL increases at a rate of 8–9 dB per doubling of excess pressure over phonation threshold pressure (the minimum pressure required to initiate or sustain phonation). Because in the present study, all the actresses were asked to project their voices during data collection, it is quite likely that a higher subglottic pressure could be the main reason for higher SPL in actresses than in nonactresses. Recall that all the actresses involved in this study had more than 5 years of acting experience and at least 1 year of formal acting voice training. Hence, it is possible to presume that when actresses were instructed to produce a projected voice, they used more breath support to increase the subglottic pressure without increasing the level of vocal folds adduction (higher CQ). On the other hand, participants from the nonactresses group, who did not have voice training before participating in this study, showed the same CQ as actresses with less radiate sound level. Consequently, contrary to the trained subjects, they might have used more glottal adduction instead of proper breath support.

Despite that we expected the vocally trained participants, who have had formal voice training, to have more vocal technique than untrained subjects, the former group had some difficulties when asked to produce changes in the sound level. To obtain proper data, it was necessary to repeat the tasks several times until they reached the experimental goals. Perhaps 1 year of voice training is not a long enough period to acquire the necessary vocal technique to easily and accurately control the degree of sound level. Nevertheless, this period could be adequate to develop a good enough breath support to increase the subglottic pressure without necessarily increasing the glottal adduction during sustained vowels.

As mentioned in the introduction, the resonant voice quality is a goal for performers, in both speaking and singing voice. Even though, some vocal coaches do not use this terminology and maybe they are not informed about the physiology behind this voice quality, many do instruct their students to produce a type of voice that projects well, produces facial tissue vibration, and without laryngeal effort. In fact, this type of phonation mode has been used in theater and singing pedagogy for decades[31] and more recently has also been used for voice rehabilitation.[32] According to Verdolini et al, resonant voice is defined as a voicing pattern involving oral vibratory sensations, particularly on the alveolar ridge and adjacent facial plates, in the context of what subjects perceive as easy phonation. Previous studies have reported that vocally, healthy, trained subjects produced resonant voice with barely abducted, or barely adducted, vocal folds, and thus this configuration would produce maximum vocal economy, which is defined as the maximized ratio between voice output (dB) and intraglottal impact stress (kPa) under constant subglottic pressure and frequency conditions. This glottal configuration might have been used for our actresses during vowel production, and this, in turn, could have allowed a higher SPL than nonactresses without increasing the glottal adduction reflected on the CQ values. Interestingly, actresses in the present study are regularly instructed during their voice technique classes to use the type of voice that could be defined as resonant voice. In this regard, it could be stated that voice training possibly helps to avoid a high vocal fold impact stress, which is considered to be one of the most important factor that contribute to vocal trauma, such as nodules and polyps.[33]

Previous studies support the possible connection between EGG CQ and the degree of vocal fold impact stress. Verdolini et al[33] explored the possible use of the EGG contact quotient as a noninvasive estimate of vocal fold impact stress. They suggested that it strongly correlates with the degree of glottal impact stress. EGG is a noninvasive method to obtain the information of the varying contact between the vocal folds during vibration.[34] When impact stress increases (stronger collision during vibration), vocal folds also tend to stay together longer and hence CQ rises.[33] Glottal CQ has also been reported to distinguish some modes of phonation, specifically resonant from pressed voice.[17] Furthermore, Laukkanen et al, proposed a noninvasive measurement to quantify the cost of voice production in terms of impact stress, the quasi-output cost ratio, which is defined as (SPL/CQ from EGG signal) × [period length (T)/T_0]. Findings revealed that it correlated inversely with CQ. Thus, it seems to reflect voice production-related mechanical loading.[35]

Considering the possible association between CQ and vocal fold impact stress supported by the cited studies, our results could suggest that trained subjects did not produce a significant higher SPL than untrained individuals by increasing the cost in terms of higher vocal fold collision and hence more impact stress. Contrarily, they probably used another physiologic strategy to reach a higher radiate sound from the mouth. This assumption is concordant to the results obtained in a previous study carried out with the same subject groups.[13] The difference between the amplitude level of the F_0 and first formant (L1–L0) was measured to explore the characteristics of the mode of phonation. L1–L0 has been correlated to the degree of glottal adduction.[21–23] The L1–L0 difference was significantly greater for actresses' than nonactresses' voices in both habitual and loud intensity levels. This suggests a lower and 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. In terms of aerodynamic measurements, flow phonation has been defined as "the type of phonation that has the highest possible glottogram amplitude that can be combined with a complete glottal closure."[22] Inspection of inverse-filtered waveforms for flow phonation in fact reveals a slightly positive minimum flow offset, implying barely abducted vocal folds.[17] Future researches should explore the difference between trained and nontrained voices by aerodynamic measurements to obtain more physiologic findings and compare them with the acoustic and EGG data.

In relation to the EGG variables, we have discussed only the contact quotient so far. However, the closing and opening quotients could have an important effect on sound level as well. The faster the closing time of the vocal folds is in relation to the open time, the more abrupt the glottal airflow is interrupted. This in turn produces a more effective conversion from aerodynamic to acoustic energy. This would facilitate higher SPL and more harmonic energy in the spectral region of 2–5 kHz.[36] The amplitude of higher harmonics are particularly sensitive to the phase velocity of closing phase of the vibration cycle (ie, the speed at which the airflow decreases at the end of open phase). For example, the faster the speed of closure, the greater the subglottic pressure, which produces the most intense high harmonics of the spectrum. In other words, the more suddenly the air-jet is interrupted, the higher the sound intensity will be, specially, in the high-frequency components. Even though in the present study, the closing time for the three intensity levels was shorter (faster closing) for actresses than nonactresses, the difference was not statistically significant. Therefore, this EGG variable would not explain the difference in SPL between groups.

Another interesting outcome in the present study is that F_0 increased significantly as the intensity level was greater. Subjects produced the lowest F_0 for habitual intensity, with higher F_0 for moderate intensity, and the highest F_0 for loud voice. The same results were obtained when participants read a text in two different intensity levels in the previous study by Master et al[13] with the same participants. Statistically significant differences for F_0 were demonstrated from habitual to loud levels for both groups. Vocal intensity and voice F_0 are normally interdependent; Gramming and Sundberg[26] reported that on the average, speakers and singers increase the mean of the speaking F_0 by about 0.4 semitones per 1 dB increase. Therefore, subjects habitually tend to raise fundamental frequency as they raise subglottic pressure.[24] Additionally, Titze et al found that subglottic pressure is raised not only for regulating vocal loudness but also to overcome phonation threshold pressure, which increases with increasing fundamental frequency. The vocal folds get stiffer and therefore need a higher driving pressure at higher fundamental frequencies.[30]

CONCLUSION

In summary, the present study demonstrated that SPL was significantly higher among actresses in all intensity levels, but in the EGG analysis, no differences were found. This apparently weak contribution of the glottal source in the supposedly projected voices of actresses, contrary to previous LTAS studies, might be because of a higher subglottal pressure or perhaps greater vocal tract contribution in total radiate SPL. Results from the present study could suggest that trained subjects did not produce a significant higher SPL than untrained individuals by increasing the cost in terms of higher vocal fold collision and hence more impact stress. Future researches should explore the difference between trained and nontrained voice by aerodynamic measurements to obtain more physiologic findings and compare them with the acoustic and EGG data. Moreover, further studies should consider both types of vocal tasks sustained vowel and running speech for both EGG and LTAS analysis.

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