Changes in Glottal Contact Quotient During Resonance Tube Phonation and Phonation With Vibrato

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Summary: Phonating into narrow hard-walled tubes of varying diameters and length as an extension of the vocal tract is considered a semioccluded vocal tract exercise. Semioccluded vocal tract postures have been postulated to have a therapeutic effect during the treatment of the dysphonic patient. They appear to affect at least two components of the voice source (1) glottal flow pulse and (2) vibrational characteristics of the vocal folds. Vibrato also has been described as a possible therapeutic tool and may decrease phonatory hyperfunction. The aim of this study was to determine the influence of resonance tubes and phonation with vibrato on the closed quotient. Thirty-six adult classical singers were recruited for this study. Subjects were asked to produce four phonatory tasks at comfortable pitch and loudness: sustained vowel [a:] without vibrato, sustained vowel [a:] with vibrato, sustained phonation into a straw without vibrato, and sustained phonation into a straw with vibrato. Computer analysis of the contact quotient (CQ) was performed for each type of phonation in every participant. An increase in CQ variability was observed during tube phonation when compared with vowel phonation. Although there was a decrease in the mean CQ values when comparing vowel phonation without vibrato with the other three phonatory tasks, the difference was not statistically significant. Intrasubject analysis demonstrated a decrease in the CQ during tube and vibrato phonation in most of the participants. Although a causal relationship is not proven, this finding suggests that the use of straws and vibrato during phonation may have potential therapeutic value in the treatment of patients with hyperfunctional voice disorders.

Key Words: Contact quotient–EGG–Semioccluded vocal tract–Resonance tube–Vibrato.

INTRODUCTION

Glottal contact quotient (CQ) is a quantitative measure obtained by electroglottography (EGG). It is defined as the ratio of the duration of the contact phase to the entire glottal cycle period.[1] When the vocal folds impact stress increases (greater collisions between the vocal folds during vibration), they stay together longer during the vibratory cycle and the CQ increases.[2] The CQ also reflects the mode of phonation, being higher in more hyperfunctional voices.[3]

Resonance tube phonation is often felt to be therapeutic and used by speech-language pathologists for vocal warm-ups or rehabilitation exercises. Resonant tubes are placed between the patient's lips and either air or water. In either case, the tube acts as an artificial lengthening of the vocal tract. The name "resonance tube" comes from the strong sensation of vibrations that are felt in the lips and facial tissues during phonation into these tubes.[4]

Tube phonation belongs to a wider category of vocal exercises called semioccluded vocal tract exercises. Lip occlusive exercises, such as lip trills, tongue trills, lip buzz, and raspberries are also included in this group. Several physiological and technical benefits have been attributed to techniques involving either semiocclusion of the lips or an artificial lengthening of the vocal tract. One such benefit is an increase in vocal tract impedance, specifically resulting in changes in the inertive reactance (inertia of the air column into the vocal tract)[5,6] that may favorably impact vocal fold vibration.[5–9] Other potential benefits include decrease in phonation threshold pressure[6,9]; increased skewing of the glottal flow waveform (faster cessation of the flow) leading to strengthening of the higher harmonics[9]; more resonant voice quality and easier voice production[10]; decreased transglottal pressure[11]; and a decrease in laryngeal muscle activity.[11] Several studies have reported a change in CQ when semiocclusion is compared with traditional vowel phonation.[12–19] A change in CQ might reflect a therapeutic effect of these techniques if the force of vocal fold adduction is truly reduced. Unfortunately, most of these CQ studies have small sample sizes.

One clinical report suggested that vibrato may also have a therapeutic effect on patients with vocal hyperfunction.[20] To date, however, no study has investigated the effect of vibrato on the CQ. The present study was designed to reassess whether there are any measurable changes in glottal contact quotient during the production of phonation into resonance tubes and investigate if vibrato affects CQ (with and without resonance tube phonation).

METHODS

Participants

This study was reviewed and approved by the St. John Hospital institutional review board. Informed consent was obtained from 36 adult classical singers (23 women and 13 men). The age range of this subject set was 19–62 years with an average of 39.45 (35 years for females and 43 for males). Twelve singers were sopranos, 11 mezzo-sopranos, one alto, five tenors, five baritones, and two basses. Inclusion criteria for this study

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included (1) no history of vocal pathology in the past year and (2) at least 5 years of classical singing training. Although 40 singers were recruited, four singers did not meet the inclusion criteria. The average length of voice training of our subjects was 9.2 years, with a range of 5–20 years. Participants were recruited from three different professional choirs and one department of music at an undergraduate institution. All were asked to undergo both flexible laryngoscopy and rigid videostroboscopy to confirm the absence of laryngeal pathology.

Phonatory tasks

One of the authors (M.A.G.) provided individual demonstrations and verbal descriptions of the required phonatory tasks. Each recording session was accomplished in approximately 15 minutes with the following protocol: Each subject was asked to perform four phonatory tasks at habitual speaking pitch and loudness level: (1) sustained vowel [a:] without vibrato, (2) sustained vowel-like sound into a tube without vibrato, (3) sustained vowel [a:] with vibrato, and (4) sustained vowel-like sound into a tube with vibrato.

The tube phonation tasks were performed with plastic commercial drinking straws of 5 mm inner diameter and 33.8 cm in length. Each participant was instructed to hold the straw with one hand, straight out from the mouth. The straw was maintained a few millimeters in between the rounded lips, so that no air would leak from the mouth, and the free end was kept in the air as an extension of the vocal tract. Participants were aware that nasal air leaking should be prevented during the exercises. They also were asked to feel the perceptible vibratory sensations on the alveolar ridge, face, and head areas.

Participants were required to produce the [a:] vowel and tube phonation tasks with careful control of both pitch and loudness throughout the sequence. Each phonatory task was produced for a minimum of 4 seconds. Loudness was monitored during the sustained vowel /a/ phonation with a sound level meter (model SPL-8810; American Recorder Technologies, Simi Valley, CA) during recordings positioned at 20 cm from the participant's mouth. Because sound pressure level (SPL) values were only used to monitor voice production during examination, SPL calibration was not performed. An electronic keyboard was used to give and control the pitch. This was closely monitored subjectively by the experimenter who is a professional opera singer (M.A.G.).

Loudness level was not controlled with a sound level meter during straw phonation because of the large reduction in radiated acoustic power during phonation into a tube, in contrast with the greater radiated sound production during vowel phonation. Instead, participants were instructed to first produce a vowel [a:] at the same pitch and loudness as the previous vowel [a:] (monitored with the sound level meter) and then to carefully transition to phonating into the tube without changing the perceived effort of voicing and breathing. Participants were taught and allowed to practice this transition for 2 minutes before performing the recordings to ensure that this procedure will be optimally executed.

Loudness and fundamental frequency (F_0) control is relevant because EGG measurements can be affected by subglottic pressure. If these features are not controlled, results could be altered, especially those related to glottal resistance. Therefore, the goal was to minimize the possibility of any change in CQ that might occur due to a change in loudness and F_0. Additionally, because vertical movements of thyroid cartilage may affect the glottal CQ values during the vibrato tasks, participants were asked to produce vibrato phonations with a small extent. This requirement allowed only minimal vertical laryngeal displacement.

Recordings

EGG data were obtained with an Electroglottograph (KayPENTAX, Lincoln Park, NJ), model 6103 connected to a Computerized Speech Lab, model 4150B, which in turn was connected to a desktop computer running a *Real-Time EGG Analysis* software (KayPENTAX), model 5138, version 3.4.1 to monitor the EGG signal, CQ contour, and F_0. Samples were recorded digitally at a sampling rate of 48 kHz with 16 bits/sample quantization. EGG recordings were carried out in a quiet, dedicated voice laboratory.

At the beginning of the examination, participants were asked to sit upright in a comfortable 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 wrapped around the participant's neck as tightly as possible to prevent any movement of electrodes throughout the data collection. The elastic band and electrodes were adjusted until the EGG signal was clearly visualized. The quality of the EGG signal was monitored consistently throughout the recordings. Samples were analyzed with *EGG Analysis* software (model 5138; KayPENTAX). Values of the following measures in each phonatory task were determined: CQ mean, CQ standard deviation, F_0 mean, and F_0 standard deviation. CQ was calculated using an algorithm provided by the KayPENTAX *EGG* software that estimates the relative lengths of the closed phase in the glottal cycle at a point that is at 50% of the peak-to-peak amplitude. All measurements were calculated with a window length of 2 seconds selected from the middle part of each sample.

Statistical analysis

Statistical analysis was performed using *Stata* software version 12.1 (StataCorp. 2011; StataCorp LP, College Station, TX). CQ and F_0 differences were assessed by the Kruskal-Wallis one-way analysis of variance and *post hoc* comparisons using the Dunn test correction as a first approach. Differences in CQ among groups were assessed by analysis of covariance (ANCOVA) to include any influence of F_0 to the model as a covariate for CQ values and Tukey test for *post hoc* comparison. Values were expressed as the mean ± standard deviation. A P value <0.05 was considered to be significant. All tests were two sided.

RESULTS

The mean and standard deviation of CQ analysis for the four phases of the experiment for men and women are presented in Table 1 and in Figures 1 and 2. There is a decrease in the mean CQ values when comparing the baseline (sustained vowel /a/) with the other three phonatory tasks across all the participants. However, ANCOVA *post hoc* comparison revealed that none of the differences reached statistical significance. Tube

TABLE 1.
Mean and Variability of CQ Analysis for the Four Phases of the Experiment for Men and Women

Task	CQ (%) for Men	CQ (%) for Women	CQ Variability for Men	CQ Variability for Women
[a:] NV	46.44 ± 5.95	44.93 ± 8.48	0.78	3.1
Tube NV	41.56 ± 5.09	40.93 ± 9.10	1.15	4.01
[a:] WV	44.29 ± 5.09	42.35 ± 8.91	1.11	2.51
Tube WV	42.93 ± 4.80	42.26 ± 8.29	1.24	4.17

Abbreviations: [a:] NV, [a:] no vibrato; tube NV, tube no vibrato; [a:] WV, [a:] with vibrato; tube WV, tube with vibrato.

phonation without vibrato obtained the lowest CQ value. Table 2 summarizes the differences among the four phases for men and women. Figure 3 is a representative diagram of the CQ change in men and women. There was also an increase in the intrasubject CQ variability during tube phonation as compared with vowel phonation both with and without vibrato. This greater variability is evidenced by the increase in the standard deviation of the mean of CQ. This information is summarized in Table 1.

There was no statistically significant difference for F_0 for any of the participants during any of the tasks (Table 3). Table 4 shows the differences of F_0 across the four tasks for men and women, respectively. Moreover, in both men and women, F_0 correlated significantly with CQ ($P < 0.001$). Therefore, it is unlikely that individual variations of F_0 affected glottal CQ across the four different phonatory tasks.

Tables 5 and 6 display the results for the intrasubject analysis in terms of the presence and direction of the changes in CQ across the different phonatory tasks. Of the 23 female participants, 86.95% showed a decreased CQ from vowel /a/ without vibrato phonation to tube phonation without vibrato; 73.91% demonstrated a decrease when comparing vowel [a:] without vibrato with vowel [a:] with vibrato. From vowel phonation to tube phonation with vibrato, 69.56% demonstrated a decrease in the CQ. Of the 13 male participants, 92.30% demonstrated a decrease in CQ from vowel [a:] without vibrato phonation to tube phonation without vibrato; 76.92% demonstrated decreased CQ when comparing baseline with vowel [a:] with vibrato; and 61.53% showed a decrease during tube phonation with vibrato in comparison with tube phonation without vibrato.

DISCUSSION

The present study is the largest study investigating the effects of semioccluded postures of the vocal tract on the CQ. It also is the first to investigate the additional effects of vibrato on CQ. We used a drinking straw for a semioccluded tract. Gaskill et al[16,17] have performed several studies with subjects phonating into resonance tubes. In a study designed to observe the effect of an artificially lengthened vocal tract on glottal CQ, the authors reported similar findings to our study. Significant changes in CQ during tube phonation in the single-subject analysis were observed but with no discernable pattern across the participants when comparing pre-, during, and posttube phonation.[16] In a similar study, the same author pointed out that, in general, there was a tendency for CQ to increase or remain constant during tube phonation and then return to a value near the baseline (vowel phonation) afterward.[17]

In a study performed with trained singers during sustained phonation into several different commercial plastic drinking and stirring straws, Titze et al[12] observed a lower CQ when phonation into straws was compared with vowel production. The authors concluded that with narrow straws, it is possible to use high subglottal pressures needed in singing all-the-while having minimal collision of the vocal folds. Bickley et al.[13] reported similar findings in their EGG study using resonance tubes at the lips during voicing. Contrary, Laukkanen[15] reported

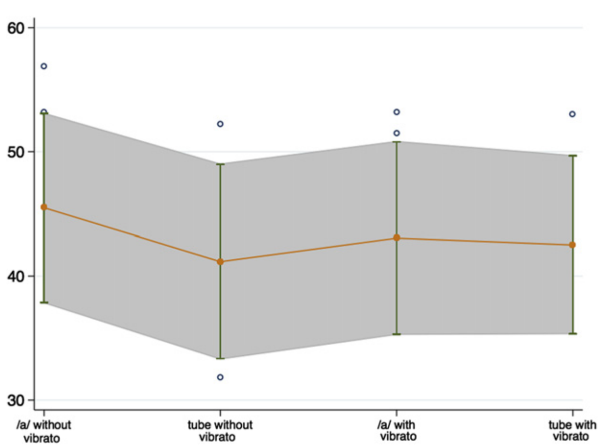

FIGURE 1. Mean and standard deviation of contact quotient for men.

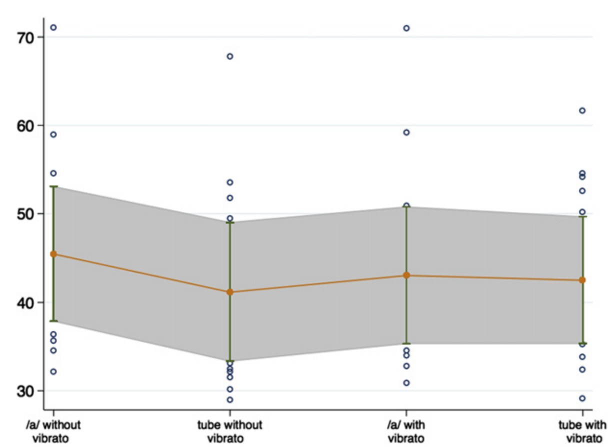

FIGURE 2. Mean and standard deviation of contact quotient for women.

TABLE 2.
Differences of CQ Among the Four Phases for Men and Women

CQ (%)	Tube NV for Men	[a:] WV for Men	Tube WV for Men	Tube NV for Women	[a:] WV for Women	Tube WV for Women
[a:] NV	−4.88 ($P = 0.147$)	−2.15 ($P = 0.779$)	−3.51 ($P = 0.415$)	−4.008 ($P = 0.490$)	−2.58 ($P = 0.798$)	−2.67 ($P = 0.780$)

Abbreviations: [a:] NV, [a:] no vibrato; tube NV, tube no vibrato; [a:] WV, [a:] with vibrato; tube WV, tube with vibrato.

that the open quotient was smaller during tube phonation compared with vowel productions. This suggested that the vocal folds remained closed longer during tube phonation.

There has been no consistent relationship between semioccluded postures and CQ demonstrated in the literature. Despite the lack of statistical significance in our study, it is notable that most of the subjects demonstrated a decrease in the CQ value in all the phonatory tasks when compared with their baseline vowel phonation. A decrease in CQ from baseline was seen in the greatest number of subjects during tube phonation without vibrato: 89.96% of female subjects and 92.30% of male subjects.

Studies have looked at other semioccluded vocal tract techniques. Gaskill and Erickson[14] measured the CQ before, after, and during lip trill. Significant decrease in the CQ was observed during phonation with lip trill. The authors speculated that to sustain simultaneous vibration at the lips and at the vocal folds, the amount of adduction might be reduced to have sufficient airflow. In other words, if there is a high glottal adduction, there will be little airflow to produce the vibration of the lips. To produce lip trill during phonation, an increase in airflow through the glottis would be necessary, which could only be obtained with reduced adduction of the vocal folds. This would result in a smaller CQ. Based on these observations, it could be inferred that an oscillatory semioccluded vocal tract exercise such as lip, tongue trill, or raspberries should be used instead of a permanent semioccluded posture such as tube phonation to modify the CQ.

Similar results were demonstrated in a study performed with Mediterranean tongue trill versus sustained vowels.[19] In another study,[18] however, CQ increased during lip trill when voice was produced at high intensity. These findings seem to be contrary to the study by Gaskill.[14] One possible explanation for this finding is that increased adduction was required to increase subglottic pressure enough to create the lip trill when phonating with high intensity.

Other explanations exist as to why semioccluded postures may reduce CQ. The amount of inertive reactance of the vocal tract may contribute to a decrease in CQ. Story et al[5] pointed out that vocal tract impedance can affect two levels of the voice source. The first level is an acoustic-aerodynamic interaction in which the acoustic pressures in the vocal tract affect the shape of the glottal flow pulse. At fundamental frequencies well below the first formant this generally has the effect of skewing the

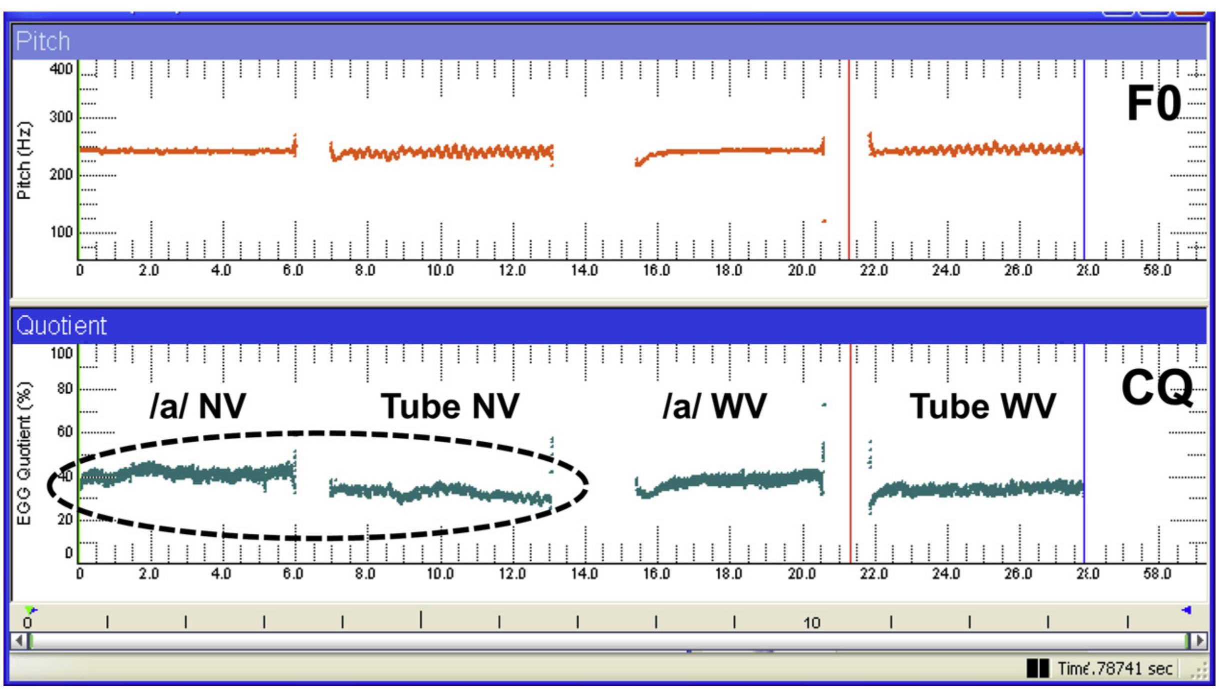

FIGURE 3. CQ and F_0 variation throughout the three phonatory tasks. The largest decrease was obtained between sustained vowel [a:] without vibrato and sustained pitch into a tube without vibrato. [a:] NV, [a:] no vibrato; tube NV, tube no vibrato; [a:] WV, [a:] with vibrato; tube WV, tube with vibrato.

TABLE 3.
Mean and Standard Deviation of F_0 Analysis for the Four Phases of the Experiment for Men and Women

Task	F_0 (Hz) for Men	F_0 (Hz) for Women
[a:] NV	146.41 ± 18.04	283.28 ± 41.43
Tube NV	146.95 ± 18.16	280.37 ± 41.67
[a:] WV	146.64 ± 18.17	281.98 ± 41.71
Tube WV	147.32 ± 18.19	279.76 ± 37.05

Abbreviations: [a:] NV, [a:] no vibrato; tube NV, tube no vibrato; [a:] WV, [a:] with vibrato; tube WV, tube with vibrato.

flow pulse so that the airflow is suppressed at glottal opening and maintained during the glottal closing phase. The second level of voice source that could be affected by vocal tract impedance is the mechano-acoustic interaction of the vocal tract pressures and the vocal folds. This occurs when the acoustic pressures in the vocal tract influence the vibrational characteristics of the vocal folds. More specifically, an increased positive or inertive reactance could lower the phonation threshold pressure (the subglottal pressure required to barely initiate and sustain phonation),[9] producing easier phonation. Lastly, because phonation through a straw increases resistance within the supraglottic vocal tract, it will not only affect vocal tract impedance but also reduce the transglottal pressure (the difference between subglottic and supraglottic pressure), which is driving vocal fold vibration. This, too, will likely affect the CQ.

There was an increased CQ variability during tube phonation in our study. The variability was not dependent on vibrato, suggesting that F_0 and intensity modulations during vibrato were not the cause. Other studies have demonstrated similar results.[16–18] The increase in vocal tract inertive reactance during artificial lengthening or occlusion may produce pressure modulations leading to the variability of the closed quotient. Titze et al[21] demonstrated that although tracheal and glottal airflow are controlled largely by lung pressure, there can be a strong influence on these airflows by backpressures created in the vocal tract. Furthermore, inertive reactance results from a delay in response of the oscillatory pressure-flow characteristics of the vocal tract. This delay might also have contributed to the variability on glottal CQ during tube phonation in our participants.

The present study not only analyzed the effect of tube phonation on glottal CQ but also the effect of vibrato. There are no studies in the literature pertaining to the relationship between CQ and vibrato. However, some clinical reports have been published about the possible therapeutic effect of vibrato in patients diagnosed with hyperfunctional dysphonia. Farías[20] states that considering the laryngeal relaxation necessary to produce vibrato, it is possible to infer that vibrato phonation could be an adequate therapeutic resource for patients with laryngeal hyperfunction. According to the author, it is possible to avoid laryngeal fixations or rigidities during vibrato phonation. Large and Iwata[22] reported that vibrato-free tones are sung with less airflow than vibrato tones. Although this study did not examine glottal CQ, it is conceivable that greater airflow in phonation with vibrato requires less vigorous glottal adduction, resulting in a smaller CQ.

In the present study, we failed to show a significant effect on CQ with vibrato. In the intrasubject analysis, however, most of the patients showed a decrease in the CQ value in all phonatory tasks that involved vibrato compared with the baseline task. Additionally, vibrato may help improve laryngeal hyperfunction through other effects. For example, vibrato phonation may result in decreased tension of the extrinsic laryngeal muscles by promoting freer vertical laryngeal movement.

There are limitations to this study. Subglottic pressure was not objectively controlled during phonation. The airflow resistance provided by the straw could have induced a higher subglottic pressure leading to a higher degree of glottal adduction as a result. Although, this may be a natural physiological reaction, it may have affected our findings. We tried to control for this by asking participants to keep the same phonatory and breathing efforts, but this may not have been effective. Furthermore, only drinking straws were used in this study. Titze et al[12] demonstrated that straws of different diameters may affect CQ differently. The effect of straw diameter on CQ may also be caused by changes in transglottal pressure produced by the different effects on supraglottic resistance.

In the present study, each subject was asked to perform the phonatory tasks at habitual speaking pitch and loudness levels. In contrast, Gaskill and Quinney[17] informed participants that the task was an exercise to improve the ease of phonation. They were instructed to vary pitch and loudness while phonating into the tube until it felt most comfortable. Perhaps this approach could have lead to more significant results in our study.

Last, but not least, all the participants were healthy, trained opera singers. It is possible that their ability to maintain good vocal technique during all tasks might also have influenced our results, tempering the potential effect of tube and vibrato phonation on CQ. Perhaps the effect in untrained voice patients would be more dramatic. The reason for choosing trained singers in this study was because they were all able to phonate with and without vibrato. Most previous studies also used trained or healthy subjects. Using untrained voice patients or patients with known hyperfunctional voice disorders in

TABLE 4.
Differences of F_0 Among the Four Phases for Men and Women

F_0 (Hz)	Tube NV for Men	[a:] WV for Men	Tube WV for Men	Tube NV for Women	[a:] WV for Women	Tube WV for Women
[a:] NV	0.53 ($P = 0.99$)	0.22 ($P = 0.99$)	0.9 ($P = 0.99$)	−2.9 ($P = 0.99$)	−1.3 ($P = 0.99$)	−3.52 ($P = 0.99$)

Abbreviations: [a:] NV, [a:] no vibrato; tube NV, tube no vibrato; [a:] WV, [a:] with vibrato; tube WV, tube with vibrato.

TABLE 5.
Change in CQ From Baseline Values for Each Female Participant

CQ Change From Baseline

Subject	Tube Without Vibrato	Vowel [a:] With Vibrato	Tube With Vibrato
1	Decreased	Decreased	Increased
2	Decreased	Increased	Increased
3	Decreased	Decreased	Decreased
4	Decreased	Increased	Decreased
5	Decreased	Decreased	Decreased
6	Increased	Increased	Increased
7	Decreased	Decreased	Decreased
8	Decreased	Decreased	Decreased
9	Decreased	Decreased	Increased
10	Decreased	Increased	Decreased
11	Increased	Decreased	Increased
12	Decreased	Decreased	Decreased
13	Decreased	Decreased	Decreased
14	Decreased	Decreased	Decreased
15	Decreased	Increased	Increased
16	Increased	Decreased	Increased
17	Decreased	Decreased	Decreased
18	Decreased	Decreased	Decreased
19	Decreased	Decreased	Decreased
20	Decreased	Decreased	Decreased
21	Decreased	Decreased	Decreased
22	Decreased	Decreased	Decreased
23	Decreased	Increased	Decreased

a controlled study might give a more accurate assessment of the effect of using resonance tubes and vibrato on CQ over time.

Of course, no two dysphonic patients are the same. There are hyperfunctional voice disorders and hypofunctional disorders. Physiological voice therapy seeks to directly alter or modify the physiology of the vocal mechanism, leading to a balance of the three subsystems involved in the production of voice (resonance, respiration, and phonation).[23] Therefore, the use of semioccluded postures and vibrato may affect each disorder or even each patient differently. Further studies should be aimed at investigating the usefulness of these techniques for specific disorders.

TABLE 6.
Change in CQ From Baseline Values for Each Male Participant

CQ Change From Baseline

Subject	Tube Without Vibrato	Vowel [a:] With Vibrato	Tube With Vibrato
1	Decreased	Decreased	Increased
2	Decreased	Decreased	Decreased
3	Decreased	Increased	Decreased
4	Increased	Increased	Increased
5	Decreased	Decreased	Decreased
6	Decreased	Decreased	Decreased
7	Decreased	Decreased	Decreased
8	Decreased	Decreased	Decreased
9	Decreased	Decreased	Decreased
10	Decreased	Decreased	Decreased
11	Decreased	Decreased	Decreased
12	Decreased	Increased	Decreased
13	Decreased	Decreased	Decreased

CONCLUSIONS

This study fails to demonstrate a statistically significant effect on CQ during tube phonation or phonation with vibrato in healthy, classically trained singers when analyzed across all subjects. However, intrasubject analysis demonstrates decreased CQ during tube and vibrato phonation in most of the participants. Although a causal relationship is not proven, this finding suggests that the use of straws and vibrato during phonation may have therapeutic value in the treatment of some patients with hyperfunctional voice disorders.

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