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Technology Translated to Teaching: Exploring Vocal Dosimetry

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INTRODUCTION

Certain items can be found in almost every voice studio, such as piano, music stand, and music books. Studios that are more high tech may have an electric keyboard, music files on a computer or iPad, or even spectrographic analysis software (like VoceVista) for real time visual feedback. Most teaching studios, however, would find little day to day use for an electroglottograph, an oscilloscope, or a phonatory aerodynamic system.

Besides the expense of stacking a voice studio with equipment like this without institutional financial support, many of us who earned voice performance degrees did not receive extensive (or any!) training on how to use these instruments, since they are more commonly used in a voice lab rather than in a teaching studio; however, we do not necessarily have to use this equipment ourselves in order for our teaching to benefit from the work of those who do. To make a comparison, most of us likely have never launched a scientific study on how to lower cholesterol; nevertheless, most of us have access to reliable information based on reputable studies indicating that a diet rich in soluble fiber can reduce overall cholesterol levels. Armed with this information, we can make dietary choices that benefit our physical health. Similarly, most of us have never launched a formal study on the intraoral pressures of semi-occluded vocal tract exercises. But, thanks in part to the *Journal of Singing*, we have access to information that demonstrates why lip trills and straw phonation can be important tools in the voice studio and how they may be implemented to great effect.

Therefore, teachers who wish to keep up with advances in voice science—in the interest of practicing evidence-based voice pedagogy—may benefit from some basic knowledge about how certain instruments of voice analysis work, in order to understand what can be gained from studies that involve these instruments. One such instrument is a voice dosimeter, also referred to as a vocal monitor or an ambulatory phonation monitor. In an effort to translate technology to the teaching studio, we will explore in this article what dosimetry is and how it is used to gather data. We will examine how these data have been used and will give an overview of some of the more significant studies in dosimetry that relate to vocal function and vocal health. Finally, we will identify some possible implications this information may have for the voice studio and offer some tactics and procedures that singing teachers may implement.

VOCAL DOSIMETRY

What is a vocal dosimeter?

Voice dosimeters are electronic devices that are used to accurately measure vocal use, quantified as vocal loads or vocal doses. They can be used in various environments, including in a natural environment. Derived from the word "dose," they measure the quantity of human voicing and the stresses placed on vocal fold tissues over a given period of time. Dosimeters are ambulatory, meaning that participants wear the devices as they go about normal daily activities. Put simply, voice dosimeters are "Fitbits" for the voice. They identify total numbers of vibrations as well as the average frequency and average amplitude of voicing. More recently, improved technology has also allowed us to use acquired dosimeter data to analyze voicing in terms of clarity, perturbation, and resonance qualities.

How does it work and how is it used?

A voice dosimeter captures an individual's voicing activity by attaching an accelerometer transducer—or contact microphone—to the neck, where it is highly sensitive to skin vibrations but minimally sensitive to vibrations from ambient sound. In the case presented here, a cable attaches the accelerometer to a digital recording device that is typically worn in a waist pack. Figures 1 and 2 are photographs of a budget dosimeter device using a commercially produced neck collar that contains both an accelerometer and an acoustic transducer paired with a standard off-the-shelf digital recorder. The data they capture are then analyzed with computing software that is typically included with a commercially produced device. In the case of the device in Figure 1, data are analyzed using MATLAB or a similar computing program. Some devices do a degree of processing on the portable recorder before undergoing additional post processing on the computer.

Figure 1. **Neck collar of the Sonvox VoxLog dosimeter.**

Figure 2. **Sonovox VoxLog collar attached at the neck and connected to a standard digital recording device.**

What sort of information does voice dosimetry provide?

Voice dosimeters capture the following "vocal dose" information for individuals during the period that they wear the device:

- Fundamental frequency (F0) describes the rate at which the vocal folds vibrate, measured in Hz, reported over time in terms of mean, median, and mode.
- Phonation time dose (Dt) refers to the cumulative duration of time (hh:mm:ss) or the percentage of time the vocal folds have actually come into contact over a given period. Since the vocal folds are not in continuous contact during the time when someone is speaking or singing (due to breathing, phrasing, and consonants), it has been estimated that actual phonation time may be as little as half of recorded speaking time.[1]
- Cycle dose (Dc) refers to the accumulated number of vibratory cycles in a particular time period. A vibratory cycle is one complete sequence of the opening and closing of the vocal folds.

- Sound pressure level (dB SPL) is a measure of vocal intensity measured in decibels (dB), reported over time in terms of mean, median, and mode. Distance of the sound level meter from the sound source will affect SPL measurements, so SPL is estimated from the accelerometer using a calibration process.
- Distance dose (Dd) is a term coined by researchers at the National Center for Voice and Speech (NCVS).[2] This measurement combines the factors of phonation time dose, F0, and phonation sound pressure level to estimate the total accumulated distance the vocal folds might "travel" over a period of time, calculating the total excursion of the vocal folds in each complete vibratory cycle.
- Voice quality. More recent developments have also allowed researchers to analyze the acquired data in terms of clarity (harmonic-to-noise ratio and pitch strength), perturbation (shimmer and jitter), and resonance qualities (amplitude ratio of high to low frequencies and energy produced within certain frequency bands).

How are these data analyzed and how is the information used?

These data allow us to observe how voices are used over time—how much, how high, how loud, and with what clarity, perturbation, and resonance qualities. A perusal of the research to date indicates that human voicing typically ranges anywhere from 5% to 25% phonation time over the course of a day. The average individual will acquire a daily cycle dose of a million vibrations or more and a daily distance dose of 5,000 meters or more, the equivalent of running a 5K every single day. Our vocal folds are built to endure an amazing amount of daily stress!

We can compare acquired vocal dose data to perceptual surveys of vocal efficiency/fatigue and acoustic analyses of how voice quality changes over time in order to see whether there might be any relationship between vocal dose and changes in vocal efficiency and quality.

What are some of the more significant studies involving vocal dosimetry and what are their implications?

Scientists began experimenting with accelerometer-based ambulatory phonation dosimeters in the late 1980s. This technology was adapted for a portable pocket computer in 2003 by a group from the National Center for Voice and Speech, including Peter Popolo, Jan Švec, and Ingo Titze.[3] The NCVS device was the basis for several commercially produced voice dosimeters that have allowed researchers everywhere to examine voice use in real time. There now exists a considerable body of studies that is beginning to reveal information about typical human voice use. Many of the studies have involved groups of people who tend to have heavy voice use and a higher rate of vocal pathologies, such as teachers, singers, and students.

The largest group of dosimeter studies to date has come from a group of researchers based at Massachusetts General Hospital, led by Robert Hillman, Steven Zeitels, Daryush Mehta, Jarrad Van Stan, and Matthias Zanartu, among others. They completed large scale comparisons of individuals with and without vocal nodules—a study that has helped to provide baseline data for typical voice use among the broader population.[4] In a large study of 70 females from the general population who wore dosimeters for a full week, Van Stan et al. found that phonation time averages were 9.3 ± 2.7% of the monitored time for a control group over 81:32 ± 11:36 hours and a very similar 10.0 ± 2.3% of the monitored time over 80:24 ± 14:49 hours for a patient group of individuals dealing with phonotraumatic lesions (nodules, polyps, etc.). The similarity in these numbers indicates that having a voice disorder may not necessarily cause people to reduce voice use.[5] This same group of researchers has also been working to develop an affordable, commercially available voice dosimeter based on a smartphone platform.[6]

Most dosimeter studies have examined the voicing activities of teachers. These studies have consistently found that teachers use their voices more than the general population, particularly in their work environment. In the largest teacher study to date, researchers from NCVS monitored 57 teachers for two weeks each, finding that their occupational voicing percentage per hour was more than twice that of their nonoccupational voicing, and that teachers experienced a wide range of occupational voicing percentages per hour (30 ± 11% per hour), with an average of 23% dose time (Dt), or about two hours in an eight hour work day.[7] These teachers averaged a 13% Dt during off-work hours, with a 12% Dt on weekends.

In another study, Morrow and Connor found that elementary school music teacher vocal doses were higher than that of other elementary school classroom teachers.[8] This is especially concerning because teachers not only accumulate a higher percentage of dose time, but they also phonate at higher volumes, increasing their overall distance dose. Rabelo et al. found that background noise significantly increased vocal dose among women,[9] and Szabo Portela, Granqvist, Ternström, and Södersten found significantly higher environmental noise in patients with work related voice disorders.[10]

Studio voice teachers also may acquire high vocal doses in the workplace. In an as yet unpublished case study, vocal doses acquired by two collegiate voice professors over seven full days were assessed through the use of voice dosimeters.[11] Monitoring included seven consecutive days of each teacher's normal academic year schedule. Mean phonation percentages during teaching hours were 35.25% and 25.88%. Both teachers estimated a lesson time breakdown of 40% personal voicing and 60% student voicing, a percentage similar to the mean percentages of teachers responding to a survey of NATS teachers' estimated voice use (38% personal voicing to 62% teacher voicing).[12] However, real time readings showed that both teachers in the study used their voices in instruction and demonstration during voice lessons more than they had estimated. Applying Hunter and Titze's estimate that actual speaking time may be nearly double a person's phonation time, the teachers in the study talked or demonstrated up to 70.5% and up to 50.8% of their lesson time.

In a self-study, a co-author of this article (MS) acquired a Dt of 34.69% during 31 hours of teaching over seven days of class.[13] This indicated talking away two-thirds or more of lesson time—a reading that has inspired a conscious rethinking of the use of lesson time. These numbers did not only indicate a great deal of vocal use; mean SPL was more than 80.5 dB at 30 cm, leaving a distance dose of 1.09km per hour of teaching. By contrast, nearly 79 hours of recorded nonteaching time acquired only 7.9% Dt with a mean hourly distance dose of just 167m.

These studies demonstrate that singing teachers may use their voices more than they realize while teaching lessons. Less teacher talk could result in not only more effective teaching, but also less fatigued teacher voices.

Preservice music teachers face some of the same challenges as working teachers. Maria Claudia Franca studied 11 female student teachers over the course of a semester using dosimeters.[14] Dosimeter data showed a significant SPL increase in the classroom. Questionnaires revealed that a majority of the participants frequently used their voices with excessive effort, and that 60% seldom used preventive techniques to save their voices. Jeremy Manternach found that preservice music educators' vocal dose time (Dt) percentages ranged from 6.87% to 13.52% during a "typical" week during a school year.[15] Although voice emphasis students experienced raised Dt percentages during voice lessons (38.54%), choral rehearsals (30.33%), and vocal performances (24.82%), participants were afforded rest times during other school related activities (e.g., nonperformance music classes and nonmusic classes). As a result, Manternach speculated that "preservice educators may be in for a 'rude awakening' in their first years of teaching."[16] He suggested that preservice music educators receive more voice care training in order to handle the increased work related vocal dose. A similar result was found in a study of two graduate voice teaching assistants, who took good care of their voices during an opera production week but who had phonation times of 25.25% and 29.45% while teaching voice lessons—an amount that could lead to high doses when expanded to a full day of teaching.[17]

Studies of university singing students have shown that these individuals may experience higher vocal doses and more voice disorders than other university students and the broader population.[18] A large study (Schloneger and Hunter) involved 19 university students who each wore a dosimeter for all waking hours during three consecutive days in which school was in session (a total of more than 800 recorded hours).[19] These singers had an average voicing percentage of 11.92%, with 38% voicing in choral rehearsals and 35% voicing in solo singing activities. Over the three days, they totaled an average of 4.15 million vibratory cycles and a distance dose of 15.8km. While their phonation percentages were highest in singing, 88% of their mean recording time was *during nonsinging periods*, which meant that the overall cycle dose and distance dose was more than double for nonsinging periods than singing over the study period (Figure 3).

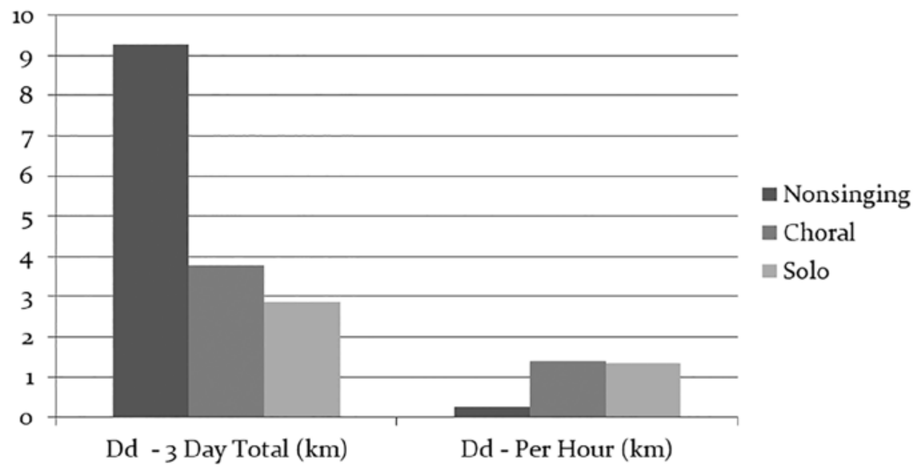

Figure 3. Mean distance dose acquired by 19 university singing students over three days of ambulatory monitoring with a voice dosimeter.

Student vocal dose data was compared with voice quality data acquired from the accelerometer over the three days. The study found that higher vocal doses, as a whole, corresponded with significantly greater voice amplitude, more vocal clarity (pitch strength and harmonic to noise ratio), and less perturbation (shimmer and jitter). This corresponded with laboratory studies that found these factors could have occurred due to increased muscular compensation after fatigue-inducing vocal loading. It was unclear for which students the voice quality changes were due to a warming-up effect and for whom the changes were due to fatigue induced compensation.

Younger singers may be most at risk for high vocal doses due to their still developing voices, yet they may also be less aware of the risk to their voices. James Daugherty, Jeremy Manternach, and Kathy Price asked two students to wear dosimeters over the three days of an all-state choral music festival.[20] The students had time doses of 20.92% and 20.34% in rehearsal and 17.96% and 19.88% out of rehearsal, indicating that a great deal of voicing was happening outside rehearsal despite the vocal intensity of the weekend. While the conductor used a rehearsal style that emphasized vocal pacing and rest, the students both indicated perceived declines in vocal efficiency over the weekend. Organized activities included a dance the night before the concert. In fact, in surveys distributed to the entire all-state group, students indicated a mean decline in several vocal health factors over the weekend, yet a majority said they felt that they were taking good care of their voices.

In an unpublished case study, voice use of two female undergraduate students was examined during an intensive rehearsal period the week before fall classes began (one incoming freshman, "Kathy," and one incoming sophomore, "Melissa").[21] The students wore voice dosimeters during waking hours for nine days, including two baseline days prior to an intensive rehearsal week, a five-day week in which they participated in a combined total of 39 hours of choral and musical rehearsals, and two baseline days exactly one week after the intensive period. Mean phonation time dose percentages (Dt) for both participants during the intensive week (Kathy 18.53%, Melissa 13.76%) exceeded mean Dts during pre- and post-baseline days (pre: Kathy 6.94%, Melissa 10.86%; post: Kathy 7.31%, Melissa 6.94%). Phonation doses were disaggregated by choir rehearsals (Kathy: 27.86% Dt, Melissa: 31.93% Dt), musical rehearsals (Kathy: 11.28% Dt; Melissa: 12.74% Dt), and nonrehearsal time (Kathy: 8.92% Dt; Melissa: 17.3% Dt) during the intensive rehearsal week. These young undergraduates had higher vocal doses *during nonrehearsal periods* in their intensive rehearsal week than they acquired during their baseline periods. By contrast, when this study was replicated with older, graduate voice students who have more experience with vocal pacing, the graduate students used their voices less during their intensive rehearsal week, nonrehearsal times than in their baseline days.[22] Daily surveys of vocal health evidenced declines in at least six of nine areas between Monday and Friday of the intensive week for both participants. However, survey results of perceived vocal handicap showed that Kathy, a self-described introvert (per the Keirsay Temperament Sorter), experienced a large increase in perceived voice handicap between the pre-baseline period and the intensive week, while Melissa, a self-perceived extrovert, perceived less voice handicap.

This result suggests that different individuals may be able to acquire higher vocal doses than others before experiencing fatigue and functional decline. More recent dosimeter studies, taking the lead from exercise science, have begun to examine the relationship between voice habilitation, fatigue resistance, and biometrics as they relate to vocal dose. Smith et al. found that teacher voicing tended to last three seconds or fewer, indicating a reliance on the immediate energy system for muscle bioenergetics.[23] This muscle activity suggested a greater reliance on anaerobic activity, even though teachers used their voices for long distances throughout the day. In a study published in the May 2019 issue of *Journal of Singing*, Mary Sandage and Matthew Hoch compared vocal dose measurements and perceived effort during a training regimen for a recital performance and found that, with training considerations, perceived vocal fatigue decreased over the same vocal dose following training.[24]

Despite all that we have been able to learn from voice dosimetry, there are still limitations to the information that can be acquired with current devices. The accelerometer signal does separate phonation vibrations from ambient sound, but sometimes loud ambient sounds near the microphone (that result from playing an instrument, for instance) do cause vibration readings in the accelerometer that could be mistaken for voicing. Some earlier devices only record sample data at regular intervals rather than recording the full accelerometer signal, meaning that one cannot go back to verify the accuracy of data later. When the full accelerometer signal is used to record at CD quality, the participant's speech is sometimes intelligible upon playback, which raises concerns about personal privacy. And, despite the rapid advancement of technology, there remain computational limitations to the enormous amount of data that can be collected by a dosimeter, and there are few commercially available devices available. We believe the benefits of dosimetry far outweigh the limitations, however, and look forward to a future in which a quality voice dosimeter will be available on a smartphone.

How does this information impact studio voice teaching?

These studies begin to provide us with a frame of reference for human voice use. Baseline data for healthy singers and teachers of singing can be compared with singers demonstrating some type of dysphonia. A body of data will help us determine what constitutes a healthy vocal dose and what constitutes overuse. Of course, many more studies are needed, and healthy dose levels will surely differ from one individual to another; but studies to date have given us a wealth of information regarding the healthy limits of the human body in terms of voicing.

For studio voice teachers, this information can instruct us both in how we care for our own voices and how we instruct our students. As teachers, we need to be aware of the volume (both in terms of dose and SPL) of our own teacher talk and vocal demonstration. We also need to be cognizant of the effect background noise has on our teaching. While studio teachers do not face the vocal dose challenges of choral directors or elementary music teachers, elements as seemingly innocuous as loud air handlers can cause us to phonate more loudly (due to the Lombard effect), which can have a real effect on our overall vocal loads over time.

Regarding our students, vocal dose studies show that we need to constantly engage in active voice use education for all students and remind them that they possess only one larynx, which they use both to speak and sing. In rehearsals, we need to be aware of overall rehearsal time and consider vocal dose in structuring rehearsal. Even more importantly, as teachers we need to be cognizant of students' nonrehearsal activities surrounding vocal and choral events and their vocal demands: sports activities, work environments, bus rides, dances, restaurants, parties, etc. We also need to remember that vocal fatigue develops from a complex array of factors, and that since, in almost all instances, more overall voicing happens outside of singing than during singing, vocal fatigue will likely have as much or more to do with voicing that happens outside of singing activities.

Voice changes resulting from large vocal doses and subsequent vocal fatigue may not be audible to even a trained voice teacher, which is one of the key takeaways from the Schloneger and Hunter study involving university singing students. If heavy voice use results in an increase in SPL and voice clarity and less perturbation, we will likely not be able to hear "fatigue" in our students until a pathological level of vocal fold swelling occurs. This means that we need to communicate with our students and ask them how their voices are feeling.

Early in our teaching careers, when students would walk into our studios and admit to experiencing vocal fatigue, we would often take them through light vocalises and conclude, "Well, you *sound* fine. You can probably sing." Due to this research, the authors now give greater consideration to students' perceptions when deciding how to proceed rather than relying solely on what we are hearing, especially during periods of heavy voice use.

Fortunately, this body of research is also demonstrating that the number of vibrations and the distance dose that a voice can undergo is not fixed. While scientists may still identify a healthy limit to the number of vibrations vocal folds can safely endure in a given period of time, good vocal hygiene, proper technique, and training regimens based on the principles of sports science and motor learning can help us to increase comfortable levels of vocal dose. Further research may help us determine the optimum levels and absolute limits of healthy vocalization over a period of time.

CONCLUSION

For those of us who are singers and voice pedagogues, the results and conclusions of many dosimeter studies may seem like common sense. Anecdotally, we know that excessive voice use can lead to fatigue, that excess background noise contributes to fatigue, and that habilitation can increase our stamina. However, as scientific thinkers, our community needs to ask: How do we know what we know? Dosimeter technology is helping us to confirm realities that, until now, we could only suspect, and it is helping us to learn about the healthy limits of the human voice. As dosimeter technology becomes more readily available, we may also soon be able to acquire it for our own studios. We will be able to have our students wear dosimeters to help them become more cognizant of their own voice use, perhaps even with a biofeedback feature that warns them when they are being too loud.

Sports science has allowed athletes to become stronger while going farther and faster than ever before. Thanks in part to the science of voice dosimetry, vocal athletes are better equipped to do the same.

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NOTES

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Schloneger currently serves as Vice President of the Kansas Chapter of NATS and is Central Region Governor of the Pan-American Vocology Association. His ongoing singing voice research, focusing on singers' health, has resulted in the Van Lawrence Fellowship of NATS and the Voice Foundation in 2017, Best Research Poster at the NATS National Convention in 2014, and Best Student Presentation at the Voice Foundation Symposium in 2015. His research has been published in the *Journal of Voice*, *The Journal of Research in Music Education*, *The Choral Journal* and the *International Journal of Research in Choral Singing*.