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Assessments of Voice Use and Voice Quality among College/University Singing Students Ages 18–24 through Ambulatory Monitoring with a Full Accelerometer Signal

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Abstract

The multiple social and performance demands placed on college/university singers could put their still developing voices at risk. Previous ambulatory monitoring studies have analyzed the duration, intensity, and frequency (in Hz) of voice use among such students. Nevertheless, no studies to date have incorporated the simultaneous acoustic voice quality measures into the acquisition of these measures to allow for direct comparison during the same voicing period. Such data could provide greater insight into how young singers use their voices, as well as identify potential correlations between vocal dose and acoustic changes in voice quality.

The purpose of this study was to assess the voice use and estimated voice quality of college/university singing students (18–24 y/o, $N = 19$). Ambulatory monitoring was conducted over three full, consecutive weekdays measuring voice from an unprocessed accelerometer signal measured at the neck. From this signal were analyzed traditional vocal dose metrics such as phonation percentage, dose time, cycle dose, and distance dose. Additional acoustic measures included perceived pitch, pitch strength, LTAS slope, alpha ratio, dB SPL 1–3 kHz, and harmonic-to-noise ratio. Major findings from more than 800 hours of recording indicated that among these students (a) higher vocal doses correlated significantly with greater voice intensity, more vocal clarity and less perturbation; and (b) there were significant differences in some acoustic voice quality metrics between non-singing, solo singing and choral singing.

Keywords

voice use; vocal dose; ambulatory voice monitoring; voice dosimeter; voice science; vocal pedagogy; voice quality

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Few previous studies provide empirical data regarding the typical vocal dose acquired by college/university students who participate in multiple singing activities. These students frequently experience heavy vocal demands: voice lessons, choral and theatre activities, student-organized music groups, church activities, busy social lives, sports, and sometimes jobs that involve heavy vocal demands (e.g. waiting tables or phone centers).[1] They may develop less-than-desirable sleep and vocal hygiene habits.[2] Further these students may be unaware of the negative, cumulative effects of heavy vocal loads on their voices, lacking or ignoring training in vocal hygiene.[3]

Both teachers and students would benefit from published, scientific standards of voice use for young singers with developing and stabilizing vocal instruments, but formulation of such standards remains an elusive task. To date, despite a considerable body of literature reporting on the vibratory, acoustic, and perceived effects of vocal loading among various populations, there remains a paucity of data pinpointing when particular vocal inefficiencies may first develop.[4–7] One potential explanation for this gap may be a lack of studies that simultaneously analyze vocal dose and voice quality in a real-time, field setting.

Numerous studies, nearly all of them in controlled laboratory situations, have been completed analyzing the effect of vocal load through measurements of acoustic quality and sound pressure level (SPL). A majority of these studies show a positive correlation between potentially related factors (e.g., increasing vocal doses, later hours of the day, reports of vocal fatigue, and/or the Lombard effect[8]) and changes in acoustic properties such as increases in fundamental frequency (F_0)[4]; loudness (dB SPL)[9–10], harmonic-to-noise ratio (HNR)[11], and spectral energy as measured by Long Term Average Spectrum (LTAS)[9, 12], as well as decreases in voice perturbation (shimmer and jitter)[13–14].

It is possible that these acoustic characteristics might relate to vocal fatigue. For example, increases in F_0 and upper frequency LTAS energy have been linked to increases in dB SPL,[15–16] and the above changes to F_0, dB SPL, HNR, shimmer, jitter and LTAS have been connected to increased muscular activity and tension that occurred following a fatiguing loading activity.[14] Nevertheless, Boucher and Ayad[5] found that individual variations in F_0 did not consistently reflect measured muscular fatigue in laryngeal structures. Further, there have been studies that either showed no change[6, 17] or increases in shimmer and jitter following vocal loading tasks.[18] Acoustic perturbation measures have not yet received attention in ambulatory field studies of voice use, where they could be measured at the vocal source by an accelerometer transducer.

A growing body of studies has also analyzed vocal load in the field, without acoustic voice quality analysis. Voice dosimeters, first developed in the early 2000s, were created to measure vocal dose, defined as vocal fold tissue exposure to vibration over time.[19–20] Rather than relying on acoustic audio recording methods, these devices used an accelerometer transducer to record skin vibrations in the neck. In this way, phonation activities could be tracked in isolation from ambient sounds. Various methods for accelerometer based voice dosimetry have been examined in the literature, and techniques for analyzing and calibrating accelerometer signals from voice have been discussed.[19, 21–23] Švec, Titze, and Popolo found that mean SPL from voiced speech could be predicted by a skin accelerometer with accuracy of better than ±2.8 dB.[21] Specifically, Mehta et al.[24] showed that while average F_0 error and estimated average SPL error dropped to 1% after 12 hours and 20 hours of monitoring respectively, dose calculations needed at least 26 hours of monitoring for average errors to drop below 10%. The study recommended that future voice dosimetry should involve the recording of raw, rather than sampled, accelerometer signals.

Several published studies began to quantify a typical vocal dose among different populations, including teachers[25–29], children[30–31], and various populations of singers (e.g., high school students[32], graduate student vocalists[33–34], and undergraduate student vocalists[1]). Although these studies provided data that addressed questions about the typical vocal doses among different populations, voice data collected included only processed information about the duration, frequency, and amplitude of vibrations with no insight of the efficiency with which those vibrations were produced. Further, these studies did not examine voice quality alongside vocal dose because the dosimeters used in these studies did not allow for simultaneous real-time analysis of spectral and voice perturbation data.

To date, no ambulatory field study of healthy singers has simultaneously acquired a combination of participants' vocal dose with additional measures obtained from post-processing of a full recording signal to examine how the quality of vocal production might relate to the vocal dose and the vocal efficiency of each individual. Such measurements in the study of young singers could be important in understanding reasons why some young singers demonstrate declines in vocal efficiency more quickly than others. Anecdotal experience suggests that some young singers may cultivate strong, efficient singing techniques through voice lessons or choral experience yet develop vocal problems due to poor vocal hygiene, unhealthy quality of speech, and heavy speech doses.[35] The opposite could also be true if young vocalists with efficient speech habits develop inefficient singing habits.

The purpose of this study was to assess the voice use, voice quality, and perceived singing voice function of college/university singing students to answer the following research question: Are there statistically significant relationships between students' vocal dose measures and common metrics related to voice quality as calculated from a raw accelerometer signal?

METHODS

Participants

A convenience sample of 25 traditional-age college/university singing students (18–24 y/o), enrolled in both voice lessons and choir, were recruited. The study was approved by the Human Subjects Committee at the primary author's university. None of these students reported a history of any vocal pathology. The students represented four different institutions of higher education (a private two-year college, a private four-year college, and two state universities) and five different private voice teachers. While a balance of men and women was sought in the sample, voice type differences were not considered due to the large number of variables already being considered.

All participants completed a short demographic questionnaire during their first meeting. In addition to confirming their current participation in a college choir and voice lessons, the questionnaire asked the students to provide details about number of semesters enrolled, estimated hours of singing per week during the current semester, years of voice lesson experience, years of choral experience, and details about any previous vocal limitation/injury which may have required a health care professional. Because the effect of musical style was not a focus of this study, the participants were not asked to distinguish between their use of classical and contemporary commercial singing styles in solo singing.

Equipment

Recordings were conducted using a Roland R-05 digital audio recorder with storage to a 16GB SD card and the collar of VoxLog portable voice analyzer collar (Figure 1), adjusted to comfortably fit the circumference of the participant's neck (Figure 2). Within each collar were two transducers: (1) a Panasonic WM-61A omnidirectional microphone to sample the airborne acoustics, and (2) a Knowles BU-1771 Model accelerometer. Participants carried the Roland R-05 in a Tune Belt Vertical Microphone Transmitter Carrier Belt worn around the participant's midsection underneath the clothes. This setup was described in detail in previous studies.[36]

Calibration

Prior to beginning the day-long recordings, each participant completed an SPL calibration; the specific procedure is described in detail by Schloneger.[37] To summarize, the participant completed a series of three spoken /a/ vowels at a comfortable pitch in a quiet room while holding a standard sound level meter at a distance of 30cm from the mouth. The VoxLog collar was worn around the neck, while simultaneously recording the /a/ vowels with an iPad video recorder. The /a/ vowel files were then processed using GoldWave v5.70 (www.goldwave.com) digital audio editing software. The researcher observed the video of each /a/ vowel frame by frame and logged each dB SPL level (from an economic sound level meter, DT 85A) on a spreadsheet. A custom MATLAB (www.mathworks.com) script was used to obtain calibration levels for each participant and each transducer.

Data Collection

Participants were recorded during all waking hours over three weekdays while classes were in session. The participants wore the monitors 10.5–18.0 hours each day, putting the monitors on immediately after dressing in the morning and removing the monitors just before retiring for the evening (AA batteries, proven to be sufficient for a 20+ hour day, were used). The researcher remained available by phone throughout the study periods in the event of any technical problems. On the second and third morning of monitoring, each participant replaced the batteries and inserted a blank 16GB SD card (externally labeled Day 1, Day 2, Day 3) in the recorder. Approximately 2 GB of data were recorded for each 3.33 hours of monitoring. Captured unprocessed data were transferred to a separate external hard drive and then backed up on a cloud storage system at the end of each participant monitoring period.

In order to determine what activities occurred during each recorded phonation period and when, the participants completed daily activity logs.[23, 25] Each participant documented vocal tasks and significant activity throughout the day along with the time each activity commenced, noting the time displayed on the Roland digital recorder.

File Processing and Analysis

Audio processing—The Roland recorded in stereo WAV file format, with the left channel recording accelerometer data and the right channel recording acoustic transducer data. Using GoldWave, accelerometer and microphone channels were segmented into individual WAV files for different activity periods and vocal tasks for comparison. The sampling rate for each file was reduced from 44100 kHz to 14700 kHz in order to make file sizes manageable. The accelerometer files recorded signals at a much lower intensity level than the audio files, so these files were normalized by amplification of 25–30 dB SPL, the maximum level that could be reached without clipping voicing data.

Multiple day data processing—Parameter extraction was accomplished using custom MATLAB to process the recordings. Files were processed in one-minute increments and then underwent an automatic pre-segmentation process similar to the technique described by Bäckström, Lehto, Alku, and Vilkman.[38] The one-minute segment then underwent several stages of analysis. First, in 10 ms intervals, MATLAB estimated dB SPL (based on the calibration) and also estimated vocal pitch and vocal F_0 using the Audswipe algorithm [39] as well as PRAAT software (command line version). Then the script concatenated all voiced segments from the one-minute interval to calculate additional metrics. In all, for each one-minute window, output included voicing percentage and the following metrics with summary statistics (e.g. mean, IRQ, standard deviation, skewness): F_0, P_0, PS, and dB SPL, LTAS slope, alpha ratio, dB 1K to 3K, shimmer, jitter, pitch strength and HNR. The MATLAB script repeated this process for each minute of the full day files and saved an output file with aggregated data for each minute. An Excel spreadsheet template was used to aggregate the time interval data and calculate the results of each measure for the entire period analyzed, with appropriately weighted averages.

The Excel spreadsheet also employed formulas that compiled several vocal dose measures: (1) *phonation time dose* (D_t) refers to the cumulative duration of time (hh:mm:ss) or the percentage of time the vocal folds have actually touched in a given period; (2) *cycle dose* (D_c) refers to the accumulated number of such repetitive cycles in a particular time period; and (3) *distance dose* (D_d) is an estimate of “how far” vocal folds travel in a period of time incorporating total phonation time, F_0, and amplitude into one dosage measure. Taken together, these three measures provide a detailed picture of the volume and intensity of voice use.[20, 40]

It should be noted that MATLAB output included two newly developed measures. First, *perceived pitch* (P_0) is a term developed for this study to represent the frequency output of the Audswipe algorithm.[39] As the algorithm examines the entire harmonic spectrum, its output can be considered similar to the perceived auditory pitch as opposed to a simple reading of $F_{0.}$ Second, *pitch strength*,[41] a measure of voice clarity, is a quantitative interpretation of the strength of the pitch sensation created by a complex tone, measured as a percentage; the higher the pitch strength, the more tonal the sound is judged.

Analysis procedures and assumptions

As with any acoustic analysis, a range of assumptions and procedures were necessary. The primary assumptions and procedures, based on previous ambulatory monitoring studies referred in this paper, are only briefly summarized here (the full detail of assumptions can be found in Schloneger 2014). In order to minimize false voicing readings, the MATLAB analysis discarded any voicing segments shorter than 40 msec, any full minutes of analysis that contained less than 3 percent voicing, and any readings of voicing for which the calibrated SPL level was below 47 dB SPL. LTAS was calculated, per an analysis based on techniques described in previously [42], from the concatenated voiced segment. From the LTAS, the spectrum between the median F_0 and 5000 Hz was used to obtain the LTAS slope in dB/Hz. The alpha ratio for any designated period of time was determined by taking the LTAS for the period and dividing the summed intensity in dB from 1001–5000 Hz by the summed intensity from 50–1000 Hz. The summed intensity of the sound between 1 kHz and 3 kHz (3,125 Hz) normalized the total intensity of the entire spectrum. [43]

Data from each of the three full monitoring days was analyzed as a whole and as disaggregated by activity. Disaggregations included choral singing, solo singing, instrumental playing and non-singing time. Due to consistent problems with the MATLAB script interpreting instruments in close proximity as voicing (e.g. loud saxophone playing), all instrumental playing minutes were removed from the overall analysis. Vocal dose and voice quality measurements for each segmented activity were compiled in one-minute intervals (using the MATLAB output) and then aggregated those data to determine overall activity measurements for each individual and the study population.

RESULTS

Of the initial 25 participants, two students withdrew from the study. Twenty-three students completed three days of monitoring, but as with many ambulatory studies,[44–45] four of them had large gaps in recording, necessitating their removal from the study. The 19 students (11 men, 8 women) who successfully completed three days of at least 10.5 hours of monitoring per day were included in the current study, following the practice of previous ambulatory monitoring studies with uneven compliance. [46] The 19 participants recorded for an average of 14 hours 36 minutes each day. They had the monitor turned off for an average of 31 minutes of reported waking hours, with a range of 0 minutes to 4 hours 23 minutes not recorded (e.g., during contact sports, avoiding contact with water (showering or swimming), and private conversations).

Table 1 provides basic demographic data for the participants. A two-tailed independent samples *t*-test, *t*(18), revealed no significant differences between age, years of choral experience, or years of voice lessons between these men and women.

Results are presented according to the research questions posed for this investigation. A pre-determined alpha level of .01 served to indicate significance for all statistical tests. The researchers chose this alpha level in lieu of an alpha level of .05 with applied Bonferroni corrections, a method that was considered too conservative when considering the large number of within-family tests. Data were examined for statistically significant relationships between each of four measures of student vocal dose (phonation percentage, Dt, Dc, and Dd) and each of ten measures of voice quality (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1–3 kHz, pitch strength, shimmer, jitter, and HNR) acquired with the VoxLog collar's unfiltered accelerometer signal.

Full days and activities totals

Accelerometer data were collected for all the above variables over three full ambulatory monitoring days and disaggregated the full days into different activities: choir, solo singing, and non-singing. Totals and measures of central tendency per day and for each activity are displayed below for all participants, men, and women (Tables 2, 3 and 4, respectively).

Correlations between vocal dose and voice quality over full monitoring days

Pearson correlation coefficient tests were employed between each of the ten voice quality measures (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1–3 kHz, pitch strength, shimmer, jitter and HNR) and each of the four vocal dose measures not derived in part from a voice quality measure (voicing %, Dt, Dc, and Dd) for two different disaggregations of full-day ambulatory monitoring data: (1) three-day totals by participant ($N = 19$), and (2) individual day totals ($N = 57$).

Voice quality means for three days vs. three-day vocal dose total—Table 5 displays Pearson correlation results for three-day ambulatory monitoring totals for each participant. There were multiple significant correlations between dose measures and perturbation measures, particularly pitch strength and shimmer, and moderately strong though not statistically significant correlations between dose measures and jitter and HNR. In each case, a higher vocal dose correlated with less perturbation.

Daily voice quality means vs. daily vocal dose totals—Table 6 displays Pearson correlation results for individual ambulatory monitoring day totals. Like the three-day totals, there were multiple moderate, significant correlations between various dose measures and perturbation measures among individual daily totals, in this case with each of the four perturbation measures (pitch strength, jitter, shimmer and HNR) having at least one significant correlation with a vocal dose measure. Among the individual days, there were also significant correlations between dB SPL and both voicing % and Dt.

Changes between activities

Accelerometer data were disaggregated for the three full ambulatory monitoring days by three different types of activities (non-singing, choral singing, and solo singing). Analysis included one-way repeated measures ANOVAs with independent variables being the three different types of activities and dependent variables being each of the four vocal dose measures and ten voice quality measures discussed above (Table 7). Because 4 of the 19 participants had no choral rehearsal during the 3 days of monitoring (though enrolled in choir), the repeated measures ANOVAS were completed with $N = 15$ participants.

Mauchly's sphericity test was completed on each measure with no significant results, indicating that sphericity could be assumed for each measure. The ANOVA revealed that there were significantly significant differences between activities for all measures except the spectral measures of dB SPL 1–3 kHz and alpha ratio.

Post-hoc pairwise comparisons of activities with Least Significant Difference *t*-tests revealed that the majority of the significant differences between these measures occurred between the speaking voice and singing activities (Table 8). Dose measures and F_0/P_0, dB SPL, jitter, and HNR all had significant differences between non-singing and singing activities, but no significant differences between the two types of singing. Alpha ratio and pitch strength were significantly higher in non-singing than in solo singing but not significantly different between choral singing and non-singing. There were four significant differences between choral and solo singing, including LTAS slope (significantly steeper in solo singing than in choral singing), pitch strength (significantly stronger in solo singing), and shimmer and jitter (significantly less perturbation in solo singing).

Correlations between singing time and overall voice quality readings—Because the overall three-day measurements had significant correlations in terms of dB SPL, pitch strength, jitter, shimmer and HNR that moved in the same direction as the significant correlations between activities, significant full day correlations could have been influenced by the total amount of singing time and singing dose. To see if this was the case, singing and non-singing times were disaggregated and Pearson Correlation tests were run among (1) the amount of total singing time recorded, (2) three-day total singing doses (Dt, Dc and Dd), (3) three-day total non-singing doses (Dt, Dc and Dd), and (4) the overall three-day totals (singing and non-singing together) for dB SPL, pitch strength, jitter, shimmer and HNR (Table 9). Results revealed moderate to strong correlations between the amount of singing time and each of the five voice quality measures, with significant correlations at the .01 level for dB SPL, pitch strength, shimmer, and jitter. While non-singing time had weak to moderate correlations that moved in the same direction, there were no significant correlations between non-singing Dt or recording duration and these four voice quality measures. It should be noted that because Dd is derived in part from dB SPL, the strength of these correlations was expected.

Correlations between non-singing doses and non-singing quality—In order to examine the relationship between non-singing doses and voice quality during non-singing periods more closely, Pearson Correlation tests were completed between three-day non-singing vocal doses and five voice quality measures acquired during only non-singing periods (Table 10). The correlations were not as strong as the three-day totals, but there were mostly moderate correlations that moved in the same direction as the full-day totals. There were significant correlations between non-singing pitch strength and both non-singing Dd and non-singing dB SPL. Once again, it should be noted that Dd was derived in part from dB SPL so a significant correlation was expected.

DISCUSSION

This investigation documented and explored relationships among the voice use, voice quality, and perceived voice function of 19 college/university singing students over the course of three active days. The instrumentation and procedures of this investigation yielded numerous statistically significant relationships ($p < .01$). These relationships can be summarized according to two major, overarching findings. First, higher vocal doses, as a whole, appear to correspond with greater voice amplitude, more vocal clarity and less perturbation. Second, significant differences in voice quality ($F_{0,}$ P_0, dB SPL and voice clarity/perturbation) also appear to correlate with various vocal activities, with solo singing having the highest pitch, dB SPL and clarity and least perturbation. Further, vocal dose readings for these young singers (11.92% voicing, 7.15 minutes Dt per hour, 97,320 Dc per hour, and 370.57m Dd per hour) were similar to the dose readings obtained in several earlier studies of student singers.[1, 33–34]

Correlations between Accelerometer Acquired Vocal Dose and Voice Quality Data

There appears to be a significant correlation between vocal dose and voice quality measures acquired during ambulatory monitoring (voice amplitude level or voice perturbation), both in terms of total three-day monitoring means ($N = 19$) and individual monitoring day means ($N = 57$). There were also moderate significant positive correlations between dB SPL and both voicing percentage ($r = .401$) and dose time ($r = .406$) during individual monitoring days.

Correlation tests between dose measures and mean dB SPL were completed separately for singing and non-singing periods. Although singing is typically louder than conversational speech, the strength of the correlations was similar between singing and non-singing. This similarity may indicate that the percentage of singing time was insufficient to have much of an influence on dB SPL readings. Rather, the overall vocal load correlated positively with amplitude, a finding that was in agreement with previous studies.[13, 47–49] The rise in amplitude may suggest that individuals engage in more effortful phonation after periods of higher vocal loading.

There were also moderately significant positive correlations between vocal dose measures and voice clarity (pitch strength and HNR) and strong, significant negative correlations between vocal dose and perturbation (shimmer and jitter). While this result may seem counterintuitive (i.e., high vocal doses should result in less vocal clarity and more perturbation), there are at least two plausible explanations for these significant correlations. First, some individuals likely sang more than others. The three-day means of these four measures correlated significantly with the amount of singing time and levels of vocal dose from singing. As compared to speaking, singing involves longer periods of time singing vowels (voicing) and greater attention to breath support and resonance. It follows that more singing time over three days would lead to greater mean readings of voice clarity and less perturbation. There were also significant differences in these measures between different activities (see below). Thus, the strength of the correlations may in part be the result of the improved voicing that one would expect with singing.

A second explanation could be that pitch clarity and perturbation measures improve after periods of vocal loading. Though the frequency of singing likely contributed to the strength of the correlations among dose and pitch strength, HNR, shimmer, and jitter, there were also moderate correlations between these measures and the vocal doses acquired during non-singing periods alone. This factor was especially true of Dd, with a significant positive correlation between Dd during non-singing time and pitch strength during non-singing time. These results accord with findings of several previous studies [13–14, 50] in which the authors suggested that vocal loading resulted in vocal hyper-function, and thereby a more firm closing of the vocal folds. This circumstance resulted in a higher amplitude and increased clarity in voicing.

Given these positive correlating changes in voice quality and dose, it is unclear to what extent self-reported healthy singers' vocal efficiency improves after a certain level of voice use (a warming up effect) and at what point vocal efficiency begins to decline. According to Boucher and Ayad,[5] there may be a discernible point after which vocal stability temporarily decreases, followed by a compensatory increase in vocal tension that masks the problem. The analysis methods in this study do not confirm the existence of this point of instability or make clear at what point it might have happened, nor do the results make clear what might constitute a warming-up effect on the voice and what might constitute increased compensatory tension due to fatigue. Detailed minute-to-minute analyses of acquired ambulatory monitoring data with this temporary change in mind would be a logical possibility for future research.

Significant Differences between Activities in Vocal Dose and Voice Quality Measures

Ambulatory monitoring data indicated significant differences between the various periods of participant activity assessed in this study. All four vocal dose measures and most voice quality means showed significant increases in vocal pitch and dB SPL between non-singing and both types of singing activities. An increase in pitch strength and HNR with a corresponding decrease in shimmer and jitter accompanied this higher dB SPL and vocal fold closure that typically occur with singing.

Choral singing and solo singing require different vocal techniques, and results of this study indicated differences between the two styles of singing among this group of singers. Pitch strength was significantly higher in solo singing than in choral singing, while jitter and shimmer are significantly lower. Measurements of vocal pitch, dB SPL, and HNR were all higher in solo singing than in choral singing, though not to a significant degree. One would expect these results given the higher demands for projection in solo singing. The greater vocal fold closure needed for projection would logically correspond with a clearer voice and less perturbation.

However, results of the three measures of vocal resonance (LTAS slope, alpha ratio, and dB SPL 1–3 kHz) used to compare participants' non-singing, choral singing, and solo singing time periods in this study appear to contradict some previous findings.[51] On the basis of previous investigations, one would expect to observe increased resonance in singing as opposed to speaking, as well as increased resonance in the upper partials in solo singing when compared to choral singing. However, LTAS slope, alpha ratio, and dB SPL 1–3 kHz each decreased from non-singing to choral singing to solo singing in the current study. LTAS slope also decreased from choral singing to solo singing. It is possible that these results could have occurred in part as a result of the technical limitations of this study, including the fact that the accelerometer transducer largely measured vocal source vibrations rather than source/filter vibrations and was less sensitive to higher frequencies. Subsequent studies should explore this apparent discrepancy to see if it is unique to the participants and procedures in this study or occurs more widely.

Limitations for this study include the need to establish thresholds for the inclusion/exclusion of data, meaning that some non-voice data may have been included (false positives) while some voicing data might have been excluded. Further, because the 19 participants did not record for a reported average of 31 waking minutes during each monitoring day, daily changes in voice quality were not compared to a full 100% of each participant's daily vocal dose. Privacy is a potential challenge for future studies that employ collars with an audio microphone. While most states allow for single consent (non-targeted) recording, including the state where this study was conducted, privacy, HIPPA, and recruitment can be issues that complicate full measurement of all phonation. Behavioral studies have long allowed the recording of study participants with consent, but if full recordings of the VoxLog's microphone are used in a healthcare environment, patient privacy becomes a much more significant concern and limitation.

CONCLUSIONS

Students studying voice performance frequently experience heavy vocal demands. Additionally, their lifestyles may not be conducive to healthy vocal habits. Because they may be unaware of the negative, cumulative effects of heavy vocal loads on efficient phonation, concern for these students' vocal well-being is warranted. Despite a considerable body of literature reporting on the vibratory, acoustic, and perceived effects of vocal loading among various populations, there remains an absence of data aimed at understanding possible relationships between vocal dose and voice quality (observed and perceived) among young, developing singers using data acquired in natural settings. This study addresses this lack of knowledge by presenting a relatively low cost protocol for measuring both multiple voice and long-term samples.

The current study identifies among its dependent variables a number of significant relationships that appear to agree with previous studies conducted in laboratories. Major findings suggest that higher vocal doses correlate significantly with greater voice intensity, more vocal clarity and less perturbation. Further, there were significant differences in some acoustic voice quality metrics between non-singing, solo singing and choral singing. The fact that these field-based results agree with the literature could indicate that the protocols and procedures of this study, while imperfect, are sufficiently robust to accurately identify trends in vocal dose and changes in voice quality.

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Figure 1.
VoxLogTM collar.

Figure 2.
VoxLogTM collar worn around the neck and attached to a Roland R-05 Digital Recorder.

Table 1

Demographic Data: Participants (*N* = 19) Completing Three Full Days of Monitoring

	Mean	**Mode**	**SD**	**Range**	***M***	***M***	***t*-test for Sex**	
					Men	**Women**	***t***	***p***
Age	19.95	19	2.51	6	20.00	19.89	.132	0.896
Years in Choir	8.40	7	3.7	13	7.27	9.78	−1.483	0.163
Years of Voice Lessons	2.78	0.5	2.55	7.5	2.86	2.67	.168	0.864

Table 2

Measures of Central Tendency, Full Monitoring Days: All Participants ($N = 19$)

Measure	Total	Non-Sing	Choral*	Solo
Rec. Hrs. – Total	42.69	37.80	2.93	2.16
Voicing %	11.92	8.63	38.10	34.50
Dt – Total (min)	305.25	195.65	62.65	44.79
Dt - Per Hour (min)	7.15	5.18	22.86	20.70
Dc – Total (Kc)	4153.53	2483.88	919.24	761.66
Dc - Per Hour (Kc)	97.32	65.71	334.40	351.96
Dd - Total (m)	15815.04	9248.14	3783.41	2879.60
Dd - Per Hour (m)	370.57	244.65	1376.31	1330.66
F_0 Mean (Hz)	228.00	209.57	260.61	271.47
F_0 Median (Hz)	215.08	252.99	265.69	368.17
F_0 Mode (Hz)	192.89	220.83	230.42	255.32
F_0 St Dev (Hz)	73.20	71.49	85.78	82.00
P_0 Mean (Hz)	225.34	251.73	351.75	370.77
P_0 Median (Hz)	216.15	198.10	287.70	268.27
P_0 Mode (Hz)	210.49	191.19	267.74	266.26
P_0 St Dev (Hz)	63.34	60.03	131.58	133.29
dB SPL Mean	76.95	75.49	79.26	77.98
dB SPL Median	77.20	75.58	80.06	78.92
dB SPL Mode	77.47	75.50	80.66	79.39
dB SPL St Dev	5.47	5.25	5.61	6.22
LTAS Slope (x100)	−0.58	−0.54	−0.63	−0.66
Alpha ratio	−23.15	−22.47	−23.64	−24.47
dB SPL 1–3 kHz	−56.87	−55.97	−57.15	−56.29
Pitch Strength *M*	32.27	29.25	34.29	37.95
Pitch Strength *SD*	10.81	10.62	10.36	12.09
Jitter	0.032	0.037	0.026	0.025
Shimmer	0.128	0.140	0.127	0.107
HNR	11.86	9.79	11.81	13.92

Note. Only 15 of the 19 participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 15 participants.

Table 3

Measures of Central Tendency, Full Monitoring Days: Men ($N = 11$)

Measure	Total	Non-Sing	Choral*	Solo
Rec. Hrs. – Total	42.54	37.35	3.66	1.98
Voicing %	13.07	9.28	38.30	36.89
Dt – Total (min)	335.55	208.06	84.01	43.86
Dt -Per Hour (min)	7.84	5.57	22.98	22.13
Dc – Total (Kc)	3475.61	2004.77	1006.50	520.17
Dc - Per Hour (Kc)	81.25	53.67	275.33	262.47
Dd - Total (m)	17914.26	10049.29	5068.46	3094.60
Dd - Per Hour (m)	418.76	269.05	1386.51	1561.49
F_0 Mean (Hz)	171.56	157.36	191.18	188.47
F_0 Median (Hz)	162.81	145.94	186.27	184.14
F_0 Mode (Hz)	148.47	131.85	171.61	165.35
F_0 St Dev (Hz)	53.42	53.03	54.81	55.29
P_0 Mean (Hz)	174.19	156.39	196.04	194.25
P_0 Median (Hz)	166.53	147.12	190.80	189.89
P_0 Mode (Hz)	164.37	145.31	189.47	179.35
P_0 St Dev (Hz)	48.90	46.13	50.71	54.99
dB SPL Mean	78.14	75.93	77.58	80.03
dB SPL Median	78.50	76.05	78.22	80.88
dB SPL Mode	78.86	76.10	79.05	81.87
dB SPL St Dev	5.50	5.21	5.55	6.26
LTAS Slope (x100)	−0.61	−0.58	−0.68	−0.72
Alpha ratio	−23.76	−23.18	−24.73	−24.62
dB SPL 1–3 kHz	−58.17	−58.07	−58.65	−56.99
Pitch Strength *M*	33.64	30.03	37.75	40.60
Pitch Strength *SD*	11.05	10.70	10.70	12.47
Jitter	0.032	0.038	0.023	0.023
Shimmer	0.123	0.137	0.112	0.099
HNR	12.11	9.83	13.73	15.08

Note. Only 9 of the 11 male participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 9 participants.

Table 4

Measures of Central Tendency, Full Monitoring Day: Women (*N* = 8)

Measure	**Total**	**Non-Sing**	**Choral***	**Solo**
Rec. Hrs. – Total	42.78	38.42	1.85	2.41
Voicing %	10.33	7.75	37.50	31.80
Dt – Total (min)	263.55	178.60	41.57	46.07
Dt -Per Hour (min)	6.20	4.65	22.50	19.08
Dc – Total (Kc)	5085.72	3142.67	941.57	1093.72
Dc - Per Hour (Kc)	119.55	81.80	509.72	452.96
Dd - Total (m)	12928.60	8146.57	2486.39	2583.98
Dd - Per Hour (m)	303.92	212.04	1346.02	1070.16
F_0 Mean (Hz)	321.30	301.73	357.78	393.68
F_0 Median (Hz)	301.61	278.83	342.25	383.37
F_0 Mode (Hz)	267.18	247.45	296.85	319.41
F_0 St Dev (Hz)	105.09	101.67	123.44	119.81
P_0 Mean (Hz)	319.82	282.92	403.16	403.01
P_0 Median (Hz)	307.79	267.71	400.76	394.33
P_0 Mode (Hz)	295.67	255.15	359.31	390.25
P_0 St Dev (Hz)	90.00	77.08	131.36	118.49
dB SPL Mean	74.73	74.45	77.96	75.88
dB SPL Median	74.81	74.31	78.44	76.34
dB SPL Mode	74.91	74.06	79.23	76.98
dB St Dev	5.41	5.22	5.77	5.55
LTAS Slope (x100)	−0.54	−0.51	−0.59	−0.63
Alpha ratio	−22.09	−21.61	−21.97	−24.19
dB SPL 1–3 kHz	−54.54	−54.15	−55.39	−55.78
Pitch Strength *M*	30.20	27.94	27.79	33.83
Pitch Strength *SD*	10.58	10.33	9.35	11.04
Jitter	0.032	0.036	0.033	0.029
Shimmer	0.135	0.145	0.160	0.116
HNR	11.52	10.01	10.78	13.07

Note. Only 6 of the 8 female participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 6 participants.

Table 5

Pearson Correlation Coefficient Tests Between Three-Day Vocal Dose Totals and Voice Quality Means

Measure		Voicing %	Dt	Dc	Dd
F_0	*r*	−.373	−.344		
	p	.116	.149		
P_0	*r*	−.341	−.302		
	p	.153	.209		
dB SPL	*r*	.493	.512	.250	
	p	.032	.025	.302	
LTAS slope	*r*	.068	.041	.393	.020
	p	.783	.868	.096	.934
Alpha ratio	*r*	−.148	−.237	−.112	−.359
	p	.546	.328	.647	.131
dB 1–3kHz	*r*	−.233	−.262	.177	−.224
	p	.337	.279	.468	.357
Pitch strength	*r*	**.665**	**.636**	.296	**.675**
	p	.002	.003	.219	.002
Jitter	*r*	−.501	−.484	−.435	−.432
	p	.029	.036	.063	.065
Shimmer	*r*	**−.689**	**−.672**	−.402	**−.656**
	p	.001	.002	.088	.002
HNR	*r*	.558	.543	.463	**.577**
	p	.013	.016	.046	.010

Note. $p < .01$, 2-tailed, is indicated in boldface.

Table 6

Pearson Correlation Coefficient Tests Between Daily Vocal Dose Totals and Daily Voice Quality Means

Measure		Voicing %	Dt	Dc	Dd
F_0	*r*	−.251	−.237		
	p	.060	.076		
P_0	*r*	−.205	−.201		
	p	.127	.134		
dB SPL	*r*	**.401**	**.406**	.213	
	p	.002	.002	.112	
LTAS slope	*r*	−.157	−.171	.163	−.225
	p	.242	.203	.226	.093
Alpha ratio	*r*	−.124	−.138	−.065	−.249
	p	.359	.306	.629	.062
dB 1–3 kHz	*r*	−.166	−.229	.115	−.211
	p	.217	.087	.393	.116
Pitch strength	*r*	**.474**	**.477**	.237	**.603**
	p	<.001	<.001	.076	<.001
Jitter	*r*	**−.508**	**−.447**	**−.414**	**−.498**
	p	<.001	<.001	.001	<.001
Shimmer	*r*	**−.457**	**−.423**	−.220	**−.504**
	p	<.001	.001	.101	<.001
HNR	*r*	**.422**	**.383**	**.382**	**.502**
	p	.001	.003	.003	<.001

Note. $p < .01$, two tailed, is indicated in boldface.

Table 7

Activity Repeated Measures ANOVA Results

Measure	Non-Sing *M (SD)*	Choral *M (SD)*	Solo *M (SD)*	*Df1*	*Df2*	*F*	*p*
Voicing %	9.35 (2.82)	39.37 (6.76)	44.34 (7.15)	2	28	156.83	**<.001**
Dt (min/hr)	5.28 (1.69)	23.18 (4.00)	25.63 (3.29)	2	28	213.18	**<.001**
Dc (kc/hr)	64.84 (24.21)	364.94 (132.89)	416.62 (166.86)	2	28	61.026	**<.001**
Dd (m/hr)	255.88(131.21)	1320.38(390.82)	1565.60(494.77)	2	28	109.02	**<.001**
F_0	213.54(74.07)	257.82 (91.89)	272.02 (112.72)	2	28	15.04	**<.001**
P_0	206.16(63.92)	278.89 (111.47)	279.18 (114.44)	2	28	21.91	**<.001**
dB SPL	75.09 (5.31)	77.48 (5.37)	78.49 (5.09)	2	28	12.24	**<.001**
LTAS slp (x100) *	−0.55 (0.86)	−0.64 (0.14)	−0.70 (0.14)	1.4	20.2	3.50	**<.001**
Alpha ratio	−22.15 (3.51)	−23.63 (2.91)	−24.42 (4.13)	2	28	4.60	.019
dB SPL 1–3 kHz	−56.07 (3.67)	−57.34 (3.76)	−56.48 (2.67)	2	28	1.69	.202
Pitch strength	29.35 (4.36)	33.76 (8.45)	38.26 (7.03)	2	28	16.68	**<.001**
Jitter %	3.87 (0.64)	2.67 (0.90)	2.47 (0.74)	2	28	17.03	**<.001**
Shimmer %	13.99 (1.97)	13.10 (3.67)	10.51 (2.39)	2	28	11.57	**<.001**
HNR	10.52 (0.47)	13.01 (0.98)	14.99 (0.74)	2	28	13.05	**<.001**

Note. $p < .01$ is indicated in boldface.

* For those variables that violated the assumption of sphericity based on Mauchly's test for sphericity ($p < .05$), a Greenhouse-Geisser correction was applied.

Table 8

Significant Differences Between Activity Means

	P		
Measure	**Non-Sing/Choral**	**Non-Sing/Solo**	**Choral/Solo**
Voicing %	**<.001**	**<.001**	.070
Dt (min/hr)	**<.001**	**<.001**	.056
Dc (kc/hr)	**<.001**	**<.001**	.101
Dd (m/hr)	**<.001**	**<.001**	.022
F_0	**<.001**	**<.001**	.286
P_0	**<.001**	**<.001**	.976
dB SPL	**.007**	**<.001**	.144
LTAS slope	**.002**	**<.001**	**<.001**
Alpha ratio	.071	**.002**	.383
dB 1–3kHz	.109	**<.001**	.152
Pitch strength	.019	**<.001**	**.008**
Jitter	**.002**	**.001**	**<.001**
Shimmer	.299	**<.001**	**.010**
HNR	**.004**	**<.001**	.093

Note. $p < .01$ is indicated in boldface.

Table 9

Pearson Correlations Between Three Day Voice Quality Means (All Recorded Hours) and Total Singing/Non-singing Doses

Measure		Total Singing Recording Duration	Total Singing Dt	Total Singing Dc	Total Singing Dd	Total Non-Singing Dt	Total Non-Singing Dc	Total Non-Singing Dd
dB SPL	*r*	.395	.496	.401	**.744**	.395	.126	**.736**
	p	.094	.031	.089	<.001	.094	.607	<.001
Pitch strength	*r*	.564	**.648**	.498	**.743**	.441	.123	.508
	p	.012	.003	.030	<.001	.059	.615	.026
HNR	*r*	.470	.548	**.590**	**.633**	.403	.311	.440
	p	.042	.015	.008	.004	.087	.195	.059
Jitter	*r*	−.570	**−.667**	**−.637**	**−.628**	−.443	−.378	−.481
	p	.011	.002	.003	.004	.057	.111	.037
Shimmer	*r*	**−.618**	**−.683**	−.509	**−.701**	−.477	−.174	−.456
	p	.005	.001	.026	.001	.039	.477	.050

Note. $p < .01$ is indicated in boldface.

Table 10

Pearson Correlations Between Three Day Non-Singing Doses and Non-Singing Voice Quality

Measure: Non-Singing Periods		Total Non-Singing Dt	Total Non-Singing Dc	Total Non-Singing Dd
dB SPL	*r*	.381	.154	**.735**
	p	.107	.528	<.001
Pitch strength	*r*	.505	.263	**.594**
	p	.027	.277	.007
HNR	*r*	.484	.431	.519
	p	.036	.065	.023
Jitter	*r*	−.439	−.492	−.458
	p	.060	.032	.049
Shimmer	*r*	−.513	−.272	−.481
	p	.025	.260	.037

Note. $p < .01$ is indicated in boldface.