Realizing the Benefits of SOVTEs: A Reflection on the Research

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There are currently more than three decades of formal research on semi-occluded vocal tract exercises (SOVTEs), as well as more user friendly sources of information such as websites, blogs, online forums, and videos. Nevertheless, questions still arise: What exactly do these exercises do? Do I have to use straws? Is this just a fad? These questions come up because this information needs to be framed with more attention to the why and the how. This article will attempt to survey the literature with an emphasis on bridging the gap between theoretical and clinical research and studio practice and to equip studio teachers with enough of the why and how to fine tune their use of SOVTE exercises.

Any exercise in which the vocal tract is made partially closed at or near the lips is considered an SOVTE. For centuries, hums, lip trills, tongue trills, and sustained voiced fricatives all have been a part of the voice teacher's toolbox to improve the functionality of singing. Over the past one hundred years, the speech community, led largely by Finnish practice and research, has used resonance tubes for therapeutic purposes.[1] In the last few decades, Ingo Titze popularized the use of straws (paper, metal, and corn-based versions available) through numerous articles and videos (including "Vocal Straw Exercise" available on YouTube),[2] and raised awareness about SOVTEs generally. As the use of SOVTEs has become more commonplace, it is important to trace what we actually know about them through theoretical models and clinical studies.

A thorough explanation of the properties of impedance is beyond the scope of this article; however, a discussion of SOVTEs requires some understanding of how the properties of impedance come into play. (The introduction to "Acoustic Impedance of an Artificially Lengthened and Constricted Vocal Tract" by Brad H. Story et al. includes helpful analogies for understanding these concepts.)[3] At its most basic, impedance describes how much opposition a system encounters as it starts up.[4] Titze defines acoustic impedance of the vocal tract as "a measure of the ratio of oscillating pressure to oscillating flow at the entry to the vocal tract."[5] Impedance breaks down into two types: *resistance*, which dissipates acoustic energy, and *reactance* which stores acoustic energy. Reactance also breaks down into two types: *compliance*, which hinders phonation, and *inertance*, which feeds the stored energy back into phonation. Inertance is the beneficial branch of reactance; thus, many sources refer to reactive inertance when discussing the type of impedance that benefits the glottal cycle. The formula for inertive reactance is as follows: the density of the air multiplied by the length of the vocal tract, divided by the cross-sectional area of the vocal tract. SOVTEs can increase reactive inertance through lengthening the vocal tract and narrowing the cross-sectional area of the vocal tract. An inertive vocal tract is understood to be a desirable condition for singing because it leads to greater efficiency, a better return on investment.

INTRAORAL PRESSURE

SOVTEs have many potential influences on the vocal tract, both mechanical and acoustic.[6] When the vocal tract has an anterior (frontal) occlusion, it raises intraoral pressure and, along with it, the pressure above the glottis. In addition, raising intraoral pressure in nonnasal SOVTEs encourages palatal lift.[7] Raising intraoral pressure also impacts the relationships of other pressures in the vocal tract. For example, transglottal pressure is calculated by subtracting the supraglottic pressure from the subglottic pressure. If these two forces become equal, phonation stops,[8] but if the difference is too high, the folds are driven hard. Exercises like SOVTEs, that raise the supraglottal pressure in relationship to the subglottic pressure, lower the transglottal pressure, thereby reducing some of the driving force of phonation. So, it is helpful to think about how exercises might be ranked in terms of their intraoral pressure.

One study that provides useful information on ranking semi-occluded exercises by their intraoral pressure is "Intraoral pressures produced by thirteen semi-occluded vocal tract gestures," by Lynn Maxfield et al.[9] According to the findings of the study, the exercises in order from least intraoral pressure to most are: /m/, /n/, /u/, drinking straw, /z/, /ʒ/, tongue trill, /β:/, /v/, small straw, raspberry, and straw in water.[10] The range of intraoral pressures was surprisingly wide across the exercises examined. For example, the intraoral pressure of straw in water was ten times that of the sustained /m/, which caused the authors to call into question whether the first three exercises provide enough intraoral pressure to function as SOVTEs.[11] It is important to note that people execute voiced fricatives with different levels of pressure between the articulators, which changes the intraoral pressure for the same exercise. The study had twenty participants: ten women (five with vocal training, five without) and ten men (five with vocal training, five without), and the intraoral pressure was lower for women than men, but the order of the exercises from least to greatest pressure was essentially the same. The reason for this difference is that, in general, women generate less pulmonary pressure than men, resulting in a lower intraoral pressure. The authors point out that there is an advantage in using exercises that are the most consistent in their results with the most different kinds of people. In this study, the small straw (3.5 mm internal diameter, 14.1 cm length) produced the most consistent results between men and women and between trained and untrained singers.[12]

Working down the vocal tract, the increase in supraglottal pressure also raises the intraglottal pressure,[13] providing a force that opposes the collision force of phonation and lessens the impact of the vocal folds. This has important implications for singers who are habitually hyperfunctional in their adduction, who are at risk for vocal injury, or who are vocally tired. The cushioning intraglottal pressure is correlated to the increase in intraoral pressure ranked above.[14]

PHONATION THRESHOLD PRESSURE

Phonation threshold pressure (PTP) is defined as the air pressure it takes to cause the folds to oscillate.[15] According to Story et al., "Low values of threshold pressure suggest an ease of phonation as well as providing a greater range of available subglottal pressures with which to produce phonation."[16] One study that examined PTP in relation to SOVTEs used eleven excised canine larynges connected to an artificial vocal tract.[17] The study measured phonation using two tube diameters, three tube lengths, and three levels of air flow. There was a significant drop in PTP compared with control for all combinations except the lowest airflow combined with the shorter two tube lengths.[18] A similar outcome was reported from a study of 24 participants asked to perform both a five- and a ten-minute straw phonation exercise.[19] PTP decreased after both protocols, but the results lasted longer after the ten-minute exercise,[20] adding support to the idea that stabilizing these benefits for students is related to length of exposure. In another study three singers were tested using different-sized straws on different pitches; one male singer, a tenor, showed evidence of increased flow as the diameter of the straw decreased on the two higher pitches, E_4 and

B_4.[21] This is counterintuitive because the narrower straw constricts the airflow, but the authors speculated that the back pressure of the narrower straw increased the intraoral pressure sufficiently to move the vocal folds apart and lower glottal resistance, allowing more air to move through the glottis. By contrast, PTP in another study went up slightly and collision threshold pressure (CTP) went up significantly in five singers after using resonance tubes in water. The authors of this study point out that these exercises increase blood flow to the vocal folds which may in turn increase vocal fold mass, leading to higher CTP.[22]

Without the interactivity of the vocal tract supplied by vocal tract inertance, PTP rises with pitch.[23] Voice teachers often see this in novice singers for whom high notes are either strained or completely inaccessible. However, in regard to PTP and rising pitch, Titze states that "there may be peaks and valleys, depending on the degree to which an individual uses source-filter interaction in phonation. We suspect that those who use little interaction will have a fairly monotonic change with f_O, whereas those who use much source-filter interaction will show peaks and valleys."[24] SOVTEs are part of building a technique in which higher does not always feel harder.

RESPIRATORY FORCE/SUBGLOTTIC PRESSURE

The more the respiratory system has to work to move air through the vocal tract, the more of a "workout" it gets. SOVTEs increase the work of the respiratory system in correlation with the resistance of the specific exercise. This provides an important warm-up effect for developed singers, but also benefits developing singers, possibly accelerating how quickly they learn to recruit the breath forces necessary for healthy, robust singing. The increased work of the respiratory system raises subglottic pressure, which is necessary for learning to sing louder but traditionally comes with a risk of taxing the voice as the student is learning to manage these pressures; that risk is reduced with SOVTEs. While these exercises raise subglottic pressure, they also raise supraglottal pressure, and the cushioning intraglottal pressure. Guzman et al. mentions that this helps less experienced singers to manage the transglottal pressure while they are learning to control subglottal pressure.[25] The ability to experiment with higher lung pressure and higher subglottic pressure while simultaneously providing protection from high collision forces in the glottis is an important confluence for singers and teachers of singing.

VERTICAL LARYNGEAL POSITION

Studies refer to the relative height of the larynx as vertical laryngeal position (VLP). Although it is generally agreed that classical singers seek a lower vertical laryngeal position than for speaking, in other types of singing one finds a range of recommendations. In looking at this topic, the present authors consider it a given that whether or not the ultimate goal is to sing with a low larynx, it is beneficial in the study of singing to be able to adjust the larynx down in a healthy and released way as part of the training process. Such an adjustment offers the opportunity to release muscles that pull up on the larynx, to disengage "locked" behaviors, and to discover different vocal tone colors.

A lower VLP is one of the potential benefits of SOVTEs. Guzman et al. looked at twenty-one subjects, all diagnosed with hyperfunctional dysphonia but without lesions, none of whom had ever had voice therapy or voice training. Each was tested on eight SOVTEs; all eight exercises resulted in a lower VLP and the three with the greatest resistance produced the three lowest VLPs.[26] Guzman et al. also conducted a single subject study using a CT scan to measure the size and shape of the vocal tract before and after tube and straw phonation. The vertical length of the vocal tract increased owing to a lower VLP after resonance tube phonation and even more after straw phonation; the change in VLP remained when the singer repeated phonation on /a/ afterward.[27] Both of these studies show a correlation between an increase of vocal tract impedance and the degree of change of the VLP.

There are two theories about why SOVTEs may facilitate a lower VLP. One is that the higher supraglottal pressure exerts a downward pressure on the larynx.[28] There is anecdotal evidence that some students will fight this downward pressure, thus rendering the exercise ineffective on that front. In such cases, it is helpful to ask the student to reduce the intensity of the exercise or to adjust the breath so as to lessen the subglottal breath pressure.

Offering instructions such as "allow the throat to feel long" may further the efficacy of the exercises as an aid to a lower VLP. Another explanation for why SOVTEs may lower VLP is that this result is a by-product of the ways in which SOVTEs reduce the work of singing leading to more relaxed extrinsic laryngeal muscles.[29] Neither of these explanations precludes the other. A lower VLP is often correlated with a wider pharynx and a narrow epiglottic area. When using SOVTEs to encourage a lower VLP, listen for the sound to get warmer and rounder as the vocal tract lengthens.

It is worth noting that, while they are not always considered SOVTEs, bilabial stop-plosives also help lower the VLP, especially because they do not involve the tongue, which can be responsible for raising the VLP.[30] Since a lip trill vibrates the lips in a position similar to a /b/, it may be especially effective among SOVTEs at lowering VLP.[31] However, another study on the voiced bilabial fricative /β:/ found that overall the VLP was higher during the /β:/ than singing on an /a/. The authors proposed that in an effort to handle the increased subglottic pressure, subjects pulled the thyroid cartilage upward to increase adduction.[32] This would be an undesirable outcome if the goal is a lower VLP, and underscores that, for any vocal exercise, teachers and students should know the intended goal and recognize signs that the goal is or is not being met. If not, the teacher should substitute a different SOVTE, a modified version of the exercise, or further instructions about how to execute the exercise.

LOUDNESS AND TONAL COLOR

It can seem too good to be true that SOVTEs can both reduce wear and tear on the vocal folds and result in a tone that is "clearer, brighter, and more sonorous."[33] What contributes most to these positive qualities is not how hard the vocal folds come together, but rather how fast the air stream through the glottis is cut off by the closing vocal folds. In essence, if the supraglottal pressure is high enough, then it helps push open the glottis at opening while simultaneously suppressing the air flow.[34] Then, at closing, the negative supraglottal pressure helps suck the folds back together while maintaining flow as long as possible before the folds close.[35] This is sometimes referred to as improving the "push-pull" of the glottis; the greater the inertance, the greater the push-pull.[36] Titze notes that an inertive vocal tract "can . . . be thought of as a feedback mechanism between the pressures in the vocal tract and the vocal fold movements that created them."[37] This relationship is what contributes to the "rightward skewing" of the airflow noted by Rothenberg.[38] Rapid closure contributes to a shallow spectral slope resulting in more acoustic energy in the higher harmonics.[39] The increased energy in higher harmonics makes the sound "brighter" and also boosts any resonant frequencies clustered in the range of singer's formant.[40]

There are mechanical contributors to vocal efficiency in addition to the aerodynamic factors mentioned in the previous paragraph. Titze explains that through the use of SOVTEs, "LCA activity is traded for a little more TA activity."[41] Results from a study by Laukkanen et al. provide evidence that an increase in vocal tract impedance tends to raise the activity of the TA muscle in proportion to the activity of the CT muscle;[42] a proportion that may loosen the cover of the fold and assist in vibration.[43]

As previously established, when the vocal tract is occluded, impedance in the vocal tract is raised. The glottis also has its own level of impedance. When the impedance of the glottis and the vocal tract are matched (called impedance matching), the best power transfer occurs.[44] A single subject study investigating the impact of an SOVTE on the TA, CT, and LCA muscles of the larynx as it relates to impedance matching supports the hypothesis that the ratio of TA/CT is correlated to vocal tract impedance. [45] It is worth noting that all the sound samples for this study were below 200 Hz.

CONTACT QUOTIENT

In each glottal cycle, the vocal folds come into contact along the bottom edge of the fold, zip up to the top edge, start to separate along the bottom edge and unzip to the top. The length of time the vocal folds touch constitutes the "contacting phase" of a contact quotient (CQ). Then there is a phase when air is flowing and the folds are not in contact, the open or decontacted phase of the CQ. Contact quotient, then, is a measurement of the percentage that the vocal folds touch in each cycle, and the open quotient (OQ) is a measurement of the percentage the vocal folds are not touching in each cycle. When added together, these two quotients equal 100%. The thicker the vocal folds, the more mass of the folds comes into contact. This larger area of contact requires a longer "zip up," which leads to a higher amplitude of the signal and also to a higher CQ.

When CQ is higher, the vocal folds experience collision forces for a longer period of time over each glottal cycle. The clinical trials often hypothesize a lower CQ during or after the use of an SOVTE. While in some cases this was true,[46] in other studies the numbers were either inconsistent,[47] trended up,[48] or CQ only went down in certain versions of the exercise [49] or at a specific intensity level.[50] One study looked at the impact of voiced fricatives on CQ. Their results underscore patterns that appear in other research: a) reduced CQ is more consistent in SOVTEs with the highest anterior constriction,[51] and b) there is significant variability between individuals.[52] Some investigators speculated that changes in CQ are more dependent on the person than the exercise.[53] This deserves further investigation, since the noninvasive nature of CQ makes it a frequent measure in research on SOVTEs.

Many things could contribute to the inconsistent results between and even within studies: the range of the exercises, the age, sex, and prior experience of the subject, how warmed up they were before the exercises were begun, the type of training received, and the physiology and temperament of the subject, to name a few. Some singers respond to the increased back pressure with increased activity in the TA muscle, which thickens the vocal folds and makes the glottis more rectangular. This tends to raise the CQ, but also to improve vocal economy by distributing the impact over a larger area.[54] For others the higher back pressure lowers glottal resistance leading to a lower CQ.[55] A note of caution was raised in regards to first introducing singers to SOVTEs with very high resistance (i.e., very narrow straws). Some people respond to unfamiliar back pressure by hyperadduction or resorting to pressed phonation.[56] For this reason, Titze recommends starting with exercises with medium resistance and working toward SOVTEs with maximum resistance. Once the student is comfortable with high resistance, the progression moves from high resistance to low resistance. Titze uses a nice turn of phrase when suggesting going from those exercises with "the greatest effect, but most artificial" to those with "smallest effect, but closest to natural."[57]

Ranking SOVTEs according to the amount of resistance they provide is only one way to categorize these exercises. Nix and Simpson proposed dividing SOVTEs into the following categories: sustained semi-occlusion, oscillatory semi-occlusion, and transitory semi-occlusion or occlusion.[58] Focusing on the first two of these categories, a study by Andrade et al. provides support for this organization. Exercises with sustained semi-occlusion have a single source of vibration.[59] The exercises examined from this category were humming, hand over mouth, and straw (in air), and were called group 1 or "steady" exercises. Exercises with oscillatory semi-occlusion have two sources of vibration. The exercises examined from this group were lip trills, tongue trills, and Lax Vox, which they called group 2 or "fluctuating" exercises. Rather than looking only at the mean CQ for each exercise, the researchers also tracked the range of the CQ, which they labeled CQr. The CQr measured the distance between the highest CQ and the lowest CQ for each exercise. The mean CQ did not show a statistically relevant drop in CQ for any of the exercises except the lip trill, when compared with singing on a vowel, but by looking at both the mean CQ and the CQr, valuable information came to light. The exercises in the "steady" group had CQr values that were close to the CQr of "comfortable phonation" on an /a/ vowel.[60] By contrast, the "fluctuating" group moved through a much more variable range of CQ values than is typically found in singing. In addition to wider CQ values, the frequency range was also wider in the "fluctuating" group of exercises.[61] In another study, Radolf et al. found that the "oral pressure oscillation" of exercises similar to those in the fluctuating group may offer a "massage effect on the vocal tract and vocal folds."[62] While this kind of fluctuation may not be the final goal in singing, the rapidly changing CQ and fundamental frequency could help a singer who is stuck in a very rigid or locked approach to their singing. Andrade et al. recommended this fluctuating group of exercises for those with "excessive tension of the extrinsic laryngeal muscles."[63] Further support for this idea was provided in a study using high speed imaging which noted an "amplitude variation on the glottal opening caused by the bubbles," highlighting the benefits of the "massage effect."[64] Another study showed "oscillation in the contact quotient" in lip and tongue trills.[65] However, the results raise caution in regard to intensity of lip trills (and possibly tongue trills). Participants were asked to sing a lip trill, a tongue trill, and an /ɛ/ at different intensity levels. At high intensity levels, the lip trill had a significantly higher mean CQ and maximum CQ than the /ɛ/. In a related study, laryngeal resistance decreased overall for straw phonation and tongue trill, but not lip trill.[66] Although by no means conclusive, there may be something about the lip trill that encourages or allows especially high CQ values at higher intensities, which may be counterproductive to the intended use of the exercise.

PROXIMITY OF f_{R1} TO f_0

Most SOVTEs lower the frequency of the first resonance (f_{R1}) primarily by lengthening the vocal tract and encouraging a larger pharyngeal space.[67] According to theoretical models, the vocal tract is inertive as long as f_0 stays below the first resonance and reaches a maximally inertive position when f_0 sits just below the first resonance.[68] Treble voices well trained in classical or legit head voice make consistent use of this close association of f_{R1}:f_0. It is helpful to note where these frequencies naturally coincide. The f_{R1} of the close vowels such as /i/ and /u/ typically falls in a range between 300 Hz and 400 Hz at speech level pitch, varying according to body size and the associated spaces of the vocal tract. The f_0 starts to gather energy as it approaches f_{R1} in an ascending scale or slide. (This gathering of energy happens in general as harmonics approach a vocal tract resonance.) With some training, treble voices can "feel" the acoustic benefit of the f_0 closing in on f_{R1} by the time they reach the bottom of the treble staff on close vowels in head voice. On open vowels, treble singers "feel" this boost around the top of the staff. Through vowel modification, treble singers make use of this acoustic and mechanical advantage through a much wider frequency range than would occur if limited to speech-like vowels. Two articles shed light on how the relatively weak glottal closure of head voice is able to provide enough resistance to subglottal pressure to allow for the strong, clear tone of classical treble high voice as well as the sustaining of relatively long phrases.[69] In fact, "the subjective experience of many female singers of high notes [is] that a well-produced tone offers an increased resistance to breath pressure, seeming to reduce airflow."[70] How is this possible without increasing adduction? Much of the credit is given to this close tuning of f_{R1} and the f_0. In short, this tuning provides a fortuitous timing of airflow whereby the peak supraglottal pressure coincides with the midpoint of the open phase of the glottis, which delays the flow of the air in the open phase.[71] This is important because the open phase in head voice can approach two thirds of the glottal cycle, and without the counter pressure of a high supraglottal pressure the unimpeded air flow during the open phase would yield a weak, breathy tone. SOVTEs offer the experience of matching f_{R1} to the f_0 in a lower part of the range than would otherwise occur, giving singers a chance to practice these sensations and coordination in a less demanding part of the range. If singers use SOVTEs on higher pitches, the f_0 is likely to sit near f_{R2} instead with similar benefits.[72]

How far can SOVTEs lower the value of the first resonance? Story et al. cite Fujimura and Lindqvist's data that a typical closed vocal track resonance frequency is about 200 Hz.[73] Titze found that the straws used in his study dropped f_{R1} below 220 Hz and the smallest straw lowered f_{R1} to 130 Hz.[74] These values are consistent with another study in which f_{R1} ranged between 150 Hz and 190 Hz for tubes and straws both in and out of water.[75] Even though this lowered f_{R1} cannot be transferred to normal singing beyond the limits of reasonable vowel modification (slightly closing the vowel, for example), the experience of matching f_{R1}:f_0 in a lower part of the range gives singers biofeedback that informs them about a desirable set of sensations.[76]

TRANSFER

The potential benefits of SOVTEs are compelling; and when implemented well, students often experience a noticeable improvement in ease and sustainability of phonation. Exercises with a narrowing at the front of the vocal tract are a good place to start with singers in the early stages of their development because this type of exercise does not require as much precision of the intrinsic laryngeal muscles in order to realize the benefits.[77] Once singers have experienced a sense of ease and coordination with no loss of potential power, they want to experience that all the time, but the issue of transfer is a complex one; as Titze notes, "[I]n any training program that uses exercises outside the norm of behavior, one must question transfer, or carryover, to normal behavior."[78]

Kang cites current learning theory when he proposes that "motor learning may play a role in the phenomenon for sustainability of an increased inertance. With practice, the neural connections that represent the task become relatively permanent (motor learning) and can be used to accomplish similar tasks (generalizability)."[79] This requires singers to get in touch with the sensations associated with their singing, especially focusing on the radiation of vibration that is a byproduct of efficient vocal fold vibration. In this approach, attention is drawn to vibrations in the face near the upper teeth, cheek bones, and hard palate because "when energy conversion process is efficient, vibrations are distributed . . . but when energy conversion process is poor, the vibrations are likely to remain more local."[80] Framing frontal sensations of vibration as a result of efficient phonation, rather than as an end in itself, may supply a better framework for discussion on the issue of "forward placement." Either way, in this approach, the sense of distributed vibration is experienced first while engaging in an SOVTE and then becomes a recognizable affirmation of desirable phonation when engaged in regular singing. As mentioned before, working backward from SOVTEs with high resistance to those of lower resistance[81] and eventually alternating vowels with nasals or voiced fricatives, strumming the lips while singing /i/[82] and rapidly covering and uncovering the mouth while singing an open vowel, all encourage kinesthetic transfer while moving closer to the full articulatory positions of language. In "Closing Your Mouth to 'Open' Your Sound," Nix makes the point that in any sequence designed to encourage transfer, one should start with familiar exercises and move toward new skills. This article has a number of exercises that model good sequencing to encourage transference of the desirable qualities of SOVTEs and even includes a model script for introducing these exercises to students.[83]

One type of SOVTE with unique potential for transfer is the mask SOVTE. Mask phonation was first proposed by Borragán et al., who sought to move the occlusion of the vocal tract in front of the mouth to allow flexibility of the articulators.[84] For this type of exercise, the singer wears a ventilated face mask. One study that used the brand name maskVox found that the benefits of mask phonation were similar to that of straw.[85] Voice teachers continue to expand the tools that can be used for "mask-like" SOVTEs including "funnel phonation" (see video on the Facebook group Voice Geeks by Jordan Travis)[86] and cup phonation as explained in *The Vocal Athlete: Application and Technique for the Hybrid Singer*.[87]

NARROWING OF EPILARYNX

Titze makes a very eloquent case that to experience the full benefit of transfer from SOVTEs, eventually a different narrowing should be employed at the opposite end of the vocal tract.[88] Narrowing the epilarynx tube causes the vocal tract to be inertive at nearly all frequencies and "the economizing effects of a front occlusion are transferred to the back of the vocal tract. The oral cavity can then be adjusted for any vowel or consonant."[89] The area between the glottis and the aryepiglottic folds has been termed the epilarynx or the epilarynx tube. For decades the resonant frequency clustering that leads to the singer's formant cluster and enhances frequencies between 2.5k and 4k has been associated with a vocal tract configuration in which a narrow epilarynx opens into a wider pharynx.[90] In addition to raising f_{R3} and lowering f_{R4} and f_{R5} leading to clustering, the relationship of a relatively narrow epilarynx and wider pharynx also improves the inertance of the vocal tract.[91] The narrowing of the epilarynx in particular supports conditions similar to the anterior constrictions of SOVTEs.

Three single-subject studies, one using MRI,[92] one using CT,[93] and the other using computer tomography and finite-element modeling,[94] examined in detail changes to the vocal tract before and after phonation into a straw, a tube and a straw, and a tube respectively. All three studies were encouraging in that a number of adjustments made during phonation into a straw or tube were maintained when returning to an /a/ vowel showing transferability. These studies indicated a widening of the pharyngeal area in proportion to the epilarynx, an adjustment that increases the inertance of the vocal tract. One study mentioned earlier in regard to lower VLP also saw an increase in pharyngeal width and a decrease in the width of the epilarynx as well as a high correlation between all three factors.[95]

The means of narrowing the epilarynx remains somewhat of a puzzle. Titze warns that the narrowing should be anterior-posterior instead of a medial-lateral constriction that is associated with vocal strain and a feeling of squeezing the throat as opposed to narrowing.[96] One hopes that research will eventually provide more information on which muscles accomplish this helpful narrowing, but in the meantime Titze's recommendations include lowering the VLP and fronting the tongue. Titze also offers that practicing hums, lip trills and bilabial fricatives with a darker quality may help induce an appropriate narrowing of the epilarynx.[97] The darker tone quality is consistent with a lower larynx and possibly a simultaneously wider pharyngeal space, both of which optimize conditions for the type of efficient phonation associated with SOVTEs.

OTHER BENEFITS

For traveling singers, SOVTEs can be used to warm up in hotel rooms so that singers do not disturb those around them. Since many SOVTEs mute the sound, they can also help students be less critical of themselves as the filtered sound allows students to hear their voice without as many preconceived notions. This may also help those who are overly focused on aural feedback to begin to pay more attention to kinesthetic feedback. As we train our students about good vocal hygiene, including the use of vocal cool downs,[98] SOVTEs, especially at lower intensity levels, make ideal exercises.

Each SOVTE also offers a unique articulation position; for example, /ŋ/ adds nasality to the sound, /z/ encourages a forward tongue position, and straw phonation rounds the lips. (It is important to remember when using a straw that air should not leak out of the corners of the mouth and through the nose; all air should come through the straw.) Singers can fit their normal exercise with a posture of an SOVTE that does not impede the work of the original warm up. In fact, a teacher can use SOVTEs to enhance teaching, allowing the exercise to retrain undesirable habits (e.g., perhaps a teacher has a student do straw phonation with the internal structure of an /i/ space to work on rounding and warming the sound of the singer). In "A Systematic Approach to Voice: The Art of Studio Application," Kari Ragan includes a number of SOVTEs along with guidance about form and sequencing that reflects current best practice in light of the research reviewed n this article.[99]

In April of 2020, the singing voice science community lost an important voice and a tireless mentor in the lives of many when Donald Grey Miller passed away. Dr. Miller focused his work on data that could be gathered on singers during real-time singing, thereby bridging the gap between singing voice science research and the voice studio. His words continue to be timely and a helpful frame as the singing voice science world and the voice teaching world work together for the benefit of students of the art and craft of singing at every level. Donald Miller notes that "the covariation of sub- and supraglottal formant, as well as fundamental frequency . . . is quite complex, and we should not be surprised to find considerable variation in the ways these coalesce in actual voices, as opposed to models."[100] In a similar way, the effects of SOVTEs are well documented, but the research continues to bring to light considerable variation in actual voices within reliable principles. By knowing the purpose, function, and correct application of SOVTEs, teachers can improve the skill with which they and their students use SOVTEs leading to more clearly defined goals and more measurable results.

APPENDIX

Terms and Abbreviations	Definitions
CTP	Collision Threshold Pressure: Subglottal air pressure required for vocal fold collision
CQ	Contact Quotient: The percentage the vocal folds are in contact during each glottal cycle
CT	Cricothyroid Muscle
Dysphonia	Difficulty in speaking due to a physical disorder of the mouth, tongue, throat, or vocal folds
Epilarynx	Starts right above the vocal folds and ends at the aryepiglottic folds
f_0	Frequency of oscillation or fundamental frequency
First Resonance	The first and lowest resonance frequency of the vocal tract; also associated with perceived vowel quality (f_{R1})
Formant	Often used synonymously as a resonance of the vocal tract
Glottis	The part of the larynx consisting of the vocal folds and the opening between them
Hyperfunction	Excessive activity or function (as of a bodily part)
Impedance Matching	The matching of the impedance of the glottis with the impedance of the vocal tract
Intraglottal	In the glottis; between the folds
Intraoral	In the mouth
LCA	Lateral Cricoarytenoid Muscle
OQ	Open Quotient: The percentage the vocal folds are not in contact during each glottal cycle
PPT	Phonation Pressure Threshold: Subglottal air pressure required to cause the vocal folds to oscillate
Resonance Tube	Glass tube used in voice therapy usually with the free end of the tube in water
Second Resonance	The second resonance frequency of the vocal tract; also associated with perceived vowel quality (f_{R2})
Singer's Formant	The clustering of f_{R3}, f_{R4}, and f_{R5} that causes a singer's voice to have a ringing quality typically between 2.5k-4k Hz
Subglottal	Below the glottis
Supraglottal	Above the glottis
TA	Thyroarytenoid Muscle
Transglottal	Through or across the glottis
VLP	Vertical Laryngeal Position

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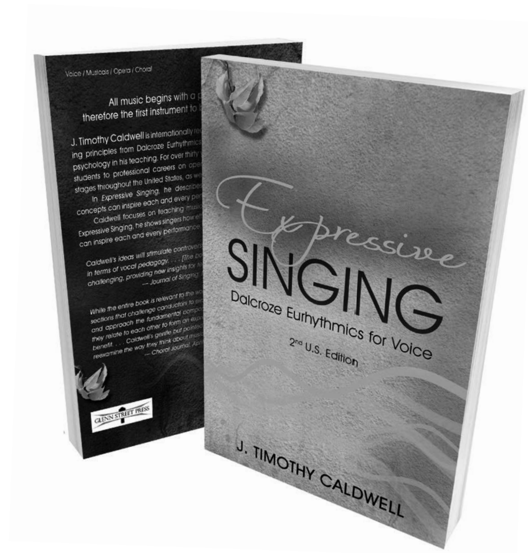

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