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Teaching Lower Laryngeal Position with EMG Biofeedback

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INTRODUCTION: THE GOSPEL ACCORDING TO SINGERS

BECAUSE OF THE RATHER COMPLEX AND DETAILED NATURE of the following research, data, and findings, it is expedient to lead the reader into the deep waters of initiation with a more lighthearted parable, lest s/he be frightened away from this exciting research by the dry, technical jargon that will necessarily prevail throughout most of the paper.

If singing were a religion, it would surely have many commandments: thou shalt stand uprightly before all men and maintain a noble posture; thou shalt drink water continually; thou shalt array thyself professionally and modestly; thou shalt not clear thy throat habitually; thou shalt release thine abdomen and keep thy shoulders relaxed when thou takest in the breath of life; thou shalt breathe silently; etc.

The Master Teacher would minister faithfully to his disciple voice students with the soberness and gravitas of a prophet. One can imagine if the Master were confronted by his disciples with the question, "Master, which of all the commandments is the greatest?"

He would probably answer something like this: "Thou shalt sing with a vibrant tone, and thou shalt sing with a focused, resonant tone. Upon these two great commandments hinge all of the law." Most classical voice teachers (priests and priestesses of the faith) can agree on these two basic principles. A vibrant tone sounds free and facile; a focused and resonant tone sounds clear, rich in color, and effortlessly strong. There are diverse paths (various breathing and breath management techniques) people traverse in search of these two great ideals, but ultimately the breath of life must pass through that strait (not straight) and narrow laryngeal gate to reach the expanse of heaven without the body. Then as it reaches the Master's ears, the singer is judged according to his sounds, whether they are good or bad, beautiful or ugly, strong or weak.

The focus of this article is that strait and narrow gate that leads to vocal sound—the larynx. More specifically, the following discourse explores a new and innovative way to teach singers how to maintain the lower laryngeal position while singing, a component of classical singing technique that many consider essential to achieving a vibrant, focused, and resonant tone.

Singing, like most things humans endeavor to do, is part spiritual and part physical. Learning to sing involves faith, works, diligence, trials, judgment, chastisement, repentance, and, occasionally, glorious transfiguration. Nevertheless, it is by small and simple physical works that all these vocal sounds are brought to pass. Therefore, components of singing can be measured and quantified to some extent. Though the methods employed in this research are admittedly cold and scientific, the results are statistically significant and even transformational for some of the participants.

WHY LOWER THE LARYNX?

One of the most significant physiological differences between the singing of a classically trained singer and an untrained singer is the position of the larynx. Untrained singers usually sing with a natural, speech-like laryngeal posture, which for most people is a neutral or slightly elevated laryngeal position. The neutral laryngeal position is easily maintained when one sings, so long as the sung pitch does not exceed the comfortable speaking range.

As an untrained singer ascends the scale and exceeds the comfortable speaking range, increased subglottic breath pressure pushes the larynx higher from beneath, while compensatory tension in the laryngeal elevator muscles reflexively pulls it up from above. The result is a shorter, more constricted vocal tract and a strained vocal tone.

It is very difficult to sing "high" notes with the high larynx posture because: 1) throat tension causes physical discomfort; and 2) the resonance properties of the vocal tract in its shortened and constricted state are not optimal for beautifying and amplifying the sung pitch. Therefore, at this point in the ascending scale, the high larynx singer either will seek relief from increased muscle tension and subglottic pressure by breaking into falsetto and allowing the vocal tract to relax and dilate; or s/he will shout the tone with greater intensity, calling upon sheer muscle power to overcome the vocal difficulty. The result of this strategy is an uneven tone; high notes will either be breathy and weak, or strained and shouted in comparison to the speaking range. The constricted vocal tract may also affect vibrato oscillations, which are often absent or uneven in the high larynx posture.

Classical singing style, because its genesis was primarily in the era of unamplified music, involves lowering the larynx, thus increasing the length and size of the vocal resonator in an effort to amplify the voice naturally. Finding optimal singing resonance can be likened to tuning in an old analog radio with a knob. One can hear the station dimly when the tuner is a little off the mark, but with a lot of white noise in the background. The music is nevertheless audible and pleasant enough to the ear that some are content to listen to it that way. But as one continues to adjust the knob and tune in the station more accurately, so that the frequency of the tuner precisely matches the frequency of the broadcast, the music becomes discernibly louder, clearer, and devoid of background noise. One turns the allegoric knob of the voice when one changes the shape of the vocal tract by moving the articulators (lips, tongue, jaw, etc.). The vocal counterpart to the radio tuner is the air in the vocal tract, which, when it vibrates within its fleshy cavern, has its own distinct frequency independent of the sung note. The vibrating vocal folds are analogous to the broadcast station. When these elements are properly coordinated and in tune, the resultant sound is clearer, louder, and more colorful.

The lengthened resonance tract of the voice that results from the lower larynx can be tuned, like the proverbial analog radio, to a greater range of frequencies that can be matched to the fundamental frequency of the sung pitch, or one of its overtones, to yield a more resonant, beautiful tone.[1] In other words, the singer's tone benefits from the lower larynx and sounds easier, effortlessly louder, and more even throughout the entire vocal range. When the singer is able to freely tune the resonance tract (change the shape of the mouth and throat) in its lengthened, dilated, and comparatively relaxed state, perceived "breaks" in the voice become less discernable.

It is not always obvious when singers fail to achieve the desired lower laryngeal position, especially when singing in a comfortable range. It usually becomes more obvious as the singer exceeds the speaking range and has difficulty reaching higher notes. Strained, high larynx singing can cause vocal injury and pathology. Electromyographic (EMG) biofeedback can take some of the guesswork out of the learning process by providing clear visual and/or aural feedback in real time as the vocalist sings.

METHODS

EMG detects and measures the bioelectric energy emitted by tensed muscles in the body through electrodes, which can be placed on the skin over the muscle of interest or inserted directly into the muscle by piercing the skin with fine wire contacts. Only surface electrodes were used in this study. EMG provides real-time visual and/or aural feedback, which indicates the relative tension or flaccidity of muscles by displaying the microvolts (μV) of electricity emitted. A microvolt is equal to 10^{-6} volts, or one-millionth of a volt.

The purpose of this research was: 1) to discover if surface electrode EMG is a reliable indicator of the activity of the laryngeal depressor muscles; 2) to test the usefulness of EMG biofeedback in teaching singers to activate the laryngeal depressor muscles and to maintain the lower laryngeal posture while singing; and 3) to determine if the achievement of said laryngeal posture improves the perceived quality of the sung tone, or changes any scientifically measureable components of the sound spectrum.

A group comprised of 22 undergraduate voice students and 8 untrained singers was tested. EMG surface electrodes were placed on both sides of each singer's larynx over the thyroid cartilage in an effort to isolate the sternothyroid (ST) and sternohyoid (SH) muscles, the primary depressors and stabilizers of the larynx. While participants sang, EMG recordings were made bilaterally from the ST and SH muscles of the neck using bipolar Ag/AgCL surface electrodes with circular, pre-gelled contact areas of 10 mm and a fixed interelectrode distance of 20 mm (Noraxon USA, Inc.) oriented parallel to the direction of the muscle fibers. The skin was prepared using standard procedures in accordance with the International Society of Electrophysiology and Kinesiology (ISEK) and European Surface Electromyography for the Non-Invasive Assessment of Muscle (SENIAM) recommendations for skin preparation.[2]

EMG data was recorded with a Noraxon Myosystem 1400A (Noraxon USA, Inc.), amplified (x1000), filtered between 10 and 500 Hz, sampled at 1000 Hz, and digitized by a 12-bit analog to digital converter. EMG data was analyzed using MyoResearch XP Master Edition 1.07.09 (Noraxon USA, Inc.) in accordance with ISEK guidelines.[3] EMG data was adjusted for DC-offset, full wave rectified, and bandpass filtered between 5 and 350 Hz.

For the control portion of the experiment, each participant was simply asked to sing a specified pitch four times on the vowel /a/. The pitch was chosen, according to voice types and gender, to be a note slightly above the comfortable speaking range, where the increase in subglottic pressure would tend to nudge the larynx upward. The pitches were assigned as follows: baritones—B_3, tenors—D_4, mezzo sopranos—B_4, and sopranos—D_5. Three types of data were recorded for each participant while singing the assigned pitch: 1) EMG output in microvolts; 2) the distance of laryngeal movement from the at-rest position to the singing position in ± centimeters; and 3) audio recordings, which were later judged by a panel of voice experts and graded on a scale of 1–5 (1 = terrible, 2 = bad, 3 = fair, 4 = good, 5 = excellent). Audio recordings were made of all control and test trials utilizing the onboard microphone on a 2008 MacBook Pro laptop computer and GarageBand '08 (Apple, Inc. 2008) recording software.The voice panel was comprised of three university voice teachers, a choir director, and an opera conductor.

The movement of the larynx was measured by drawing a horizontal line on the skin with a dry erase marker over the superior process of the thyroid cartilage (Adam's Apple) in the at-rest position. The investigator placed his middle finger over the mark on the neck and gently pressed the cartilage with his fingertips as the participants sang. Based on the perceived laryngeal movement upward or downward across the fingertips, measurements were taken using the OB/GYN method of measuring cervical dilation, where one fingertip's width is estimated to be 1 cm. The perceived movement of the larynx was recorded in + cm for upward movement and –cm for downward movement.

After the control phase of the experiment, the singers were trained for about two minutes to lower the larynx by yawning while watching the EMG biofeedback bar graph for confirmation that the larynx was lowered successfully. Each singer had to successfully activate ST/SH and receive EMG biofeedback confirmation three times before moving on to the test phase.

Participants sang the same note and vowel in the test trial that they had sung in the control trial, only this time they were instructed to raise the bars on the EMG biofeedback device by lowering the larynx as they sang. The same methods of measuring EMG data, laryngeal movement, and tone quality were employed.

DATA ANALYSIS

Paired t-tests were conducted to determine if there were differences between the control and test trials for EMG mean and peak voltage (μV), laryngeal movement (cm), and rating of sung tone (scale of 1 to 5). Repeated measures ANOVA was utilized to detect any interaction of gender with EMG mean and peak voltage, laryngeal movement, and rating of sung tone. All analyses were performed using SPSS 16.0 (SPSS, Inc., Chicago, IL). Data are presented as mean ± SD; statistical significance was accepted at $p \leq 0.05$.

The test data was compared against the control data to determine if there was a correlation between quality of tone, lowering of the larynx, and increased EMG biofeedback. Selected audio-recorded samples of participants who demonstrated great change in quality of sung tone measurements between control and test trials were run through voice analysis software CantOvation Sing & See Professional (Mac) v1.3.2 (CantOvation Ltd) to compare the spectrographic and power spectrum data for measurable differences. The spectrographic data revealed elements of tone quality that were not specifically assessed in the survey, such as: relative amplitude/loudness of sung tone, intensity of harmonics in relation to the fundamental frequency, presence or absence of the "singer's formant cluster," and frequency of vibrato oscillations.

RESULTS

A significant difference in mean EMG voltage was found between the control (5.07±2.8 μV) and test (8.16±4.2 μV) trials ($p = 0.000$). A significant difference in peak EMG voltage was also found between the control (5.57±3.4 μV) and test (9.70±5.3 μV) trials ($p = 0.000$). In other words, the average participant nearly doubled EMG output in the test trial, which indicates that s/he successfully activated ST/SH.

If electrode placement is not sufficiently anterior to the thyroid cartilage, one runs the risk of interference from the sternocleidomastoid muscles located on either side of the larynx. Care must also be taken that the platysma muscle is not tensed during training. The platysma is a superficial sheet of muscles that covers the neck and inserts at the jaw. It is flexed when one grimaces or frowns. When tensed, there is a characteristic flaring of the neck and wrinkling of the skin of the neck along the vertical fibers of the platysma. Therefore, care must be taken that the participant relaxes the facial muscles and neck while lowering the larynx. Among the thirty participants tested, interference from other muscles was only noticed in one female participant because of poor electrode placement, and one male because of platysma tension.

There was a significant interaction of gender with both mean EMG voltage ($p = 0.003$): control (females: 5.57±3.2 μV, males: 4.31±2.0 μV), test (females: 7.43±3.9 μV, males: 9.25±4.5 μV); and peak EMG voltage ($p= 0.006$): control (females: 6.22±4.0 μV, males: 4.58±2.1 μV), test (females: 8.76±5.1 μV, males: 11.12±5.4 μV). Men were able to achieve greater change in EMG output between control and test trials. Larger muscles can produce more microvolts under tension. The probable reason for men's ability to produce more EMG biofeedback in the test trial is the comparably larger larynges and musculature of men.

Laryngeal movement was found to be significantly different between the control (0.75±0.49 cm) and test (−0.69±0.73 cm) conditions ($p = 0.000$). That represents an average 1.44 cm (0.75 cm upward + 0.69 downward) range of laryngeal movement between control and test trials. There was not a significant interaction of gender with laryngeal movement ($p = 0.150$): control (females: 0.659±0.42 cm, males: 0.856±0.57 cm), test (females: −0.500±0.74 cm, males: −0.917±0.69 cm). In other words, men and women were equally successful at lowering the larynx during the test trial.

Some men were able to move the larynx as much as 2 cm up and 2 cm down from the at-rest position (4 cm range of motion), while most women's larynges moved no more than 1 cm up or down from the at-rest position (2 cm range of motion). Laryngeal movement could not be determined in a small minority of women. The larynges of these women seemed to be drawn inward toward the spine when activating ST/SH, so that the superior process of the thyroid cartilage could not be felt with the fingertips. One possible reason for this anomaly is the action of the omohyoid muscle, which is a laryngeal depressor muscle that originates at the scapula and inserts at the hyoid bone. When flexed, it lowers the larynx, but the omohyoid may also draw the larynx slightly toward its point of origin, which is posterior to the larynx. Another possible reason is that a woman's thyroid cartilage is usually smaller than that of her male counterpart and is, therefore, more difficult to locate. Also, laryngeal movement could not be determined for one male participant with localized fat deposits in the neck area. Those participants whose laryngeal movement could not be determined were not included in the laryngeal movement statistics.

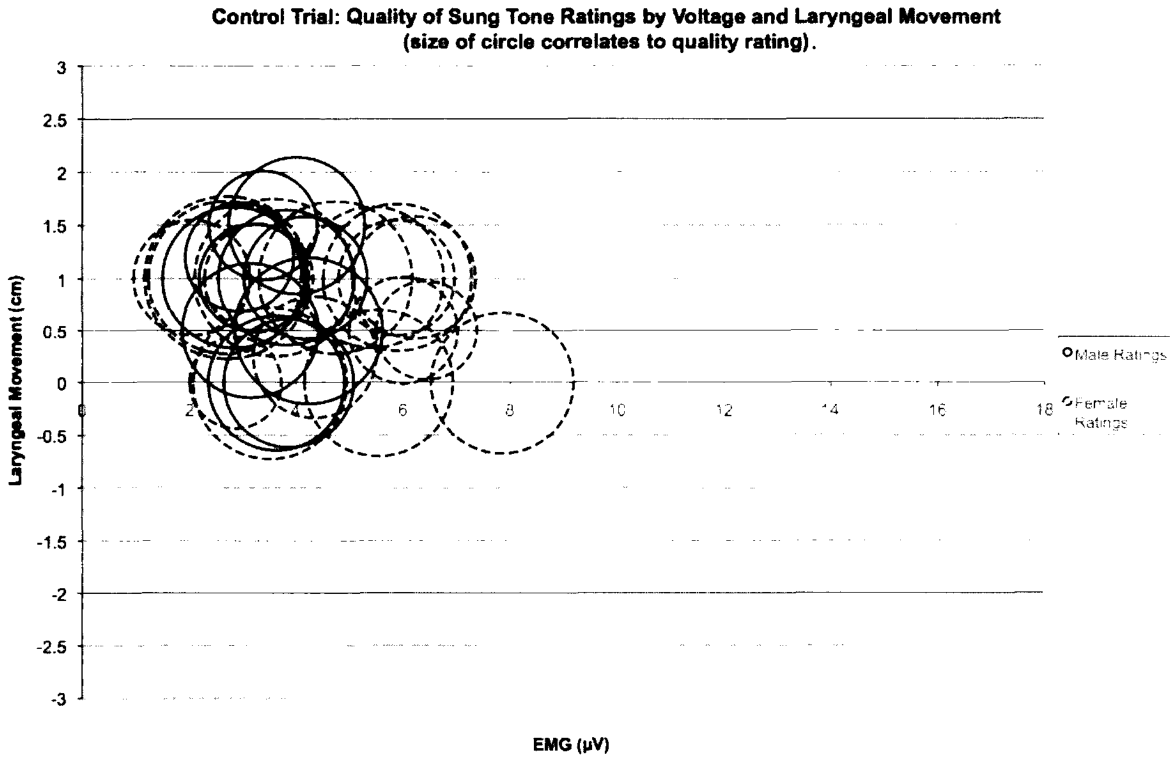

Figure 1. Tabular summary of EMG voltage, laryngeal movement, and quality ratings for control trial.

Rating of sung tone was also found to be significantly different in the control (2.63±0.74) versus the test (3.23±0.78) trial ($p = 0.000$). The average control trial tone quality rating of 2.63, therefore, represents a quality assessment of better than bad, but less than fair. The average test trial singing was scored at 3.23, better than fair, but less than good. This means the average participant improved by 0.60 points on the 5-point scale, which represents 12% improvement. Considering the extremely short training period of only a couple of minutes between the control and test trials, these results are impressive. Some participants improved as much as a full point on the scale, or 20% (See Figures 1 and 2 for a tabular summary of results from control and test trials).

There was not a significant interaction of gender with rating of sung tone ($p = 0.559$): control (females: 2.71±0.86, males: 2.50±0.51), test (females: 3.26±0.94, males: 3.17±0.49). In other words, the singing of both men and women improved equally during the test trial.

Because the base of the tongue attaches to the top of the larynx at the hyoid bone, it is important for the singer to realize that the tongue will be drawn down slightly as the larynx descends. One does not push the larynx into a lower position by tensing and depressing the base of the tongue as many people erroneously assume. The tone may sound throaty or swallowed if the singer does not relax the tongue and allow it to assume what may feel like a higher position than normal to compensate for the lower position of the base of the tongue in the low larynx posture.

Spectrographic comparisons of control and test trials revealed a consistent increase in intensity of the "singer's formant cluster" (between 2000 Hz and 4000 Hz), as well as all harmonics above 4000 Hz (see Figures 3 and 4). It is interesting that the higher harmonics increased in intensity since the panel of voice experts generally perceived the tones heard in the test trial recordings to be "warmer" or "rounder," not brighter as one might expect with an increase in higher harmonic intensity.

Vibrato oscillations were slow, inconsistent, or completely absent from some of the sung tones recorded in the control trials. However, during the test trial (especially among those participants who greatly increased their EMG output by successfully lowering the larynx) there was an increase in occurrence of vibrato (see Figures 5

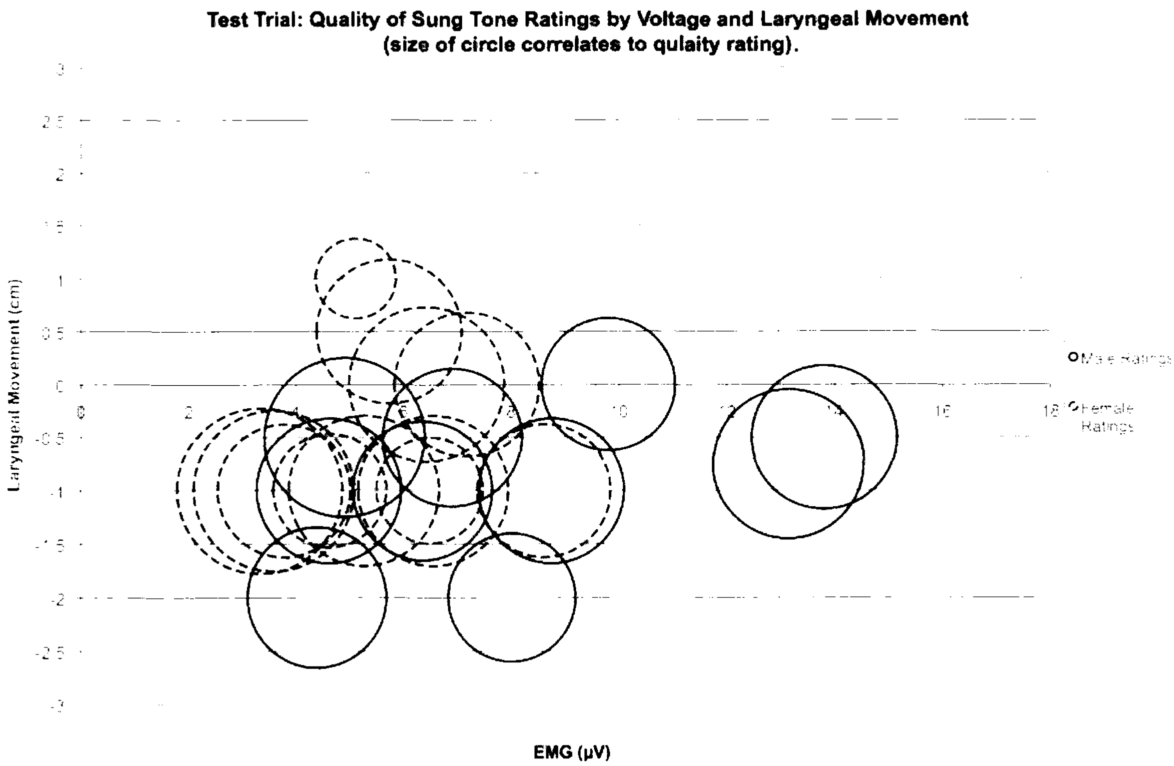

Figure 2. Tabular summary of EMG voltage, laryngeal movement, and quality ratings for test trial.

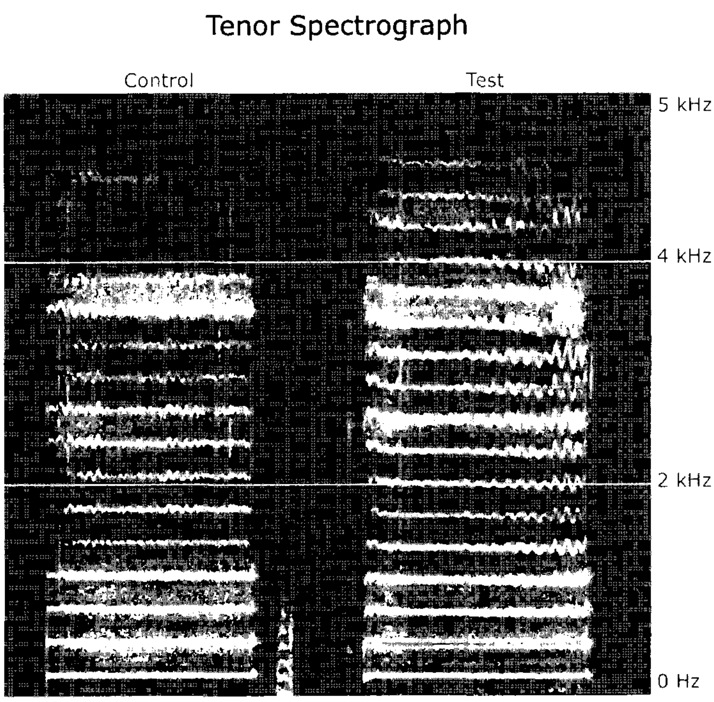

Figure 3. Spectrographic comparisons of control and test trials revealed a consistent increase in intensity of the "singer's formant cluster" (between 2000 and 4000 Hz), as well as all harmonics above 4000 Hz.

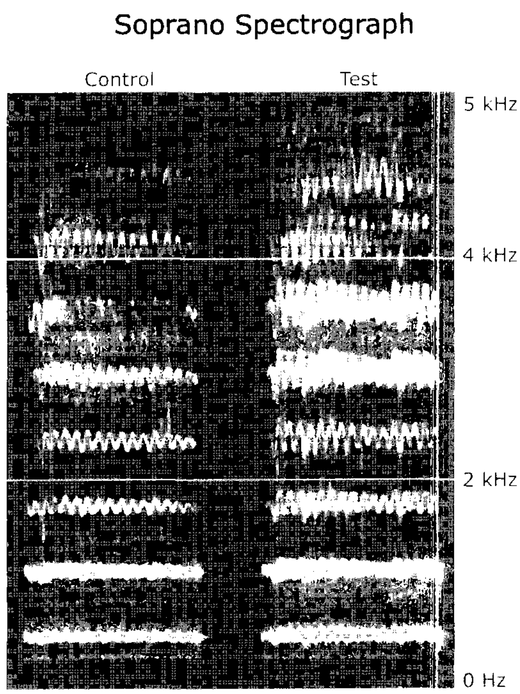

Figure 4. Spectrographic comparisons of control and test trials revealed a consistent increase in intensity of the "singer's formant cluster" (between 2000 and 4000 Hz), as well as all harmonics above 4000 Hz.

and 6). Upon successfully lowering the larynx and increasing EMG biofeedback, participants whose vibratos were slow in the control trial generally experienced an increase in vibrato speed. When participants successfully increased EMG biofeedback and lowered the larynx, the resultant tone sounded louder, more resonant, and vibrant.

CONCLUSION

The data suggest: 1) that surface electrode EMG biofeedback is a reliable indicator of the activity of the laryngeal depressor muscles ST/SH; 2) that EMG biofeedback is useful in teaching both male and female singers to activate the laryngeal depressor muscles and to maintain a lower laryngeal posture while singing; and 3) that the achievement of said laryngeal posture improves the perceived quality of sung tone, intensifies the "singer's formant cluster," increases the overall amplitude of the tone, and encourages vibrato oscillations.

EMG has been utilized by physical therapists for more than thirty years to aid in the treatment and recovery of patients suffering from paralysis, paresis, and other neuromuscular problems. EMG biofeedback has also been used in the training of athletes. Singers are vocal athletes and deserve the benefits of this technology. The data from this research suggest that there is great potential for utilizing EMG in the training of singers.

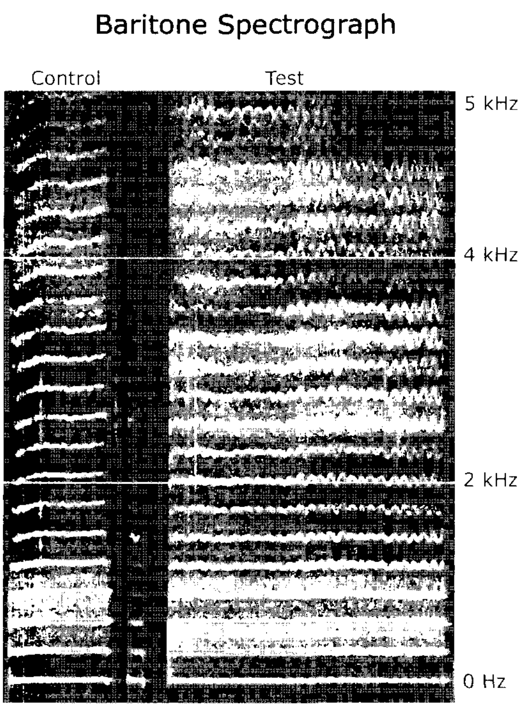

Figure 5. Spectrographic comparisons of control and test trials revealed an increased presence and regularity of vibrato oscillations.

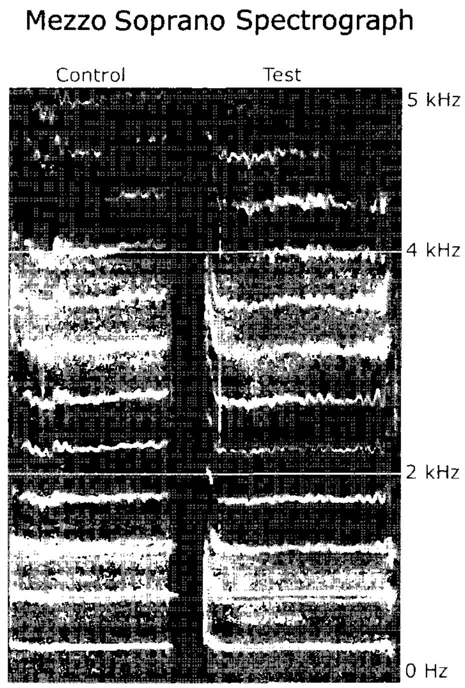

Figure 6. Spectrographic comparisons of control and test trials revealed an increased presence and regularity of vibrato oscillations.

One can imagine university voice students in voice labs where singers can practice while hooked up to a portable EMG biofeedback device. They would receive real-time visual and/or aural biofeedback. In addition to teaching the lower laryngeal position, there are many other possible applications for EMG in training singers; EMG could be utilized to correct unwanted shoulder, jaw, or neck tension, for example. Singers would receive an audible cue when the offending muscle was tensed.

If the average singer can improve tone quality by 12% after only a few minutes of training to lower the larynx with EMG biofeedback, imagine how much improvement could be achieved over the course of a semester. While the description of how EMG was employed in this study sounds daunting and confusing, it is relatively simple. With some basic knowledge of the location and muscle fiber orientation of targeted muscles (and an hour or two of training on how to properly prepare the skin, place the electrodes, and operate the equipment), EMG biofeedback devices can be used by just about any voice professional who seeks to improve the singing process.

NOTES

1. Berton Coffin, *Chromatic Vowel Chart for Voice Building and Tone Placing* (Metuchen, NJ: Scarecrow Press, 1980).
2. H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau, "Development of Recommendations for SEMG Sensors and Sensor Placement Procedures," *Journal of Electromyography and Kinesiology* 10, no. 5 (October 2000): 361–374.
3. R. Merletti, "Standards for Reporting EMG Data," *Journal of Electromyography and Kinesiology* 9, no. 1 (February 1999): 3–4.

Dr. Adam Kirkpatrick, associate professor of music at Kennesaw State University, has sung operatic roles and concerts professionally in many theaters throughout the United States, singing with the Cincinnati Opera, Atlanta Opera, Santa Fe Opera, Tri-Cities Opera (NY), Dayton Opera, Florida State Opera, Knoxville Symphony, Newton Symphony (MA), Tallahassee Symphony, LaGrange Symphony (GA), Cobb Symphony (GA), Northwest Florida Symphony, and more.

Dr. Kirkpatrick is the inventor of a patented new method for teaching the lower laryngeal position in singing using electromyographic (EMG) biofeedback, and he is the architect of the BioGraph Infinity voice training software suite designed to work with this methodology, available through the Biofeedback Foundation of Europe (www.bfe.org).

Kirkpatrick holds a BM and MM in voice performance from the Cincinnati College-Conservatory of Music, and earned his Doctor of Music degree from Florida State University.

John McLester, PhD, FACSM, received his doctorate at The University of Alabama, specializing in Exercise Physiology. Dr. McLester is currently full professor and Coordinator of the MS program in Applied Exercise and Health Science at Kennesaw State University, Georgia. He taught and performed research at University of West Georgia from 2000 to 2002 and at Western Kentucky University from 2002 to 2005. Dr. McLester's research interests include physiological and biomechanical relationships, environmental physiology, and impact trauma.