The Effect of an Artificially Lengthened Vocal Tract on Estimated Glottal Contact Quotient in Untrained Male Voices

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Summary: The use of hard-walled narrow tubes, often called resonance tubes, for the purpose of voice therapy and voice training has a historical precedent and some theoretical support, but the mechanism of any potential benefit from the application of this technique is not well understood. Fifteen vocally untrained male participants produced a series of spoken /ɑ/ vowels at a modal pitch and constant loudness, before and after a minute of repeated phonation into a 50-cm hard-walled glass tube at the same pitch and loudness targets. Electroglottography was used to measure the glottal contact quotient (CQ) during each phase of the experiment. Single-subject analysis revealed statistically significant changes in CQ during tube phonation, but with no discernable pattern across the 15 participants. These results indicate that the use of resonance tubes can have a distinct effect on glottal closure, but the mechanism behind this change remains unclear. The implication is that vocal loading techniques such as this need to be studied further with specific attention paid to the underlying mechanism of any measured changes in glottal behavior, and especially to the role of instruction and feedback in the therapeutic and pedagogical application of these techniques.
Key Words: Artificially lengthened vocal tract–Resonance tube–Vocal tract loading–Voice training–Contact quotient.

INTRODUCTION

There is a long history of the use of resonance tubes for voice training, mainly in Scandinavia and Germany,[1] but the reasons for any potential benefits from the use of resonance tubes remain unclear. Resonance tubes are hard-walled narrow tubes held in the mouth as an extension of the vocal tract, which would presumably increase what is referred to as vocal tract loading. Some researchers have proposed that vocal tract loading, or an increase in vocal tract impedance (more precisely, the inertive reactance[2,3]), may affect vocal fold vibration in a favorable manner under certain conditions.[2–6]

The impedance of the vocal tract, which is for the most part a flexible tube, can be increased in two basic ways: by means of either a narrowing its diameter, or by increasing its length.[2] Certain techniques from both the realms of vocal pedagogy and speech therapy involve either a narrow anterior constriction or a lengthening of the vocal tract in some way, including the use of such tasks as phonating with nearly occluded lips, producing voiced fricatives, or phonating into resonance tubes as an extension of the vocal tract.[1,2,7–9] Some behavioral studies have been designed to examine the effects of various vocal tract loading techniques, including both constriction and artificial lengthening of the vocal tract,[1,10–19] but to date, there have been no consistent findings regarding any changes (in glottal behavior that can be attributed directly to an increase in vocal tract impedance). Because these techniques are thought to increase vocal tract loading through an alteration in vocal tract impedance, this could be one mechanism to explain any perceived benefit from their use, and warrants continued study. Titze[20] has recently reported on a computer simulation that supports the idea that phonation can be made more efficient through impedance matching between the voice source and the vocal tract, by using therapy techniques involving either semiocclusion of the lips or a combination of adjustments in vocal fold adduction and epilaryngeal constriction.

Review of the literature

Some investigators have described the dynamics of phonation when the fundamental frequency (F_0) comes near the values of the first formant ($F1$), as is the case for a soprano singing in the upper register.[21–25] This phenomenon is by nature relevant to a discussion of the effects of increased vocal tract impedance, given the changes in vocal tract impedance, or more specifically, inertive reactance, that occur when F_0 approaches $F1$, as presented by Story et al.[2] The reactance of the vocal tract is positive when the F_0 is below the $F1$, and the acoustic load of the vocal tract is considered inertive and may assist in vocal fold vibration. When F_0 coincides with and then exceeds $F1$, reactance becomes negative and the acoustic load of the vocal tract is considered to be compliant, and may negatively affect sustained vocal fold vibration[3,26] (Figure 1). Phonation at a F_0 near the $F1$ has been examined primarily in the soprano voice, and the phenomenon of "tuning" the vocal tract to align the $F1$ with the fundamental while singing in the upper register has been documented in previous studies.[23–25]

There have been several studies designed to examine the effects of an artificial extension of the vocal tract on the voice.[1,14,15,17,19,27] Baken and Orlikoff[27] reported a transient drop in F_0 for five normal participants when the impedance of a tube coupled to the lips was suddenly changed, indicating an interaction between the control of the voice source and changes in impedance of an artificially lengthened vocal tract. Rothenberg[19] conducted a similar experiment with two professional sopranos, and reported a reduction in EGG

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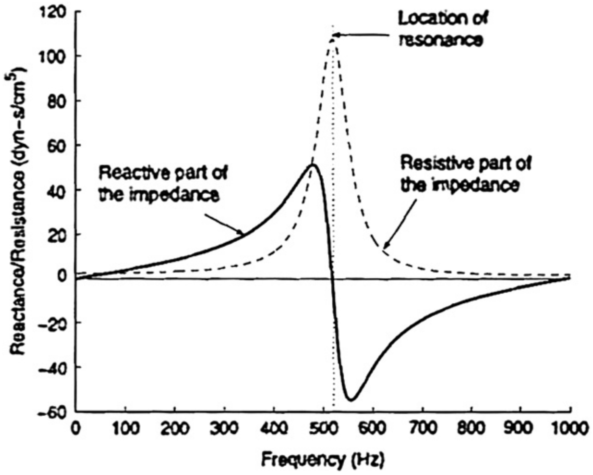

FIGURE 1. Impedance curves for a uniform tube of 3 cm^2 cross-sectional area and 17.5 cm length. Reprinted from Story et al.[2] Used with permission from The Voice Foundation.

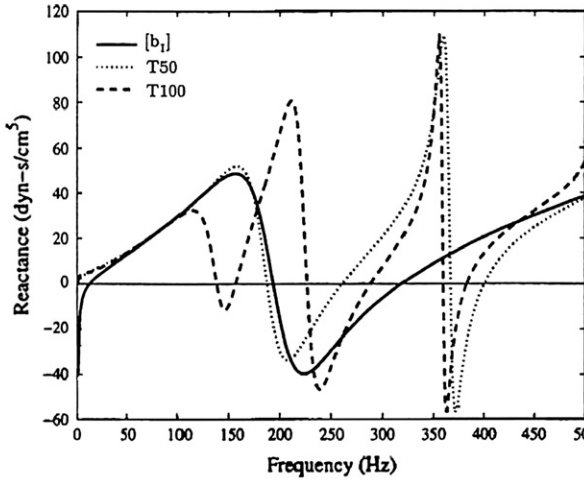

FIGURE 2. Reactance curves for bilabial occlusion, and vocal tract extension tubes of 50 and 100 cm. Reprinted from Story et al.[2] Used with permission from The Voice Foundation.

(electroglottography) amplitude roughly proportional to the degree of lowering of $F1$ as a 10 cm tube was coupled to the vocal tract during sung phonation. He suggested that this change most likely indicated a decrease in vocal fold oscillatory energy as the supraglottal impedance increased during coupling to the tube.

Laukkanen et al have conducted several research studies involving the use of resonance tubes,[1,14,15,17] with both male and female participants phonating into resonance tubes of varying lengths and diameters. Changes in several different variables both during and after tube phonation were reported across these studies, including glottal waveform shape, laryngeal height, glottal efficiency, laryngeal resistance, and perceived vocal effort. Although some of the findings are in keeping with theoretical predictions about glottal behavior under conditions of an artificially lengthened vocal tract, the differences in method and measured variables make it somewhat difficult to draw firm conclusions regarding glottal source changes induced by the use of resonance tubes.

Purpose of the present study and research questions

The purpose of this study was to investigate the effect of phonation into a resonance tube on the degree of glottal closure as indicated by the glottal contact quotient (CQ) in untrained male participants. The study was designed to induce conditions of phonation in the context of near-maximal inertive reactance by lowering the $F1$ to a frequency level near normal male speaking F_0, using a resonance tube of 50 cm, as calculated by Story et al.[2] Figure 2 shows their calculated reactance curves for an occluded vocal tract as well as a vocal tract coupled to a 50 and a 100 cm resonance tube. The 50 cm tube provides near-maximal reactance in the region of 100–180 Hz, which is the normal range of male modal pitches. A male would typically need to raise F_0 of phonation to around 500 Hz, well above speaking range, to experience the same increase in inertive reactance induced by coupling to a 50-cm resonance tube.

These authors have hypothesized that phonation under this unique condition where $F1$ is lowered to just above F_0 may alter glottal dynamics during phonation, due to a nonlinear interaction between the vocal folds and the vocal tract. For this reason, glottal CQ has been chosen as the measure of interest in comparing phonation before, during, and after phonation into a resonance tube.

The present study attempted to answer the following questions:

1. How does phonation into a resonance tube designed to reduce $F1$ to a value just above the normal modal pitch range for males affect glottal CQ?
2. Does phonation into a resonance tube as an exercise for approximately 1 minute produce any measurable sustained effects as evidenced by a persistent change in the glottal CQ after the exercise?

METHODS

Overview

This experiment used a single-subject, multiple-baseline, ABA design with direct replication across 15 normal, vocally untrained, adult male participants. The time series data for each participant was analyzed using Statistical Process Control (SPC).[28–31] The data from all 15 participants were also treated as a group and a *post hoc* comparison of pre-, during, and post-tube phonation CQ means was made using a repeated-measure analysis of variance (ANOVA). This was used to supplement the single-subject design analysis and help answer the questions of both treatment and posttreatment effects of tube phonation on glottal CQ.

EGG was used to obtain an estimate of the glottal CQ[32] during each participant's repetitions of a sustained spoken /ɑ/ vowel before and after tube phonation as well as during repetitions of tube phonation in the treatment phase. EGG provides