Vocal Economy in Vocally Trained Actresses and Untrained Female Subjects

*Suely Master, †Marco Guzman, and ‡Jayme Dowdall, *São Paulo, Brazil, †Santiago, Chile, and ‡Boston, Massachusetts

Summary: Objectives. Vocally trained actresses are expected to have more vocal economy than nonactresses. Therefore, we hypothesize that there will be differences in the electroglottogram-based voice economy parameter quasi-output cost ratio (QOCR) between actresses and nonactresses. This difference should remain across different levels of intensity.

Methods. A total of 30 actresses and 30 nonactresses were recruited for this study. Participants from both groups were required to sustain the vowels /a/, /i/, and /u/, in habitual, moderate, and high intensity levels. Acoustic variables such as sound pressure level (SPL), fundamental frequency (F0), and glottal contact quotient (CQ) were obtained. The QOCR was then calculated.

Results. There were no significant differences among the groups for QOCR. Positive correlations were observed for QOCR versus SPL and QOCR versus F0 in all intensity levels. Negative correlation was found between QOCR and CQ in all intensity levels. Considering the differences among intensity levels, from habitual to moderate and from moderate to loud, only the CQ did not differ significantly. The QOCR, SPL, and F0 presented significant differences throughout the different intensity levels.

Conclusion. The QOCR did not reflect the level of vocal training when comparing trained and nontrained female subjects in the present study. Both groups demonstrated more vocal economy in moderate and high intensity levels owing to more voice output without an increase in glottal adduction.

Key Words: Vocal economy–Impact stress–Vocal loading–Contact quotient–Actors.

INTRODUCTION

Vocal economy is defined as the ratio between voice output (decibels) and intraglottal impact stress (kilopascal) under constant subglottic pressure and frequency conditions. This is a way of measuring the maximum vocal output with the least amount of stress on the larynx. According to Verdolini et al,[1] barely abducted vocal folds are required to produce a maximum vocal economy during phonation. Maximum vocal economy is an important goal in both voice therapy and voice training. From the physical point of view, the impact stress or collision stress is the impact force divided by the contact area of the vocal folds. In other words, it describes how strongly the vocal folds collide during vibration.[2]

High fundamental frequency (F0), high sound pressure level (SPL), and high glottal adduction are expected to increase the degree of impact stress on vocal fold tissues; therefore, a higher possibility of vocal fold trauma is plausible.[3] High impact stress has also been associated to high subglottic pressure.[2–4] At extremely low subglottic pressures, the vocal folds vibrate, but with amplitude so small that the folds never collide. On the other hand, if subglottic pressure is increased, vocal fold collision normally occurs.[3,5]

The softer tissues of the lamina propria are the most likely structures to absorb most of the impact stress during phonation. Moreover, there is evidence to suggest that impact stress is the main vocal loading and traumatizing factor during voice production. Hence, impact stress is the main cause of vocal fold nodules and other traumatic lesions of the superficial lamina propria.[3,6] Vocal fold nodules are considered to be the consequence of vocal trauma and, more specifically, a tissue reaction to repeated localized mechanical stress to vocal tissues.[6,7]

In an attempt to quantify vocal economy, Berry et al[8] proposed the output-cost ratio (OCR). This is defined as the amount of acoustic output obtained during phonation divided by the amount of mechanical stress on vocal folds tissue. The OCR was measured in excised canine larynges using a pressure transducer. The authors concluded that OCR can be optimized as a function of the glottal width, and that the barely abducted laryngeal configuration could be a general target relevant for both subject with glottal hyperfunction and hypofunction.

Several studies have measured vocal fold impact stress in human subjects.[9–13] However, this procedure is not practically performed in routine daily practice in voice clinic. This measurement requires the placement of a sensor between the vocal folds themselves during phonation under topical anesthesia.[11,13]

Less-invasive measures of vocal economy have been proposed. Titze and Laukkanen[14] presented the ratio between the maximum flow declination rate (MFDR) and the maximum area declination rate (MADR) as a measure of vocal economy. This is based on the fact that an increase in MFDR would imply in a more sound output with less mechanical stress on the vocal fold tissue when the MADR in the glottis does not increase proportionately. The ratio between alternating and direct currents that flow through the glottis during phonation has also been proposed as another measure of vocal economy.[15]

Accepted for publication May 9, 2013.

From the *Department of Performing Arts, UNESP—Universidade Estadual Paulista, Campus São Paulo, São Paulo, Brazil; †University of Chile, School of Communication Sciences, Santiago, Chile; and the ‡Department of Otology and Laryngology, Harvard Medical School, Massachusetts Eye and Ear Infirmary, Brigham and Women's Hospital, Boston, Massachusetts.

Address correspondence and reprint requests to Suely Master, Department of Performing Arts, UNESP—Universidade Estadual Paulista, Campus São Paulo, R. Dr. Bento Teobaldo Ferraz 271, CEP 01423040, São Paulo, Brazil. E-mail: suely.master@uol.com.br

Journal of Voice, Vol. 27, No. 6, pp. 698-704
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2013.05.005

Verdolini et al[16] reported that the glottal contact quotient (CQ) correlates with the degree of impact stress. This provided a foundation for Laukkanen et al[17] to propose a new, noninvasive estimate of OCR, the quasi-OCR (QOCR). Authors then presented the QOCR, which simply modified the equation proposed by Berry et al.[8] The QOCR or economy ratio was calculated as QOCR = (SPL [dB]/CQ EGG) × (T/T0), where SPL is the sound pressure level, CQ EGG is the CQ measured from electroglottogram (EGG) signal, T is the period length, and T0 is the period length for the mean F0 in speech (0.005 seconds in females and 0.01 seconds in males). In the study to validate QOCR, female subjects with and without voice training were assessed. Findings showed that teachers had a higher QOCR than the students in loud speech. In another study designed to estimate vocal economy, the QOCR was used to investigate the relationship among perceived voice quality, self-reported symptoms of vocal fatigue, and vocal economy vis-via the QOCR, in kindergarten teachers.[18]

The present study investigates voice economy via the QOCR between vocally trained actresses and untrained nonactresses. The QOCR measurements are also recorded at different intensity levels. Correlations between acoustic variables and QOCR were also studied. We hypothesize that the actresses should demonstrate a higher vocal economy (higher QOCR) than nonactresses because formal vocal instruction is based on a well-projected voice with minimal phonatory effort.

METHODS

Participants

A total of 30 vocally trained actresses and 30 untrained nonactresses were included in this study. The average age of the subjects was 26 years, with a range of 20–50 years. The mean age of the actresses group was 30 ± 5.8 years, whereas the mean age of the nonactresses group was 22 ± 8.7 years. Inclusion criteria for actresses included: more than 5 years of theater acting experience, at least 1 year of formal vocal training, and no current or past history of voice disorder. Inclusion criteria for nonactresses included: the same age range as actresses, no current or past history of vocal disorders, no professional use of the voice, and no previous experience in voice training. Participants from both groups were native Brazilian Portuguese speakers recruited at the Universidade Estadual Paulista, Campus São Paulo, São Paulo, Brazil.

Phonatory tasks

Participants were asked to produce sustained vowels (/a/, /i/, and /u/) for at least 5 seconds, in three different intensity levels (habitual, moderate, and high). A total of 540 samples (60 subjects × 3 vowels × 3 intensity levels) were obtained. Actresses were asked to project their voice during recordings. During data collection, a measurement of perception of intensity was recorded by the analyst to verify the level of intensity.

Equipment

The EGG evaluations were performed with a KayPentax electroglottograph (KayPENTAX, Lincoln Park, NJ), model 6103 connected to a *Computerized Speech Lab* (CSL), model 4500 (KayPENTAX, Lincoln Park, NJ). A *Real-Time EGG Analysis* software (KayPENTAX), model 5138 was used to control and analyze EGG signals. 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 (Shure, Niles, IL) 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 the recordings, the relative sound level values were obtained using the software *Multidimensional Voice Profile*.

Before the recordings, each participant was seated comfortably in an upright position. Two surface electrodes were attached over the thyroid cartilage with an elastic neckband. The electrodes were attached with a Velcro strip, which was comfortably wrapped on the participant's neck on each side of his/her thyroid lamina. The elastic neckband was sufficiently tight as to ensure adequate electrode-to-skin contact. Readjustments of the elastic band and electrodes was 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, only the middle part of each signal was analyzed. 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 high):

1. SPL (decibel)
2. EGG measurements
   - F0 (hertz): number of cycles of vocal folds vibration per second.
   - CQ: contact quotient plus opening quotient, that is, the ratio of the duration of the "contact phase" to the entire glottal cycle period.

The QOCR values were then calculated according to the formula proposed by Laukkanen et al.[17]

$$QOCR = (SPL[dB]/CQ\ EGG) \times (T/T0)$$

Given that all of the participants are females, T0 was set at 5 milliseconds, corresponding to 200 Hz.

Values obtained separately from vowels /a/, /i/, and /u/ for all the variables were averaged to obtain a single mean value to neutralize the articulation setting of the vocal tract.

Statistical analysis

Statistical analysis was performed using the software *Statistical Package for the Social Sciences* (*SPSS*, version13.0; IBM

TABLE 1.
Descriptive Statistics for Sound Pressure Level (SPL), Fundamental Frequency (F0), and Contact Quotient (CQ) by Intensity and Groups

		SPL (dB)			F0 (Hz)			CQ		
Groups	Frequencies	Habitual	Moderate	High	Habitual	Moderate	High	Habitual	Moderate	High
Actresses (n = 30)	Minimum	59.05	67.68	75.19	177.52	204.53	222.13	0.35	0.37	0.35
	Percentiles									
	25	70.88	77.73	83.10	212.22	235.45	276.40	0.41	0.43	0.44
	50	74.97	80.61	86.42	236.54	263.33	303.93	0.46	0.45	0.47
	75	77.48	83.46	88.57	253.92	280.81	329.76	0.47	0.50	0.51
	Maximum	81.43	86.89	91.14	286.88	309.30	393.33	0.53	0.55	0.56
	Mean	73.90	79.90	85.16	233.64	260.37	301.82	0.44	0.46	0.47
	SD	5.13	4.55	4.50	26.95	29.12	39.94	0.05	0.05	0.05
Nonactresses (n = 30)	Minimum	60.97	64.11	67.25	188.01	213.16	213.89	0.37	0.40	0.39
	Percentiles									
	25	67.55	73.65	77.87	223.55	243.05	273.85	0.43	0.45	0.46
	50	70.65	75.78	81.50	241.74	260.16	303.04	0.46	0.48	0.49
	75	74.08	80.00	83.55	259.74	289.01	327.23	0.49	0.51	0.53
	Maximum	82.77	87.54	95.17	314.62	357.02	446.35	0.54	0.54	0.56
	Mean	71.38	76.60	81.17	241.65	269.62	305.76	0.46	0.48	0.49
	SD	5.25	4.99	5.46	28.08	37.32	50.88	0.04	0.04	0.04

Abbreviation: SD, standard deviation.

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 among the groups considering the interaction effect between two factors: groups (trained actresses and non-actresses) and intensity level for QOCR (habitual, moderate, and high). A *P* value lower than 0.05 was considered to be significant. Pearson's correlation coefficient (*r*) was used to measure the strength of the association among the variables at 0.01.

This study was reviewed and approved by the Universidade Estadual Paulista, Department of Performing Arts in São Paulo, Brazil.

RESULTS

Descriptive statistics for SPL, F0, and contact quotient are described in Table 1. The SPL did not differ among groups in habitual loudness, but the SPL did differ for moderate ($P = 0.00$) and high ($P < 0.01$) loudness. The F0 and contact quotient (CQ)

TABLE 2.
Descriptive statistics for Quasi-Output Cost Ratio (QOCR) by intensity and groups

		QOCR		
Groups	Frequencies	Habitual	Moderate	High
Actresses (n = 30)	Minimum	140.20	162.66	170.43
	Percentiles			
	25	169.94	191.93	246.63
	50	192.07	227.29	276.69
	75	211.20	255.44	301.94
	Maximum	322.49	348.53	442.06
	Mean	197.05	229.41	277.29
	SD	38.64	42.66	58.29
Nonactresses (n = 30)	Minimum	137.93	161.39	176.78
	Percentiles			
	25	171.97	186.81	212.92
	50	185.20	208.59	256.32
	75	213.50	242.49	279.40
	Maximum	246.92	363.41	451.91
	Mean	190.50	219.24	256.69
	SD	30.34	45.13	57.16

Abbreviation: SD, standard deviation.

TABLE 3.
Values of the Pearson Correlation for the Acoustic Variables and the QOCR by Intensity

Sound Pressure Level			Fundamental Frequency			Contact Quotient		
Habitual	Moderate	High	Habitual	Moderate	High	Habitual	Moderate	High
0.55*			0.67*			−0.48*		
	0.60*			0.73*			−0.59*	
		0.61*			0.78*			−0.57*

Abbreviation: QOCR, quasi-output cost ratio.
* Correlation is significant at the 0.01 level (two tailed).

did not show differences among the groups in all loudness levels. Descriptive statistics for QOCR are presented in Table 2. There were no significant differences among the groups.

Considering the differences in SPL, by intensity level, only the CQ did not show significant differences. The QOCT, SPL, and F0 presented significant differences throughout different intensity levels ($P > 0.03$).

Correlations between acoustic variables and QOCR by intensity are presented in Table 3 and Figures 1–3. Significant, moderate, and positive correlations were observed for SPL and F0 versus QOCR in all loudness. The CQ versus QOCR showed a significant, moderate, and negative correlation in all intensity levels.

DISCUSSION

Exploring the concept of vocal economy, as defined by the ratio between voice output (decibel) and intraglottal impact stress (kilopascal), one would expect that in general the vocally trained subjects demonstrate higher values of QOCR owing to high SPL and low CQ. Because vocal instruction for theater actors (who do not routinely use amplification systems) emphasizes good voice projection without vocal effort, it is reasonable to assume that this training would be reflected in a measure of vocal economy, QOCR.[17,18] Despite the actresses demonstrating a higher QOCR than nonactresses, the differences did not reach statistical significance. Different results were obtained by Laukkanen et al.[17] in a study designed to evaluate vocal economy in vocally trained and untrained

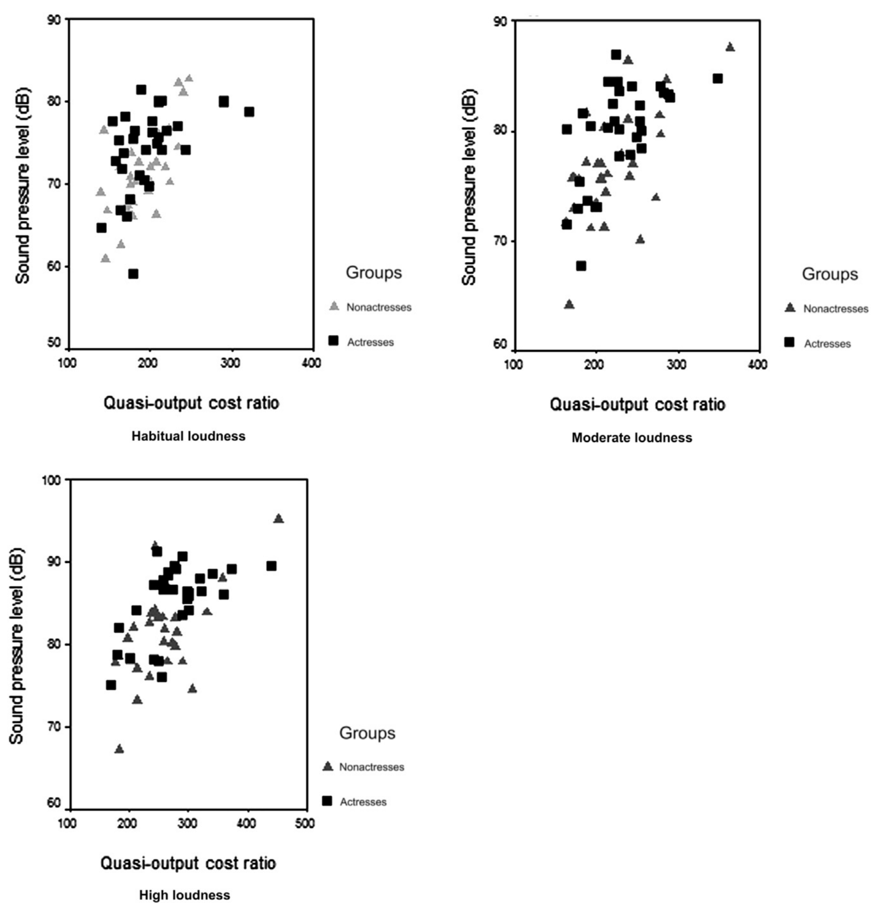

FIGURE 1. Correlation between quasi-output cost ratio and sound pressure level in habitual, moderate, and high intensities.

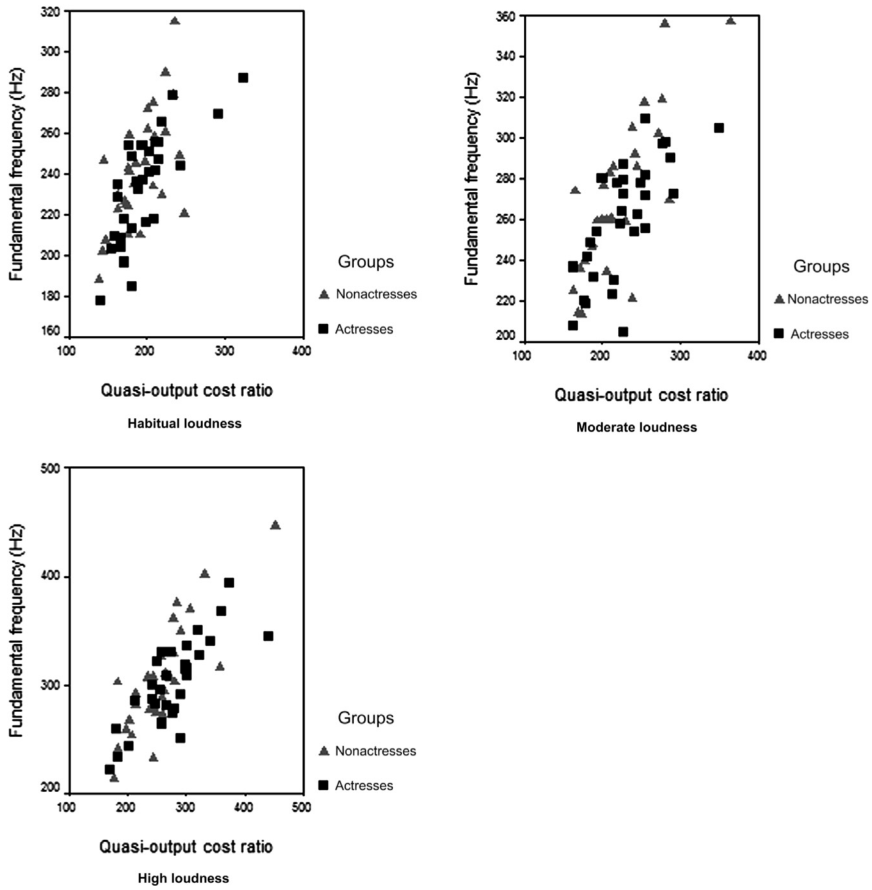

FIGURE 2. Correlation between quasi-output cost ratio and fundamental frequency in habitual, moderate, and high intensities.

subjects. More vocally experienced participants (teachers) demonstrated significant higher values for QOCR when compared with the students. According to the authors, these findings may support the beneficial effects of both voice training and experience. In a later investigation, Kankare and Laukkanen[18] evaluated kindergarten teachers. The outcomes showed QOCR for kindergarten teachers somewhere in the middle: QOCR lower than trained students and higher than untrained students in the study by Laukkanen et al.[17] These data appear to corroborate the assumption that the QOCR increases with the level of vocal training or experience.

Jiang and Titze[3] reported that the impact stress increases with the degree of SPL, F0, and glottal adduction. Thus, when there is low SPL, F0, and CQ, low impact stress should be expected. Results from the study by Laukkanen et al[17] concur with the previous statement. Authors found lower F0, SPL, and CQ values in trained speakers when compared with untrained speakers. In the present study, no differences among groups were found for F0, SPL, and CQ in habitual loudness level. By extension, this is also true when comparing among groups for QOCR.

Although we see, in moderate and high intensity, actresses demonstrated higher values of SPL than nonactresses, QOCR values did not differ among groups. Possibly, the SPL differences among groups were not enough to significantly affect the QOCR value.

Earlier studies demonstrated a positive linear relationship between CQ and impact stress.[16,19] Furthermore, modes of phonation (defined by different glottal widths) have also been related to glottal impact stress, for example, pressed phonation should demonstrate a high degree of impact stress, whereas breathy phonation a low impact stress.[3] Consequently, a negative relationship should be expected between glottal adduction and vocal economy. In the present study, a significant, moderate, and negative correlations between CQ and QOCR were obtained in all loudness levels for both actresses and nonactresses. Our results are concordant with earlier studies performed with the vocal economy measure QOCR.[17,18] In both investigations, there was an inverse correlation among those variables.

Regarding the relationship between CQ and vocal fold impact stress, our results may indicate that actresses did not produce a significant higher SPL than untrained speakers in moderate and high loudness levels by increasing the cost in terms of higher vocal fold collision (no CQ increase was observed). They may have used another physiologic strategy to produce a higher acoustic output. This seems to be supported by the acoustic findings obtained in an earlier study with the same subject groups.[20] The difference between the amplitude level of the F0 and first formant (L1–L0) was assessed to explore the characteristics of the mode of phonation. The L1–L0 has been correlated to the degree of glottal adduction.[21–23]

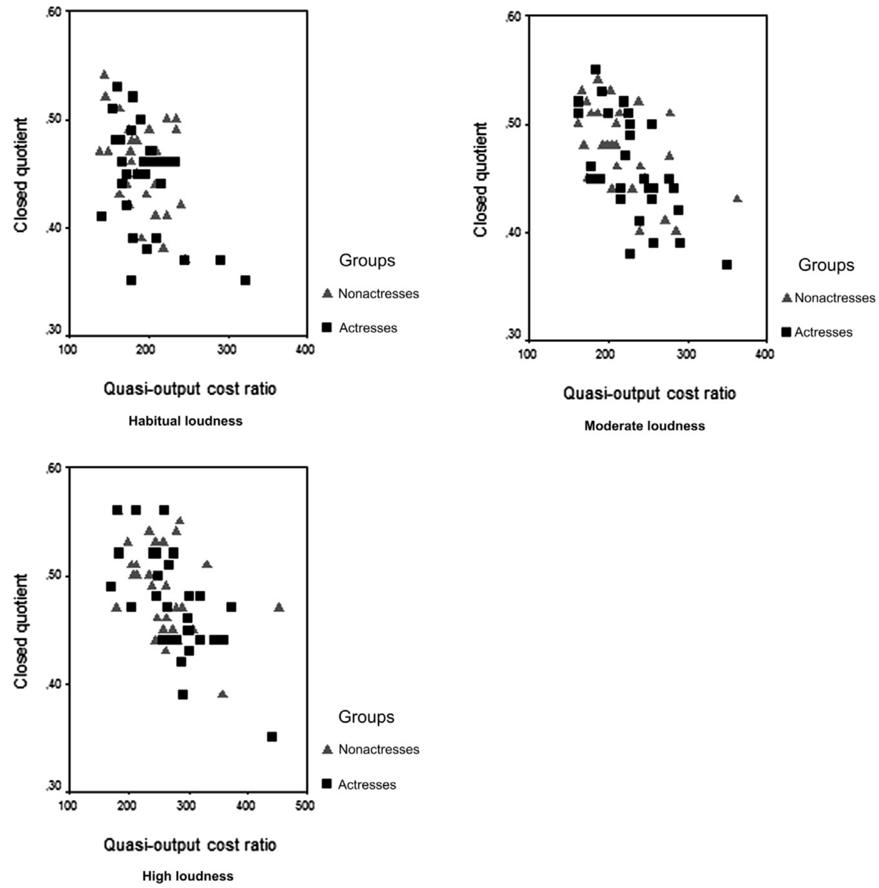

FIGURE 3. Correlation between quasi-output cost ratio and contact quotient in habitual, moderate, and high intensities.

The actresses showed significantly lower L1–L0 values than nonactresses. This may reflect less glottal adduction and hence a more flow mode of phonation in the vocally trained participants. In terms of aerodynamic measurements, flow phonation has been defined as “that type of phonation that has the highest possible glottogram amplitude that can be combined with a complete glottal closure.”[22]

The QOCR versus F0 demonstrated a negative correlation in the study by Laukkanen et al.[17] The same correlation was found in a later investigation.[18] However, in the present work, a positive correlation between F0 and QOCR was demonstrated. Previous researchers have pointed out that high F0 is associated with high values of glottal impact stress.[3] Therefore, an increase in F0 would be linked to less economic voice production. Supporting this statement, Horácek et al[2] reported that high values of F0 produce greater vocal fold tissue acceleration and deceleration than low F0. Because tissue acceleration is considered a loading factor owing to it is association with more impact stress,[2,24] it is possible to infer that a high F0 might contribute toward a low vocal economy. However, in a simulation study,[4] the degree of impact stress was found to be inversely related to F0. A likely reason for this is that the maximum glottal opening (maximum amplitude of vibration) decreases as F0 increases owing to increase in vocal fold stiffness.

The relationship between QOCR and SPL is the least consistent among studies. A positive correlation was found among these variables in the present study. Earlier studies have demonstrated negative[17] and no correlation,[18] respectively. Regarding the formula of the QOCR, the SPL is located in the numerator; hence when it increases, the quotient SPL/CQ also increases and this in turn would affect in the same way the final QOCR value. On the other hand, from the physiologic point of view, an increased SPL would imply more impact stress[3,4] and hence less vocal economy. The SPL increase is most likely owing to an increased subglottic pressure, which in turn would produce an increment in the tissue acceleration and impact stress.[24] Nevertheless, if this increment of SPL is carried out without a proportional increase in glottal adduction, the vocal economy should not decrease, but rather increase instead (more radiated sound with less intraglottal impact stress).

In the present study, the mean QOCR value showed an increase from habitual to moderate and from moderate to high intensity levels. The SPL and F0 also demonstrated an incremental change. On the other hand, CQ did not show significant differences neither in actresses nor in nonactresses throughout the intensity levels. These changes are interesting from the physiologic point of view because despite SPL and F0 increased together, the QOCR did not demonstrate a decrease (less vocal economy), likely owing to the lack of changes in the glottal CQ throughout the loudness levels. In practical terms, this may indicate that participants from both the groups were able to demonstrate a higher voice output without a glottal adduction increase. Therefore, in moderate and high intensity vocal productions, more vocal economy was observed than in habitual intensity. One should expect that vocally trained speakers demonstrate more SPL (more vocal projection) without an increase of impact stress, but not necessarily untrained participants. Thus, QOCR seems to be not able to reflect the effect of voice training in the voice use when comparing trained and untrained subjects in the present study. Additionally, the fact that SPL and F0 varied but CQ remained constant is surprising because CQ vary not only with phonation type but also with SPL and F0.[1,25]

Our results showed that F0 increased significantly as the intensity level was greater. Subjects produced the lowest F0 for habitual intensity, with higher F0 for moderate intensity, and the highest F0 for loud voice. This relation is in line with the earlier studies. Vocal intensity and voice F0 are normally interdependent.[26–28]

CONCLUSION

The vocal economy QOCR was not able to significantly reflect the level of vocal training or experience when comparing trained and untrained subjects in the present study. Considering the increase in SPL from habitual to moderate and from moderate to high intensity levels, both actresses and nonactresses demonstrated more vocal economy in moderate and high intensity levels than in habitual intensity owing to more voice output without an increase in glottal adduction.

REFERENCES

1. Verdolini K, Druker DG, Palmer PM, Samawi HJ. Laryngeal adduction in resonant voice. *J Voice*. 1998;12:315–327.
2. Horácek J, Laukkanen AM, Sidlof P, Murphy P, Svec JG. Comparison of acceleration and impact stress as possible loading factors in phonation: a computer modeling study. *Folia Phoniatr Logop*. 2009;61:137–145.
3. Jiang JJ, Titze IR. Measurement of vocal fold intraglottal pressure and impact stress. *J Voice*. 1994;8:132–144.
4. Horácek J, Laukkanen AM, Sidlof P. Estimation of impact stress using an aeroelastic model of voice production. *Logoped Phoniatr Vocol*. 2007;32:185–192.
5. Enflo L, Sundberg J. Vocal fold collision threshold pressure: an alternative to phonation threshold pressure? *Logoped Phoniatr Vocol*. 2009;34:210–217.
6. Titze IR. Mechanical stress in phonation. *J Voice*. 1994;8:99–105.
7. Titze IR. *Principles of Voice Production*. Englewood Cliffs, NJ: Prentice Hall; 1994.
8. Berry DA, Verdolini K, Montequin DW, Hess MM, Chan RW, Titze IR. A quantitative output-cost ratio in voice production. *J Speech Lang Hear Res*. 2001;44:29–37.
9. Reed CG, Doherty ET, Shipp T. Direct measurement of vocal fold medial forces. *Am Speech Hear Assoc Rep*. 1992;34:131(A).
10. Verdolini K, Hess MM, Titze IR, Bierhals W, Gross M. Investigation of vocal fold impact stress in human subjects. *J Voice*. 1999;13:184–202.
11. Yamana T, Kitajima K. Laryngeal closure pressure during phonation in humans. *J Voice*. 2000;14:1–7.
12. Gunter HE, Howe RD, Zeitels SM, Kobler JB, Hillman RE. Measurement of vocal fold collision forces during phonation: methods and preliminary data. *J Speech Lang Hear Res*. 2005;48:567–576.
13. Hess MM, Verdolini K, Bierhals W, Mansmann U, Gross M. Endolaryngeal contact pressures. *J Voice*. 1998;12:50–67.
14. Titze IR, Laukkanen AM. Can vocal economy in phonation be increased with an artificially lengthened vocal tract? A computer modeling study. *Logoped Phoniatr Vocol*. 2007;32:147–156.
15. Hillman RE, Holmberg EB, Perkell JS, Walsh M, Vaughan C. Objective assessment of vocal hyperfunction: an experimental framework and initial results. *J Speech Hear Res*. 1989;32:373–392.
16. Verdolini K, Chan R, Titze IR, Hess M, Bierhals W. Correspondence of electroglottographic closed quotient to vocal fold impact stress in excised canine larynges. *J Voice*. 1998;4:415–423.
17. Laukkanen AM, Maki E, Leppanen K. Electroglottogram-based estimation of vocal economy: 'quasi-output-cost ratio'. *Folia Phoniatr Logop*. 2009;61:316–322.
18. Kankare E, Laukkanen AM. Quasi-output-cost-ratio, perceived voice quality, and subjective evaluation in female kindergarten teachers. *Logoped Phoniatr Vocol*. 2012;37:62–68.
19. Horácek J, Laukkanen A-M, Š vec JG. Closed quotient as an estimate of impact stress: a computer modelling study. In: Proceedings AQL 2006: Advances in Quantitative Laryngology, Voice and Speech Research, October 6–7, 2006. Groningen, The Netherlands [CD-ROM]. 1–8). Groningen Voice Research Lab, University of Groningen.
20. Master S, De Biase N, Chiari BM, Laukkanen AM. Acoustic and perceptual analyses of Brazilian male actors' and nonactors' voices: long-term average spectrum and the "actor's formant". *J Voice*. 2008;22:146–154.
21. Hammarberg B, Fritzell B, Gauffin J, Sundberg J, Wedin L. Perceptual and acoustic correlates of abnormal voice qualities. *Acta Otolaryngol*. 1980;90:441–451.
22. Gauffin J, Sundberg J. Spectral correlates of glottal voice source waveform characteristics. *J Speech Lang Hear Res*. 1989;32:556–565.
23. Kitzing P. LTAS criteria pertinent to the measurement of voice quality. *J Phon*. 1986;14:477–482.
24. Jiang JJ, Shah AG, Hess MM, Verdolini K, Banzali FM Jr, Hanson DG. Vocal fold impact stress analysis. *J Voice*. 2000;15:4–14.
25. Hanson DG, Berratt BR, Berke GS. Frequency, intensity and target matching effects on photoglottographic measures of open quotient and speed quotient. *J Speech Hear Res*. 1990;33:45–50.
26. Sundberg J, Titze I, Scherer R. Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *J Voice*. 1993;7:15–29.
27. Gramming P, Sundberg J. Spectrum factors relevant to phonetogram measurement. *J Acoust Soc Am*. 1988;83:2352–2360.
28. Titze I, Sundberg J. Vocal intensity in speakers and singers. *J Acoust Soc Am*. 1992;91:2936–2946.