# The Effect of a Voiced Lip Trill on Estimated Glottal Closed Quotient

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**Summary.** The use of lip trills has been advocated for both vocal habilitation and rehabilitation. A voiced lip trill requires continuous vibration of the lips while simultaneously maintaining phonation. The mechanism of any effects of a lip trill on vocal fold vibration is still unknown. While other techniques that either constrict or artificially lengthen the vocal tract have been investigated, no studies thus far have systematically examined the effect of lip trills on vocal fold vibration. Classically trained singers and vocally untrained participants produced a lip trill for approximately 1 minute, and vocal fold closed quotient (CQ) was calculated both during the lip trill and on a sustained spoken vowel before and after the trill. Data are reported for both a group design and a single-subject design. Most participants showed a tendency for a reduction in CQ during the lip trill, with a more pronounced change in the untrained participants.

**Key Words:** Lip trill–Vocal tract loading–Voice training–Closed quotient–Singers.

## INTRODUCTION

Lip trills are often recommended as a vocal warm-up or rehabilitation exercise by both singing voice teachers and speech-language pathologists. A voiced lip trill, as described in this article, is produced with phonation (unlike the unvoiced lip trills often used by brass or woodwind players to relax the embouchure) and a closed lip posture that is firm enough to cause a complete airstream occlusion, but relaxed enough to allow the lips to vibrate audibly due to air pressure variations at the point of labial contact. A lip trill is similar to other vocal training or rehabilitation techniques in that it focuses the attention of the speaker or singer on the anterior vocal tract. Many commonly used vocal exercises or therapy programs involve focused attention on the sensations at the anterior vocal tract, and often include some instructions to widen the posterior vocal tract while narrowing or partially occluding the anterior vocal tract. These would include simple exercises such as sustained phonation with nasals, voiced fricatives,[1–4] or the "Y-buzz" technique,[5] and also more formal techniques such as resonant voice therapy,[6] vocal function exercises,[7] and phonation into narrow hard-walled tubes as advocated by some European voice teachers and therapists.[3,8]

Lip trills are unique among these vocal training techniques in that the vocal tract posture alternates rapidly between occluded and nonoccluded (but constricted) positions at the lips, creating a low-frequency vibration at the lips in addition to the vibration of the vocal folds. It would seem then that lip trills create a rather unique demand on the vocal mechanism, given the need for adequate subglottal pressure and airflow for sustained phonation as well as adequate airflow to overcome the vibration threshold pressure of the occluded lips and set them into continuous oscillation. The possible benefits of lip or tongue trills have been discussed,[9] and there has been some investigation into the acoustics and aerodynamics of tongue vibration during a tongue trill,[10] but to date, research on lip trills and their effect on vocal behavior is limited.[11] Advocates of lip trills describe various potential benefits of performing lip trills as an exercise. These include encouraging consistent breath flow and extending the upper range,[12] adjusting subglottal pressure with rising pitch,[9] as well as benefits such as relaxing the tongue and other articulators, and encouraging a more desirable vocal fold configuration by discouraging either hypo- or hyperadduction.

Potential benefits regarding breath flow and vocal fold adduction seem to be linked to the attention paid during a lip trill to producing steady and continuous lip vibration, with the assumption that if this is present, there will be adequate subglottal pressure for efficient phonation with a glottal configuration that is neither breathy nor pressed. This would be a desirable outcome in both the voice studio and the voice clinic, since a basic goal of both classical voice training and voice therapy is to induce an ideal combination of subglottal pressure and glottal configuration, resulting in what has been referred to as "flow phonation."[13] This is also a primary goal of resonant voice therapy, which seems to encourage a "barely adducted" vocal fold configuration.[6]

While there is little to no experimental evidence regarding the effects of lip trills, there are theoretical and experimental studies that have considered the effects of what is often referred to as "vocal tract loading" by means of either a narrow anterior constriction or an artificial lengthening of the vocal tract.[1–4,8,14–18] It has been proposed that vocal tasks such as these may induce an increase in vocal tract impedance, or more specifically the inertive reactance.[17] Lip trills would fall into this general category of vocal tract loading techniques, given the constriction created at the lips. It would seem then that the primary benefit of lip trills may be due to the need to modify respiratory flow and subglottal pressure in the presence of a secondary load on the airstream, or the change in vocal tract impedance caused by the anterior vocal tract constriction, or both. First, however, what happens at the level of the vocal folds regarding glottal closure needs to be established. The present study sought to determine if there are any measurable changes in glottal closed quotient (CQ) during the production of a lip trill.

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# METHODS

## Participants

Thirty-nine healthy, nonsmoking adult males with no history of a voice disorder were originally recruited for the study. Data from 10 of the participants were not analyzed due to either an inability to perform the lip trill adequately or to insufficient data available for analysis (poor electroglottography (EGG) signal strength, incomplete data, equipment issues, etc). Data from another four participants were later excluded from analysis due to either ambiguity in the participants' voice classification (trained or untrained) or due to a high level of jitter in the EGG signals that prevented reliable calculation of the CQ. Two of the trained singers participated twice: once in experiment 1 with a group design and once in experiment 2 with a single-subject design.

Of the 25 participants whose data were used for analysis, 11 trained participants were members of the Knoxville Opera Chorus or the University of Tennessee Opera Studio (ages 24–64 years, mean age = 40 years) and had between 6 and 40 years of classical vocal training or experience (mean duration of experience = 22 years), and 14 untrained participants were University of Tennessee undergraduates or staff members with no singing training or experience (ages 18–46, mean age = 21). All participants signed a statement of informed consent that had been approved by the Institutional Review Board of the University of Tennessee. Tables 1 and 2 give complete information about the participants, including a self-report from the singers regarding how often they used lip trills in their own vocal routine, based on a five-point scale ranging from "Never" to "Very Often."

Males were used for this study given that it is usually easier to obtain clear EGG signals due to the size and shape of the thyroid cartilage and the typically smaller amount of surrounding adipose tissue for males compared with females.[19] On the day of testing, all participants presented with normal vocal quality as judged perceptually by the primary investigator who is a licensed speech-language pathologist. All participants were also free of any signs or symptoms of an upper respiratory infection and came to the session with a clean-shaven neck in the area surrounding the thyroid cartilage in order to ensure adequate surface electrode-to-skin contact. In addition, the trained participants were asked to come to the experiment as vocally "cold" as possible, given the demands of their individual singing schedules.

**TABLE 1.**
**Untrained Participants' Numbers and Ages**

| | Participant # | Age (y) |
|---|---|---|
| Experiment 1 | 1 | 19 |
| | 4 | 20 |
| | 15 | 19 |
| | 22 | 20 |
| | 23 | 18 |
| | 24 | 19 |
| | 25 | 19 |
| | 26 | 21 |
| | 27 | 21 |
| | 28 | 19 |
| Experiment 2 | 31 | 19 |
| | 32 | 18 |
| | 34 | 19 |
| | 36 | 46 |
| | Mean: | 21 |

## Measurement of glottal closed quotient

While various methods to investigate glottal source changes during supraglottal vocal tract loading have been used, the present study was limited to an examination of the EGG signal, namely data regarding the vocal fold CQ, which is simply an estimation of the percentage of time the vocal folds are closed during each vibratory cycle. Since any measure of CQ depends on an arbitrary decision of at what points in the glottal cycle the vocal folds are considered to be opening and closing, there is

**TABLE 2.**
**Trained Participants' Ages, Years of Singing Experience, and Frequency of Use of Lip Trills**

| | Participant # | Age (y) | Years of Experience | Use of Lip Trills |
|---|---|---|---|---|
| Experiment 1 | 3 | 24 | 9 | Never |
| | 6* | 53 | 35 | Rarely |
| | 7 | 53 | 35 | Sometimes |
| | 9 | 29 | 10 | Very often |
| | 14 | 24 | 6 | Sometimes |
| | 18* | 24 | 8 | Rarely |
| | 20* | 36 | 15 | Very often |
| | 21* | 64 | 40 | Never |
| Experiment 2 | 35 | Same as #6 | | |
| | 38 | 27 | 9 | Very often |
| | 39 | Same as #7 | | |
| | 40 | 55 | 40 | Never |
| | 42 | 55 | 40 | Never |
| | Mean: | 40 | 22 | |

* EGG gain setting on "high" to collect data.

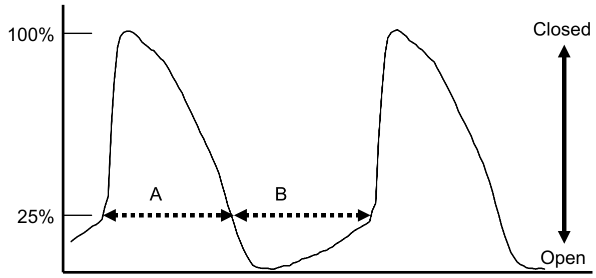


**FIGURE 1.** Calculation of glottal CQ from the EGG waveform using a 25% peak-to-peak algorithm (After Scherer et al[21]).

variability in the literature and clinical practice regarding this measurement. For this study, CQ was measured using an algorithm that estimates glottal closure based on a 25% value of the peak-to-peak amplitude of the waveform (Figure 1). This measurement algorithm for CQ was selected given the frequency of its reported use in the literature and the availability of normative cutoff values corresponding to hypoadducted (breathy), normal, and hyperadducted (pressed) phonation in male speakers.[20–22]

There are a few reasons to limit the present study to measures of glottal CQ. Air pressure and airflow measures as well as acoustic measures of the signal and inverse filtering would all be confounded for this investigation by the secondary vibrating source at the lips. While transnasal pressure measurements have been reported on a single subject,[14] this was judged to be too invasive and therefore impractical for a study with multiple subjects. Inferences about "laryngeal effort" have also been made using surface electromyography (EMG) during and after exercise with a lengthened or constricted vocal tract,[4,8] but these measurements are inherently problematic given their inability to isolate specific muscles, and are unable to provide any information regarding glottal configuration.

## Procedures and equipment

Data were collected in two separate experiments, one with a group design (experiment 1) and one with a single-subject design (experiment 2). The differences between these two experiments will be explained below, but the majority of the experimental procedure was the same for both. All participants were seated in a single-walled sound-treated booth (Acoustic Systems Model RE-144, ETS-Lindgren, Cedar Park, TX) for data collection. Both the participants' necks and the EGG surface electrodes were cleaned with an alcohol pad prior to placement of the electrodes. The electrodes were also coated with conductive gel prior to placement. A dual-channel electroglottography unit (Glottal Enterprises Model EG2, Syracuse, NY) was used to transduce the EGG signal, with a high-pass filter setting of 40 Hz, and the waveform inverted using the inverted vocal fold contact area (IVFCA) setting on the EGG unit. The EGG signals were sampled at 10 kHz and fed directly into a desktop computer running the *CSpeech* acoustic analysis program (Paul Milenkovic, University of Wisconsin-Madison, 1997).

Each participant was assisted in placing and holding the surface electrodes on either side of his thyroid cartilage, and was

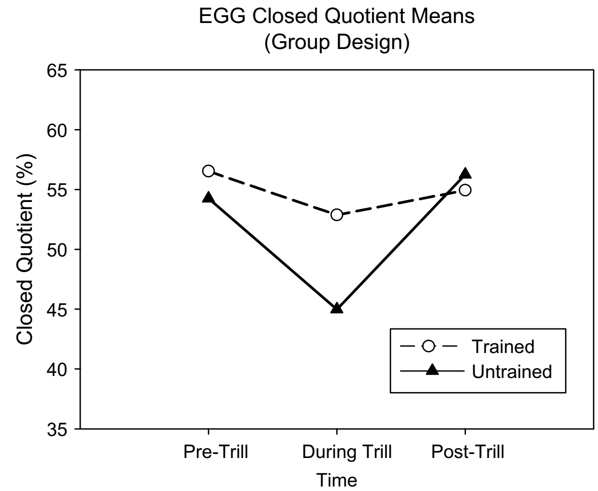


**FIGURE 2.** EGG closed quotient means for the trained and untrained participants in experiment 1 (group design).

instructed to hold them in position throughout the data collection process. Having each participant phonate a trial /ɑ/ vowel, the experimenter used the light-emitting diode (LED) readouts on the EGG unit to verify adequate signal strength and vertical electrode position. For four subjects (Table 2), the signal gain on the EGG unit had to be set to the "high" position in order to obtain adequate signal strength. The experimenter monitored the LED readouts throughout the data collection to ensure consistent electrode placement. The loudness of the trial /ɑ/ vowel was also monitored, and the participants were instructed to adjust their loudness in order to zero the needle on an analog sound level meter (Realistic Model 33-2050, Radio Shack, Fort Worth, TX) set at 70 dB sound pressure level (SPL) (A-weighting) positioned at an approximately 30-inch mouth-to-meter distance. The participants were instructed to use the sound level meter as visual biofeedback in order to phonate all the /ɑ/ vowels for the experiment at this level of loudness. All participants were able to produce this level within ±4 dB by using the sound level meter as visual feedback and also with occasional verbal cueing from the experimenter. The fundamental frequency of the spoken /ɑ/ vowels before the lip trills was determined using *CSpeech* and converted into semitones in order to cue the participant using an electronic keyboard (Yamaha PSR-195, Buena Park, CA) for the same fundamental frequency of the /ɑ/ vowels after the lip trills.

**TABLE 3.**
**EGG CQ Means and Standard Deviations for the Trained (n = 8) and Untrained (n = 10) Participants in Experiment 1**

| Group | Time | Mean (%) | Standard Deviation |
|---|---|---|---|
| Trained | Pre-trill | 56.53 | 3.66 |
| | During trill | 52.87 | 7.70 |
| | Post-trill | 54.94 | 5.82 |
| Untrained | Pre-trill | 54.25 | 6.23 |
| | During trill | 44.98 | 7.94 |
| | Post-trill | 56.25 | 7.20 |

**TABLE 4.**
**EGG CQ Means and Standard Deviations Before, During, and After the Trill for All Participants in Experiment 1 (Group Design)**

| | | Pre-trill | | During Trill | | Post-trill | |
|---|---|---|---|---|---|---|---|
| | | Mean | | Mean | | Mean | |
| | Participant # | CQ | Standard Deviation | CQ | Standard Deviation | CQ | Standard Deviation |
| Untrained | 1 | 58.53 | 1.09 | 46.63 | 2.85 | 57.03 | 1.56 |
| | 4 | 49.00 | 2.52 | 39.17 | 3.63 | 47.85 | 3.49 |
| | 15 | 59.47 | 1.12 | 46.08 | 3.18 | 61.37 | 0.66 |
| | 22 | 52.94 | 0.87 | 34.68 | 0.60 | 61.27 | 2.08 |
| | 23 | 60.26 | 0.84 | 41.71 | 1.22 | 59.55 | 1.31 |
| | 24 | 49.37 | 0.30 | 42.50 | 4.57 | 47.19 | 0.64 |
| | 25 | 64.28 | 0.52 | 42.24 | 2.61 | 66.07 | 0.40 |
| | 26 | 48.25 | 1.92 | 56.95 | 6.61 | 61.64 | 4.69 |
| | 27 | 55.61 | 0.85 | 58.23 | 1.24 | 55.03 | 0.66 |
| | 28 | 44.83 | 1.27 | 41.63 | 3.23 | 45.54 | 1.99 |
| Trained | 3 | 52.42 | 1.70 | 40.24 | 1.99 | 51.89 | 1.03 |
| | 6 | 53.50 | 1.60 | 49.75 | 0.81 | 52.16 | 1.61 |
| | 7 | 52.27 | 0.62 | 46.53 | 0.83 | 49.04 | 0.81 |
| | 9 | 57.50 | 1.42 | 56.88 | 1.11 | 53.17 | 1.34 |
| | 14 | 60.65 | 0.62 | 52.41 | 0.89 | 51.42 | 2.29 |
| | 18 | 57.23 | 0.37 | 64.47 | 5.10 | 67.51 | 0.90 |
| | 20 | 61.79 | 1.06 | 52.14 | 1.25 | 59.39 | 0.87 |
| | 21 | 56.92 | 1.88 | 60.59 | 2.14 | 54.98 | 2.14 |

It should be noted that no attempt was made to control the fundamental frequency and loudness of the lip trill during either experiment. Instead, each participant was instructed to produce a lip trill in an easy manner, the only criterion being to produce continuous vibration at the lips with simultaneous phonation. Some participants were excluded due to an inability to meet this requirement. It was felt that for this initial investigation into the effects of lip trills, rigid control of pitch would have been problematic for easy production of a lip trill. Loudness was also not controlled during the lip trill, given the marked reduction in radiated sound pressure caused by the occlusion at the lips, and the between-subject loudness variability displayed by the participants in order to successfully produce the trill.

### Experiment 1 (Group design)

There were 10 untrained and eight trained participants in experiment 1 (group design). Each of these participants performed three tasks: (1) sustained a spoken /ɑ/ vowel for 10 seconds at a constant comfortable pitch, while monitoring electrode position and loudness as described above; (2) produced a lip trill, with continuous voicing and audible lip vibration throughout, for a timed period of 60 seconds at a comfortable pitch, with brief pauses for breaths or to reset the lips and continue the trill as needed; and (3) sustained another spoken /ɑ/ vowel for 10 seconds, at the same constant pitch as before the lip trill, with cues from the experimenter as described above.

### Experiment 2 (Single-subject ABA design)

There were five trained and four untrained participants in experiment 2 (single-subject ABA design). These participants also performed three tasks: (1) a series of four repeated spoken /ɑ/ vowels at the same comfortable pitch for 4 seconds each, with a 15- to 20-second pause between each token; (2) 60 seconds of lip trills as in experiment 1; and (3) another series of four repeated spoken /ɑ/ vowels, at the same constant pitch as before the lip trill, with cues from the experimenter as in experiment 1. These repeated /ɑ/ vowels (A condition) were used to establish a pre-trill baseline for the glottal CQ in this single-subject design, in order to compare CQ during the lip trill (B condition) with CQ during the sustained vowel phonation.

### Analysis

The inverted (IVFCA) EGG waveform files were saved and converted to the .wav format from the *CSpeech* format using the RIFF batch command in *CSpeech*. The .wav files were then saved as stereo files using *Cool Edit Pro 2.0* (Syntrillium Software, Phoenix, AZ). This process re-inverted the EGG waveforms to display them as standard vocal fold contact area waveforms, with rising slope indicating vocal fold closure. The stereo files were analyzed using the real-time EGG analysis program for the Computerized Speech Laboratory (*CSL 4800*, KayPENTAX, Lincoln Park, NJ).

Four 1-second portions from each of the 10-second sustained /ɑ/ vowels from experiment 1, and a 2-second central portion from each of the repeated 4-second /ɑ/ vowels from experiment 2, were selected for analysis. Care was taken to make selections that were separated from voice onset or offset by a minimum of 1 second, and spaced evenly (approximately 1 second apart) throughout the 10-second phonations. Four 2-second portions of the lip trill waveforms were selected for analysis at roughly

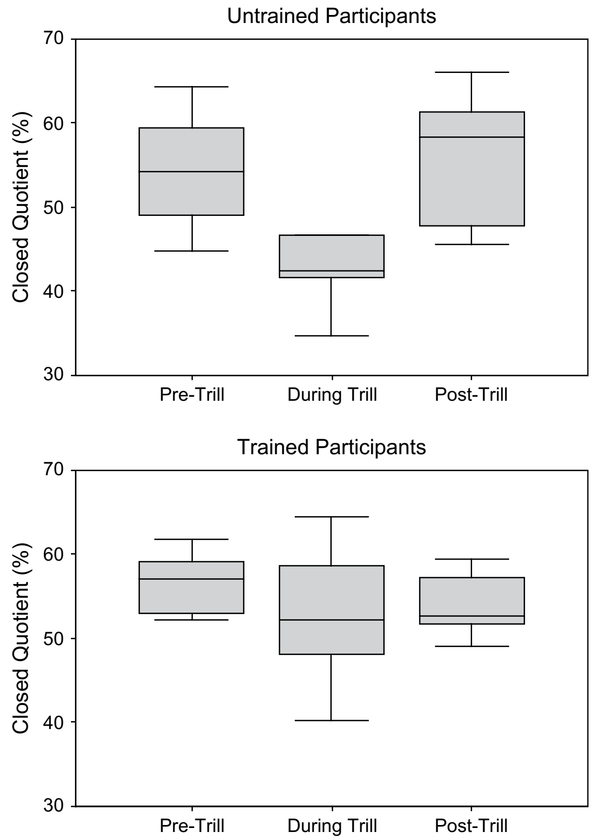


**FIGURE 3.** Range, first and third quartiles, and median values of average CQ before, during, and after the lip trill for the untrained and trained participants in experiment 1 (group design).

equal intervals across the 60 seconds of data recorded from each participant in both experiments. At times, selections were made based on the location of portions of the lip trill with sufficient length to obtain a 2-second portion, while avoiding onsets and offsets and any portions of the signal with high levels of jitter.

An EGG CQ was calculated for each selected portion of the waveforms using the 25% of peak-to-peak amplitude option in the Real-Time EGG Analysis program. For experiment 1 (group design), an overall average CQ value for each of the three time segments in the experiment (before, during, and after the lip trill) was calculated using the four individual CQ values obtained from the separate portions of the sustained /ɑ/ vowels or from the lip trill segment. For experiment 2 (single-subject design), the four values obtained before, during, and after the trill are reported individually.

## RESULTS

### Experiment 1: Group design

CQ means for the trained and untrained participants are plotted in Figure 2, and the means and standard deviations are shown in Table 3. While both groups show a reduction in CQ during the trill followed by a return after the trill to a mean value close to the initial value, this effect is much more pronounced in the untrained participants. Table 4 shows the means and standard deviations for each participant, while Figure 3 plots the median, first, and third quartiles and the range of these averaged CQ values for all the participants in experiment 1 before, during, and after the lip trill. An analysis of variance for repeated measures was calculated for these CQ data (Table 5). The main effects of time ($P < 0.001$) and group ($P = 0.005$) as well as the two-way interaction ($P < 0.001$) were all statistically significant.

**TABLE 5.**
**Repeated Measures Analysis of Variance Computed for the Main Effects of and Two-Way Interaction Between Time and Group for the Trained (n = 8) and Untrained (n = 10) Participants in Experiment 1**

| Factor | *df* | *F* | *P* |
|---|---|---|---|
| Time | 2 | 35.92 | *<0.001* |
| Group | 1 | 6.14 | *0.016* |
| Time × group | 2 | 13.43 | *<0.001* |

Italicized *P* values are statistically significant (<.05).

Post hoc *t* tests were computed to compare the means before, during, and after the lip trill for the trained and untrained participants (Table 6). Both the untrained and trained participants showed a significant reduction in the CQ mean during the trill compared with before the trill ($P < 0.001$ and $P = 0.019$, respectively). The untrained participants also showed a significant increase in the CQ mean from during the trill to after the trill ($P < 0.001$).

### Experiment 2: Single-subject design

The EGG CQs for each of the participants in the single-subject design are plotted in Figure 4 (untrained) and Figure 5 (trained). The four measured values of CQ are plotted before, during, and after the trill as time-series data with accompanying simple regression lines. The regression lines were plotted so that changes in both level and slope or trend could be determined through visual inspection of the plots, which is commonly used for analysis.[23] In addition, Table 7 shows the mean CQ values and standard deviations for each participant.

**TABLE 6.**
**Post hoc *t* Tests Comparing EGG CQ Means Before, During, and After Lip Trills for the Trained (n = 8) and Untrained (n = 10) Participants**

| | *df* | *t* | *P* |
|---|---|---|---|
| Untrained | | | |
| Pre-trill (vs) during trill | 78 | 5.81 | *<0.001* |
| Pre-trill (vs) post-trill | 78 | −1.33 | 0.188 |
| During trill (vs) post-trill | 78 | −6.65 | *<0.001* |
| Trained | | | |
| Pre-trill (vs) during trill | 44.29* | 2.43 | *0.019* |
| Pre-trill (vs) post-trill | 62 | 1.31 | 0.196 |
| During trill (vs) post-trill | 62 | −1.21 | 0.230 |

Italicized *P* values are statistically significant (<.05).
* Equal variances not assumed per significant Levene's test for equality of variances.

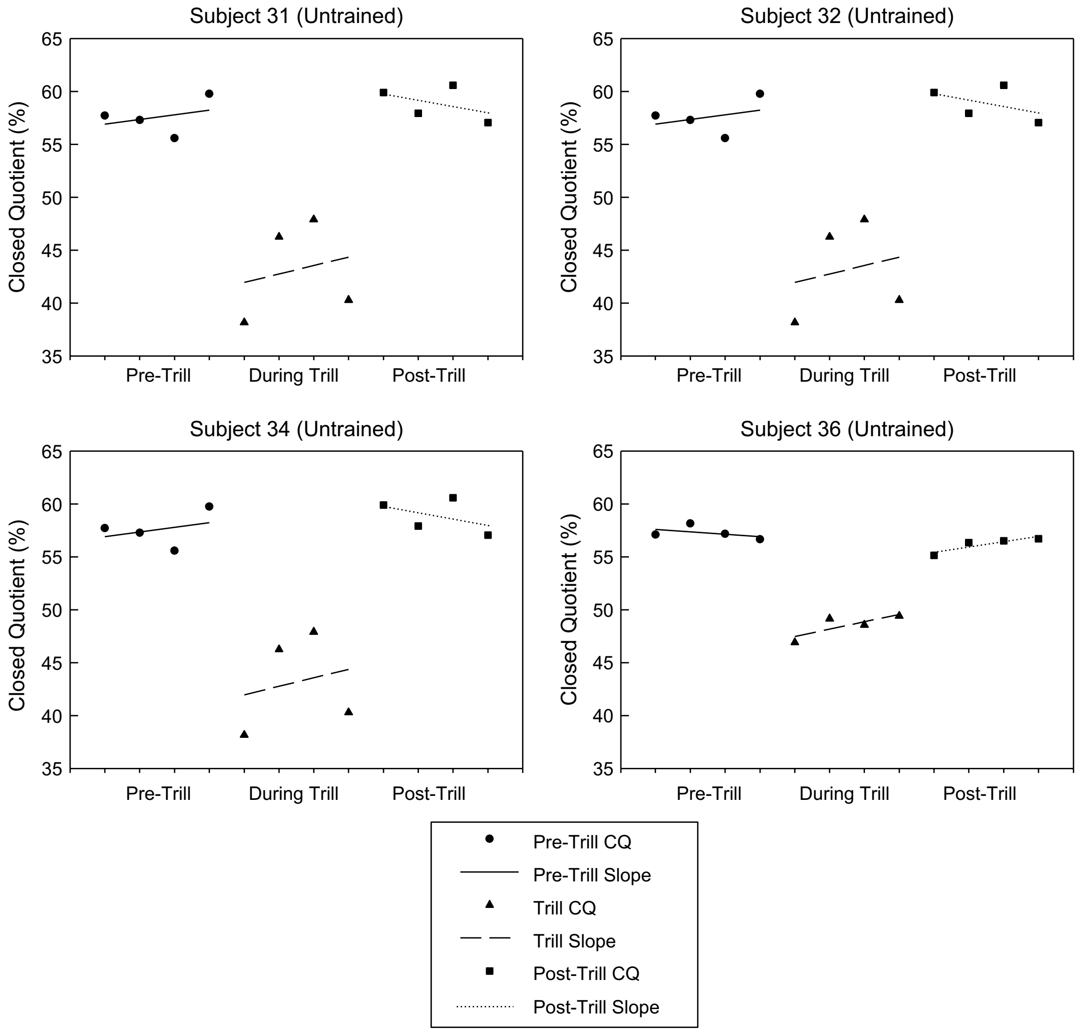


**FIGURE 4.** EGG CQs before, during, and after the lip trill for the four untrained participants in experiment 2 (single-subject design).

On examining the individual plots of the untrained participants, it was found that all four show a reduction in CQ during the trill compared with before the trill. All of the untrained participants show a return to a level of CQ that is consistent with the pre-trill values, and also show no marked change in slope. Only participant 36 had CQ values that remained entirely within the normal range of 40–60%, and all of these participants' CQ values before and after the trill are at the upper end of normal (55–60%), while during the trill their CQ values range between 40% and 50%.

The five trained participants' plots show some notable differences from the untrained group. The overall level of CQ is lower in the trained group, especially before and after the lip trill. All but one participant show a reduction in CQ during the trill from the pre-trill baseline. All but one also show CQ values that are well within the normal range and tend to cluster around 50%. As in the untrained group, the values of CQ during the trill tend to be between 40% and 50%. Participant 35 shows what may be a linear trend downward before and continuing during the trill, followed by a return after the trill to a CQ level near baseline, but with a flatter slope.

As an adjunct to visual inspection of the single-subject plots, individual *t* tests were calculated for each subject in order to further assess the significance of any changes in CQ during or after the lip trill (Tables 8–10). All of the untrained participants showed a significant difference in CQ before and during the trill (Table 8), but only one participant (32) had a significant difference ($P = 0.030$) between pre- and post-trill CQ values. For the trained participants, all five had a significant difference ($P < 0.05$) before and during the trill (Table 8), and three of the five also had a significant difference ($P < 0.05$) between pre- and post-trill CQ values (Table 9). All but one participant (trained, 39) showed a significant increase ($P < 0.05$) in CQ from during the trill to after the lip trill (Table 10).

## DISCUSSION

From these data, it appears that lip trills have a measurable effect on the glottal CQ. For the most part, there is a reduction in CQ during the production of a lip trill, with values tending to fall in the range of 40–50%. The change in CQ (usually a reduction) was more pronounced for individuals with no vocal training than for highly trained singers. For the single-subject data,

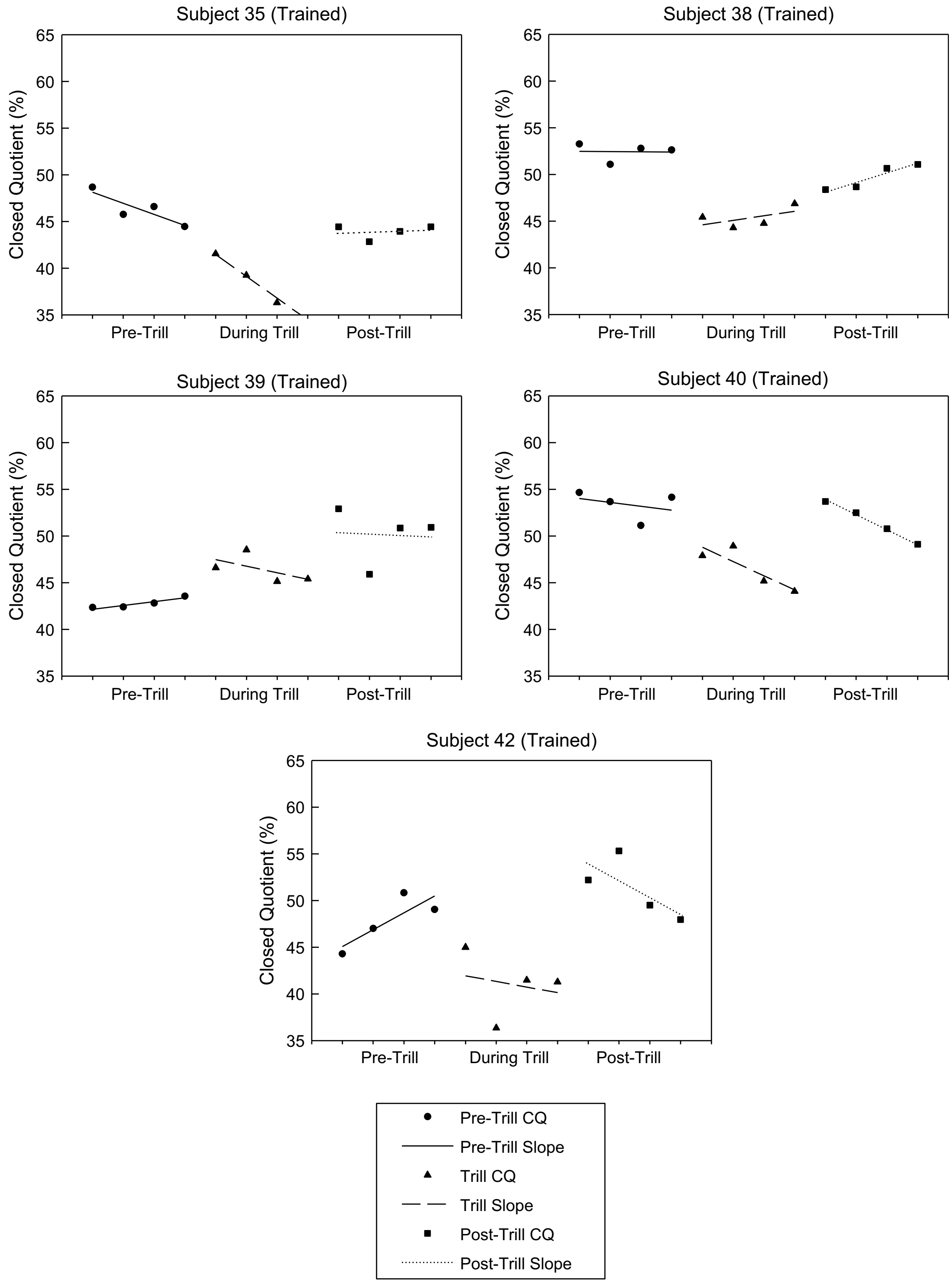


**FIGURE 5.** EGG CQs before, during, and after the lip trill for the five trained participants in experiment 2 (single-subject design).

both the trained and untrained participants' CQs tended toward the 40–50% range, but given the higher pre- and post-trill values in the untrained group, the magnitude of the reduction was greater than for the trained singers. Interestingly, for the group data, both trained and untrained participants' pre- and post-trill CQ values are at the higher end of what is considered a normal range,[22] with a larger drop during the trill in the untrained group. In addition, the untrained participants showed a greater overall variability in CQ values and were more likely to demonstrate values outside the normal range of 40–60%. This is especially apparent in Figure 3 for experiment 1.

One reason for these measured differences in CQ for the untrained versus the trained participants could be the more inconsistent glottal closure patterns produced by the untrained group as a whole compared to the trained group. This fits with general expectations and existing literature suggesting that trained singers are in general able to produce more consistent phonation than individuals without vocal training. It could also be

**TABLE 7.**
**EGG CQ Means and Standard Deviations Before, During, and After the Trill for All Participants in Experiment 2 (Single-Subject Design)**

| | | Pre-trill | | During Trill | | Post-trill | |
|---|---|---|---|---|---|---|---|
| | | Mean | | Mean | | Mean | |
| | Participant # | CQ | Standard Deviation | CQ | Standard Deviation | CQ | Standard Deviation |
| Untrained | 31 | 57.58 | 1.48 | 43.16 | 4.04 | 58.87 | 1.43 |
| | 32 | 55.63 | 1.00 | 44.72 | 2.29 | 58.88 | 1.71 |
| | 34 | 60.69 | 2.50 | 49.82 | 0.71 | 61.10 | 0.71 |
| | 36 | 57.27 | 0.54 | 48.51 | 0.97 | 56.19 | 0.62 |
| Trained | 35 | 46.37 | 1.53 | 37.97 | 2.63 | 43.92 | 0.66 |
| | 38 | 52.44 | 0.82 | 45.35 | 0.97 | 49.72 | 1.18 |
| | 39 | 42.78 | 0.49 | 46.43 | 1.34 | 50.17 | 2.59 |
| | 40 | 53.41 | 1.36 | 46.54 | 1.97 | 51.54 | 1.74 |
| | 42 | 47.77 | 2.43 | 41.02 | 3.07 | 51.23 | 2.80 |

that the trained singers showed less variation in CQ due to the fact that since they are trained to keep glottal closure more or less consistent, they for the most part resisted the tendency to approach either a breathy (<40% CQ) or pressed (>60% CQ) configuration.

The untrained participants as a group might also have shown greater changes in CQ during the trill due to being less familiar with producing lip trills, or any unusual nonspeech vocal task as an exercise with the goal of altering phonation patterns. While this could have been a factor, in spite of all the trained singers being aware of the practice of lip trills, only about half of them reported using them in their own practice routine either "sometimes" or "very often." The rest of the trained participants reported using lip trills either "rarely" or "never." Informal observation revealed variability in all the participants' facility with the production of a sustained lip trill, regardless of being trained or untrained. Wide variations in the loudness of voicing were also observed during the trill, along with variations in the degree of lip tension, and the magnitude of lip vibration, and the length of lip trill bursts before needing to breathe or "reset" the lip posture to continue sustaining the trill. This amount of observed variation in the execution of the experimental task suggests a certain degree of caution regarding any conclusions drawn from this study, and also suggests the need for future investigations to address these issues of variability.

There are several possible reasons why glottal CQ would be reduced during the production of a lip trill. The simplest explanation would be that in order to sustain simultaneous vibration at the lips and at the glottis, the amount of vocal fold adduction might be reduced in order to have sufficient air pressure. Given that $P = pU$, where $P$ is pulmonary power, P is lung pressure, and $U$ is airflow, and also given that acoustic power is proportional to pulmonary power,[24] it would be necessary to either increase lung pressure or increase airflow to provide sufficient acoustic energy to initiate and sustain vibration at the glottis and the lips. Therefore, in order to achieve sustained lip oscillation with simultaneous phonation and overcome the vibratory thresholds at both the glottis and the lips, either the lung pressure must be increased to overcome the constriction at the lips or, assuming constant lung pressure, it may be necessary to decrease vocal fold adduction slightly to increase airflow.

It could also be that a lip trill causes a mechano-acoustic interaction related to the increased vocal tract impedance due to the alternating occlusion and constriction at the lips. As theorized by Story et al, a mechano-acoustic interaction would

**TABLE 8.**
**Individual *t* Tests Comparing EGG CQ Before and During the Lip Trill**

| | Participant # | *df* | *t* | *P* |
|---|---|---|---|---|
| Untrained | 31 | 3.80* | 5.80 | *0.005* |
| | 32 | 6 | 7.56 | *<0.001* |
| | 34 | 6 | 7.26 | *<0.001* |
| | 36 | 6 | 13.59 | *<0.001* |
| Trained | 35 | 6 | 4.78 | *0.003* |
| | 38 | 6 | 9.64 | *<0.001* |
| | 39 | 6 | −4.43 | *0.004* |
| | 40 | 6 | 4.98 | *0.002* |
| | 42 | 6 | 2.99 | *0.024* |

Italicized *P* values are statistically significant (<0.05).
* Equal variances not assumed per significant Levene's test for equality of variances.

**TABLE 9.**
**Individual *t* Tests Comparing EGG CQ Before and After the Lip Trill**

| | Participant # | *df* | *t* | *P* |
|---|---|---|---|---|
| Untrained | 31 | 6 | −1.08 | 0.320 |
| | 32 | 6 | −2.83 | *0.030* |
| | 34 | 6 | −0.28 | 0.791 |
| | 36 | 6 | 2.27 | 0.064 |
| Trained | 35 | 6 | 2.54 | *0.044* |
| | 38 | 6 | 3.27 | *0.017* |
| | 39 | 6 | −4.86 | *0.003* |
| | 40 | 6 | 1.47 | 0.193 |
| | 42 | 6 | −1.62 | 0.157 |

Italicized *P* values are statistically significant (<0.05).

**TABLE 10.**
**Individual *t* Tests Comparing EGG CQ During and After the Lip Trill**

| | Participant # | *df* | *t* | *P* |
|---|---|---|---|---|
| Untrained | 31 | 3.74* | −6.35 | *0.004* |
| | 32 | 6 | −8.57 | *<0.001* |
| | 34 | 6 | −19.45 | *<0.001* |
| | 36 | 6 | −11.55 | *<0.001* |
| Trained | 35 | 3.37* | −3.81 | *0.026* |
| | 38 | 6 | −4.94 | *0.003* |
| | 39 | 6 | −2.22 | 0.068 |
| | 40 | 6 | −3.30 | *0.016* |
| | 42 | 6 | −4.26 | *0.005* |

Italicized *P* values are statistically significant (<.05).
* Equal variances not assumed per significant Levene's test for equality of variances.

imply that the increased acoustic pressures in the vocal tract during production of a lip trill have a direct effect on vocal fold vibration.[17] If this is true, the changes in CQ could be due to changes in the glottal closure pattern that are unrelated to changes in laryngeal adduction. Some evidence that increasing the inertance of the vocal tract does affect vocal fold vibration has been provided by Titze and Story,[25] who found that an epilaryngeal constriction can lower phonation threshold pressure. However, it must be noted that an anterior vocal tract constriction, while also resulting in increased inertance, is not acoustically identical to an epilaryngeal constriction. Therefore, these results may not apply to the current study.

Because the present data yield no direct information regarding the degree of vocal fold adduction, it is difficult to determine the role of either changes in adduction or a mechano-acoustic interaction in the observed reduction in CQ during the production of the lip trill. It is certainly possible that the reduction in CQ is due to both phenomena: an actual reduction of vocal fold process adduction in order to allow sufficient airflow at the lips, as well as interaction between the increased inertive load on the vocal tract and the glottal source. One prior study by Miller and Schutte[14] may provide some insight into determining which of these two phenomena is likely to have been more active in the present study.

Miller and Schutte[14] examined the effects of a potential mechano-acoustic interaction during the production by a trained male singer of either the repeated syllables /bibi/ or a voiced "finger-trill" produced by alternating a horizontally held finger between the lips. Both of these were performed at a rate of approximately 10 Hz. The authors state that the alternations in labial occlusion were rapid enough to preclude any voluntary vocal fold adjustments, so changes in vocal adduction during occlusion were unlikely. They compared the glottal pressures and EGG waveforms between the moments of labial occlusion and labial opening for both the production of /bibi/ and the finger trill during an ascending scale. They found only a slight reduction in glottal closed phase and closing slope at the moments of occlusion, in spite of increased supraglottal pressure. While glottal CQ data are not provided, estimations of glottal CQ from example EGG waveforms provided in the article tend to be around 50%, with a slight decrease during bilabial closure. This small increase likely falls within the range of measurement error.

Unlike the Miller and Schutte[14] study, the present study did not compare aerodynamic and glottal measures obtained from the unoccluded and occluded portions of the lip trill, but rather compared CQ values averaged over a portion (multiple cycles) of the lip trill to CQ values averaged during a portion of a sustained /ɑ/. Given that the acoustic power demands for these two tasks are quite different, one having only the vocal folds as a vibrator, the other having both vocal folds and lips, it seems more likely that the observed CQ differences in the present study would be primarily due to changes in laryngeal adduction rather than a mechano-acoustic interaction. Also, given the small change in estimated glottal CQ observed in Miller and Schutte's[14] data, it is unlikely that the large changes in CQ observed in the present study were primarily due to a mechano-acoustic interaction.

Since the ultimate aim of any vocal exercise such as a lip trill is to alter vocal behavior in a reproducible way during normal phonation, it would seem that a behavioral reduction in vocal fold adduction during a lip trill would more easily lend itself to application as a therapeutic exercise than would a mechano-acoustic change in CQ that is strictly task dependent. Some have suggested that there could be lasting benefits from using exercises that occlude or constrict the vocal tract, but it remains unknown exactly how this can be exploited to alter glottal closure beyond application of the specific exercise.

## CONCLUSION

This study provides evidence supporting the notion that lip trills can induce a reduction in glottal CQ compared to values during normal phonation. Most individuals in this study tended to adjust CQ to a value between 40% and 50% during the lip trill. It could be that this was due to the need to increase airflow in order to sustain both vocal fold and lip oscillation.

Future research needs to focus on determining whether the production of a lip trill does indeed reduce vocal fold adduction. Future research could also augment the present findings by using more sophisticated single-subject design and analysis techniques. Additional experiments that more strictly control various parameters during the production of a lip trill, especially pitch and loudness, but also the degree of lip tension and magnitude of lip vibration, would help clarify what influence these variables have on glottal dynamics during a lip trill. Finally, given the previous studies of other means of increasing vocal tract impedance (resonance tubes, voiced fricatives, etc), it would be important to design well-controlled experiments comparing the relative effects of these tasks on glottal CQ.

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