Article

AMERICAN CHORAL DIRECTORS ASSOCIATION

IJRCS

International Journal of Research in Choral Singing

The Scientific Research Journal of the American Choral Directors Association

International Journal of Research in Choral Singing
(2026) Vol. 14 20-36

Sound Energy Levels Produced by a Choral Ensemble: Considering the Risk of Music-Induced Hearing Loss

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Abstract

Choral ensemble instruction serves a prominent role in the music education of students from primary to postsecondary schools. While the field of performing arts health is growing, minimal research has been implemented on the hearing-health concerns of choral ensemble participants or choral conductors/directors. The purpose of this study was to assess the sound-level creation of a collegiate choir and assess the conductor's risk for hearing problems from sound level exposure according to Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) criteria. Dosimeter measurements were taken over five consecutive rehearsal periods of an elite, collegiate a cappella ensemble. The overall sound exposure was compared to the OSHA/NIOSH standards. Because the NIOSH organization focuses on research, rather than regulation and enforcement, and because it is more conservative in its approach to conservation, its standard was deemed the best fit for the demands of music making and was thus used moving forward throughout the study. The mean dose (NIOSH) per event was 5.76%, ranging from 4.87% to 7.72%; this is the percentage of a total safe daily dose. The average difference between L_{eq} measurements at C (LC_{eq}) and A (LA_{eq}) weightings was 1.66dB. These findings reflect a lower dose exposure compared to similar instrumental studies and supports the need for further research within the choral musician population.

Keywords: *dosimeter, hearing health, hearing conservation, choral hearing health, sound level exposure, choral pedagogy, TEKS, NASM*

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Introduction

Music Induced Hearing Loss (MIHL) is a term describing the hearing loss due to loud sound exposure in the context of music (Morata, 2007; Chasin et al., 2020). In response to this health concern, three significant events surrounding musician's health, specifically hearing health, occurred. First, the National Association of Schools of Music (NASM) together with the Performing Arts Medical Association adopted a health mandate in 2011 to address the maintenance of health and safety within the contexts of practice, performance, teaching, and listening (NASM Handbook, 2023–24). Current language within the NASM handbook states the following:

> Students enrolled in music unit programs and faculty and staff with employment status in the music unit must be provided basic information about the maintenance of health and safety within the contexts of practice, performance, teaching, and listening. For music majors and music faculty and staff, general topics include, but are not limited to, basic information regarding the maintenance of hearing, vocal, and musculoskeletal health and injury prevention. They also include instruction on the use, proper handling, and operation of potentially dangerous materials, equipment, and technology as applicable to specific program offerings or experiences. Beyond the provision of basic general information, and the identification of available resources, decisions regarding topic areas and breadth and depth are made by the institution, and normally are correlated with the nature, content, and requirements of specific areas of specialization or specific courses of study. For non-majors enrolled in courses offered by the music unit, including performing ensembles, or other curricular offerings of the music unit, topics chosen in addition to the maintenance of hearing health are directly related to health and safety issues associated with their specific area of study or activity in music. Music program policies, protocols, and operations must reflect attention to maintenance of health and injury prevention and to the relationships among: the health and safety of musicians; suitable choices of equipment and technology for various specific purposes; appropriate and safe operation of equipment and technology; and the acoustic and other conditions associated with health and safety in practice, rehearsal, performance, and facilities. Specific methods of providing information and addressing injury prevention, technology, and facilities are the prerogative and responsibility of the institution. (p. 69–70)

Following this initiative, the Texas Education Agency adopted elements of health and safety towards music into the Texas Essential Knowledge and Skills standards in 2013 (Texas Education Agency, 2020). Listed under "Knowledge and skills" for Middle School 1, 2, and 3, students are expected to *explore*, *describe*, and *demonstrate*, respectively, the "health and wellness concepts related to musical practice such as body mechanics, hearing protection, vocal health, hydration, and appropriate hygienic practice" (p. 11, 14, 16). Under High

School Music Levels 1, 2, and 3, students are expected to *apply* the same concepts (p. 16, 18, 21). Level 4 of High School Music then expects students to *analyze* and *apply* this information (p. 23). Unfortunately, most music educators lack the awareness of and training to comply with such TEKS standards (Chesky & Surve, 2016; Fraser, 2016). There is a lack of research in which to help teachers meet these requirements. One area that is significantly lacking research, is hearing health within choral ensemble-based instruction. The third significant event surrounding hearing health in regards to music came from the World Health Organization (WHO). In 2019, the WHO reported that roughly over a billion young people worldwide were potentially at risk for hearing loss as a result of unsafe listening practices. As a result, WHO launched its Make Listening Safe campaign in March of 2015 (World Health Organization, Make Listening Safe, 2019). This estimate was updated to between .67 and 1.35 billion in 2022 (Dillard et al., 2022). Continued efforts in this arena are needed to understand the risks undertaken by musicians.

Research addressing the sound-level exposure to instrumental musicians within ensembles by using objective measurements exists (Chesky, 2010; Gopal et al., 2013; Henoch & Chesky, 2000; Powell & Chesky, 2017); however, little research exists for choral ensembles (Titze, 2008). Research has tried to apply the Occupational Safety and Health Administration (OSHA) and The National Institute for Occupational Safety and Health (NIOSH) standards of risk to music activities (US Dept. of Labor, 2019; Sherburn, 2014; NIOSH, 1998); yet, growing research concerned with performing arts health has shown that this application is not always appropriate (Gopal, 2013; Kardous et al., 2015). NIOSH and OSHA standards are intended to measure consistent levels of exposure, not variations such as those found in music. Their primary purposes are to evaluate and recommend safe daily doses of sound energy exposure to workers managing 8-hour work days; amounting to 40 hours of exposure over a week's time for 40 years. See Table 1.

Table 1

NIOSH and OSHA Hearing Health Standards

Duration (time equaling 100% dose)	OSHA Permissible Exposure Limit	NIOSH Recommended Exposure Limit
8 hours	90 dBA	85 dBA
4 hours	95 dBA	88 dBA
2 hours	100 dBA	91 dBA
1 hour	105 dBA	94 dBA
30 minutes	110 dBA	97 dBA
15 minutes	115 dBA	100 dBA

Researchers have examined the amount of daily and weekly sound energy exposure to university music students (Pietrzak, 2019; Smith et al., 2019; Tufts & Skoe, 2018). Tuft and Skoe compared the week-long activities of student musicians vs. non-musician students, and reported, according to the NIOSH standard, that "nearly half (47%) of the musicians' days exceeded a daily dose of 100%, compared with 10% of the non-musicians' days" (Tuft & Skoe, 2018, p. 20). Smith's study assessed individual musician's practice, large ensemble instruction, as well as the reverberation impact on sound exposure. Pietrzak's study assessed instrumental musicians over the duration of a typical work day during solo practice, chamber ensembles, symphony orchestra, wind orchestra, and within a "Big Band" ensemble. This study's data showed variance of sound energy level exposure based on instrument and activity. A more significant finding, was that the NIOSH daily limit was exceeded by most instrumentalists within 5 hours of their time (Pietrzak, 2019). None of these studies included vocalists or choral ensembles in their data collection.

In their 2024 paper, Lowrance et al. studied vocal performance students, observing "immediate and long-term effects of music and singing practice on the peripheral auditory system of vocal performers using otoscopy, pure-tone audiometry, and noise dosimetry" (Lowrance et al., 2024, p.1047). For the majority of their participants, dosimetry data indicated exposure beyond recommended NIOSH limits (Lowrance et al., 2024).

Research on sound levels within choirs has been largely limited to individual dosimeter readings recorded over a singular ensemble event (Cook-Cunningham, 2014), or primarily focused on an individual's sound production or vocal load while singing within an ensemble (Daugherty et al., 2011). To date, most research involving the "sound" produced by a choral ensemble reflects a lack of objective sound energy measurements; instead, focusing on perceptual and acoustic feedback (Ternström, 1991, 1994, 1999; Tonkinson, 1994), the quality (Ekholm, 2000; Ford, 1999), as well as various standing formations (Daugherty, 1996, 1999, 2001, 2008; Daugherty et al., 2013).

Sound energy levels have been considered in a few studies. One such study assessed the dynamic range of individual singers within a choral ensemble (Coleman, 1994). Coleman reported that individual ranges varied from 11dB to 33dB, and that trained singers had a greater ability to produce soft vocal dynamics. Sound energy levels were also considered by Titze and Maxfield (2017), who created a voice range profile for a choir based on 5 male and 5 female singers. A Voice Range Profile (VRP), also known as a phonetogram, is a visual representation of a person's vocal capabilities, showing the range of frequencies and intensities they can produce. These graphs are used in clinical settings for assessing voice disorders, evaluating treatment effectiveness, and tracking vocal changes over time. They reported 6 distinct dynamic levels (*pp p mp mf f ff*), with the difference in each level ranging between 3-6dB. They noted that the dynamic range of a choir is not solely dependent upon its size, but rather can be influenced greatly by the inclusion of highly trained participants (Titze & Maxfield, 2017). While these studies assessed sound energy produced by the choir, they were largely concerned with dynamic variability, not what sound levels would mean for the hearing health of a conductor or director of the ensemble. A 2023 pilot study from Finola et al.

looked at rehearsal sound exposure within a choral ensemble; taking baseline, post-exposure, and 24-hour post-exposure measurements (Finola et al., 2023). A significant need for objective sound level measurements for choral ensemble-based instructional activities remains. To understand the auditory health concerns of choral singers and ensemble directors, and to address the potential risk of MIHL, objective measurements must be taken; studies should include a variety of ensembles, rehearsal period lengths and spaces, and must carefully consider methodological design within the dynamic setting of ensemble rehearsals (Finola et al., 2023). At this time, no known studies exist that address the Sound Pressure Levels or sound energy produced by a choir in relation to hearing health and conservation of the ensemble director. While many studies exist to address the hearing health of instrumental musicians, singers within a choral ensemble and their directors have largely been neglected.

Over the last two decades research related to MIHL has begun to address the problematic application of the equal-energy theory, as it applies to music and musicians. The equal energy theory asserted that hearing damage from noise exposure was based solely on the total sound energy absorbed by the ear, regardless of how that energy was distributed over time (Ward, 1984). The fluctuation of sound energy demonstrated within music has called into question whether the OSHA and NIOSH hearing-conservation standards, used to assess other occupations that experience a constant level of sound energy, are appropriate for assessing music. These points have principally been championed by Kris Chesky, who's research on wind bands and jazz bands has called for a significant shift in understanding towards MIHL versus noise-induced hearing loss (NIHL). Chesky highlighted that the A-weighted L_{eq}, which is the typical protocol used to assess occupational noise exposure, presented a challenge in studying musicians' hearing conservation due to its low frequency exclusion. A, C, and Z weightings can be simplified in the following ways: A-weighting measures the sound levels in a manner that closely reflects human ears' perception of sound, C weighting includes more low-frequency sounds, and Z weighting is an filtered and unweighted standardization of sound measurement (Švec & Granqvist, 2018).

Chesky (2010) argued for the need to observe and record variables such as the "time spent at various intensity levels, maximum and peak sound levels, degree of variability of sound levels overtime, and percentage of time playing music" (p. 29). In studying jazz band sound levels, Henoch & Chesky (2000) reported that the sound level exposure during a 50-minute instructional-based rehearsal ranged from 95-105.8dB and that though temporary, significant threshold shifts were measured in the jazz-musician participants. Measuring the exposure within a jazz ensemble-based instructional activities, Walter et al. (2012) reported that players were exposed to 183% of the recommended NIOSH dose over two days. Henoch and Chesky (2000) compared the sound energy levels of a jazz band ensemble to the OSHA standards and reported that 3 hours of exposure exceeded the "allowable exposure limits" 10 out of 15 measurements (p. 17). This research has illuminated the role of the ensemble conductor/director in reducing the risk of music induced hearing loss (MIHL) within instrumental ensemble-based instructional activities (Gopal, 2013; Henoch & Chesky, 2000; Powell & Chesky, 2017).

Instrumental ensemble-based instructional activities have been studied far more than choral ensemble-based instructional activities in regards to hearing risk, and while the OSHA and NIOSH standards are greatly accepted in general occupational risk assessments, there is a need for contextualizing these measurements in a novel method when regarding musicians' hearing health. Assessing time series data will provide nuance to the discussion of MIHL and its risk within choral ensembles.

Purpose

The scope of this study is to measure, characterize, and contrast the sound energy levels generated by five consecutive choral ensemble-based instructional activities. Sound energy exposure, dose, and, therefore, risk will be assessed for the instructional position before such an ensemble.

Method

Procedures

The choir observed was part of a university that boasts one of the largest student enrollment populations in the United States and as such, provides ample ensemble-based activities. The researcher took measurements in the main choral rehearsal space. This data was then collected using a Larson Davis LxT Sound Track[1] (LDLST) type 1 dosimeter with Larson Davis Model EXC positioned on a mic stand. For the first recording, the mic stand was placed upon a .48 meters tall wooden piano bench, bringing the total height of the mic to 2.36 meters. The microphone was located 1.22 meters from the front edge of the conductor's podium, and the podium measured 3.28 meters from the closest edge of the choral raisers. While the mic remained stationary in the room for the subsequent recordings, the director set the piano directly between the mic and the raisers; seating himself behind the piano and directing from that position. The distance between the microphone and raisers was constant for all rehearsal recordings and measured 3.84 meters, see Figure 1 on the next page. The dosimeter was started and stopped manually at the exact times the class period was to begin and end by the researcher; amounting to five consecutive rehearsals, each consisting of 50 minutes. The data was then uploaded to the G4 software program and exported to Statistical Package for the Social Sciences (SPSS) software analysis.[2]

Context

The observed ensemble was a 43 mixed-voice ensemble consisting of 81.4% undergraduate music students and 18.6% graduate students. The choir rehearses in a variety of standing formations on four levels of collapsible risers, with singers also positioned on the floor. The rehearsal space was a 205 m2 space consisting of painted cinderblock walls, industrial-tile

[1] Larson Davis. LD G4 Utility Software, MTS Systems Corporation, 2019.

[2] IBM. IBM SPSS Software, 2019. https://www.ibm.com/analytics/spss-statistics-software, accessed April 7, 2019.

Figure 1
Rehearsal Recording Arrangement

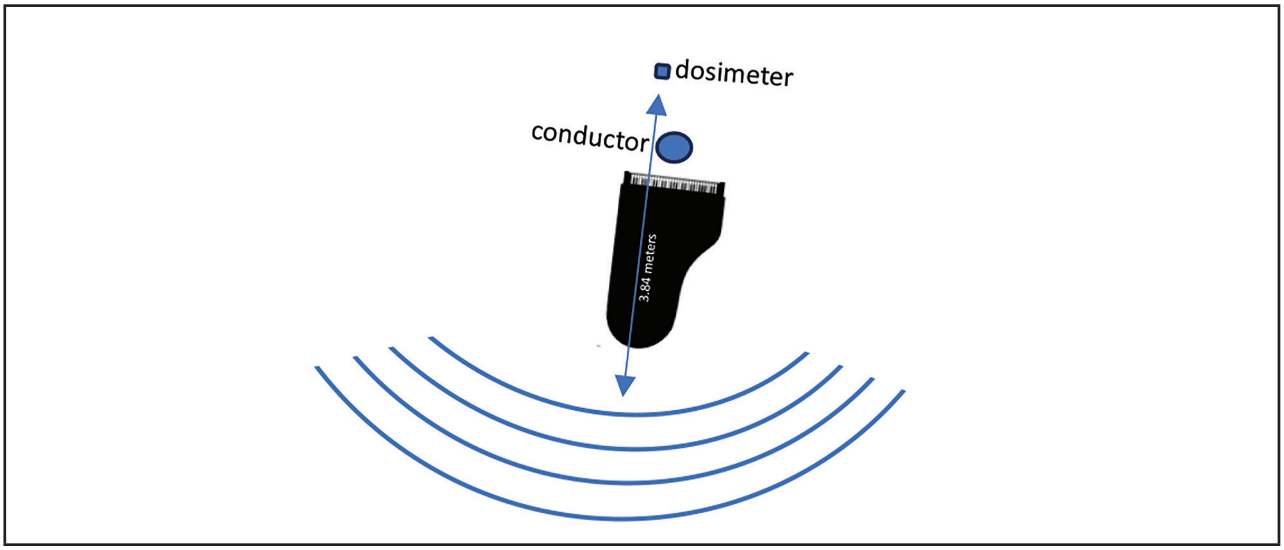


Table 2
Repertoire Rehearsed

I Need Thee Every Hour, Robert Lowry arr. Sam Robson
Messe Pour Double Chœur, Frank Martin
Bogorodiste Devo, Sergei Rachmaninoff
The Lord is the Everlasting, Kenneth Jennings
Christ in the Appletree, Stanford E. Scriven

floors, and a paneled ceiling with a height of 4.88 meters. The repertoire rehearsed during the 5 days of measurement are outlined in Table 2 above.

Equipment and Settings

The LDLST dosimeter was set for A, C, and Z weighting with a time history sample interval of 1 per second by the researcher. The criterion level was set for 85dB with 3-dB exchange rate. According to the NIOSH standard an increase in 3dB equals a doubling of sound energy. Using these settings, the following measurements were taken:

- **Dose** is the percentage of time that a person is exposed to noise that is potentially damaging to hearing. It is calculated by dividing the actual time of exposure by the allowed time of exposure, where 0 represents no exposure and 100 or more represents complete exposure.

- **Leq** is the level of a constant sound, expressed in decibel (dB), that in a given time period has the same energy as does a time varying sound.

- **LPeak** is the maximum value of the instantaneous, frequency-weighted, sound pressure in a given time interval.

- **Lmax** is the maximum value, expressed in dB, of the frequency and exponential-time-weighted sound level in a given time interval.

- **Projected NIOSH Dose** is the measurement of exposure for an 8-hour period of time based on the event data (see Table 3).

- **LCeq-LAeq** C-A for low frequency indication sound energy being excluded from the A weighting, 3 dB differential is concerning.

Data Analysis

The researcher uploaded the files to G4 and exported the information to SPSS for analysis, two databases were then created. The first database consisted of time series records of each 50-minute rehearsal, broken into seconds; the second database comprised of Duration, NIOSH Dose, Projected NIOSH Dose, dB Leq, Lmax, Lmin, Lpeak, Timestamp for Lmax, Lmin, and LPeak, measurements at A weightings, and the differential between the Leq C and A weightings. Descriptive statistics were used to explain the summary data according to NIOSH standards; however, the time series data provided an innovative method of analyzing and comparing the range and variability of the summary averages over time and between events. The mean dose of each event and projected dose for each event were provided by the G4 software. All datapoints (Leq per second of the event) were compiled and arranged in ascending order within an Excel spreadsheet for calculation of time spent over 70dB by the researcher. Using the times series data and SPSS, temporal views of each rehearsal were created for comparison, including the percentage of time spent over 70dB, and then the Lmax, Lmin and Lpeak were located and marked. Events 3 and 5 were the most extreme in range; the researcher created a histogram with binned dB measurements in SPSS for a breakdown of time spent within dB Leq ranges. See Graph 3 in the following results section.

Results

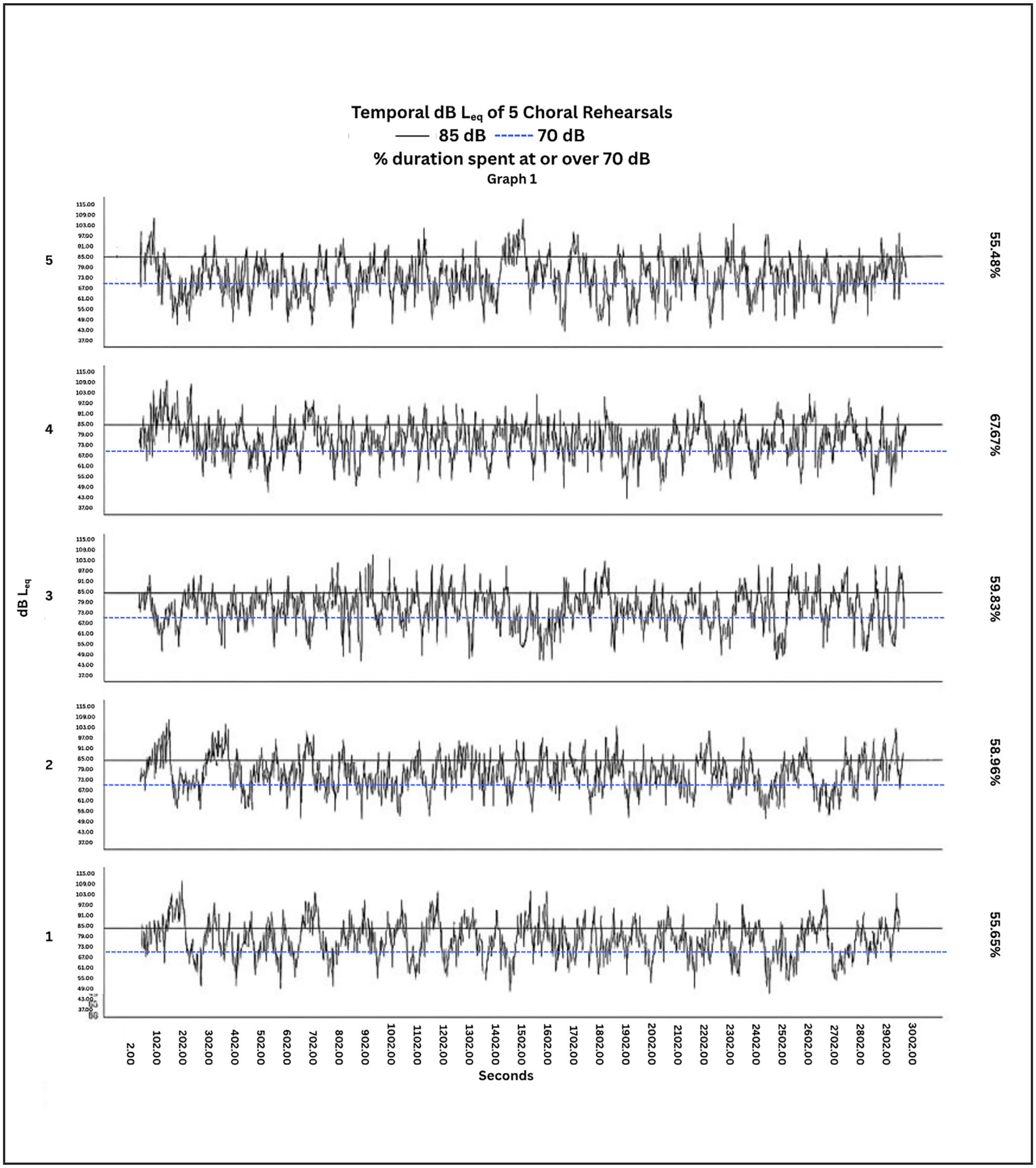
The researcher collected dosimeter data over a 7-day period, with 5 events each equaling 50 minutes, between 3000 and 3002 seconds. As shown in Graph 1 on the next page, the measurement of dB Leq is presented over time with the events in ascending order, the 85dB NIOSH threshold has been marked with a solid horizontal line and the 70dB level is marked with a faint dotted line. Every second received its own Leq average, and the percentage to the right of each event, represents the time spent per that event at or over 70dB. Measurements below 70dB represent spoken instruction and/or the ambient noise levels within the rehearsal space.

Graph 1

Temporal dB L_{eq} of 5 Choral Rehearsals

85 dB ——— --------- 70 dB

% duration spent at or over 70 dB



To understand the pattern or variance between events, Graph 2 presents each event's Lmax, Lmin and Lpeak measurement within the temporal occurrence. The Lmin measurement tends to occur in the latter half of each recorded event, although event 4 presents an outlier, demonstrating when "softer" singing is most prominent. The Lmax and Lpeak tend to occur in the first half of each rehearsal, these note when the "loudest" singing is happening. In events 2 and 3 these measurements occurred at the same time; with events 1, 4, and 5 reflecting the latest Lpeak measurements. Noting these measurement locations within the rehearsal gives insight into the rehearsal structure itself.

Graph 2

Temporal Locations of Lmin, Lmax, and Lpeak in 5 Choral Rehearsals

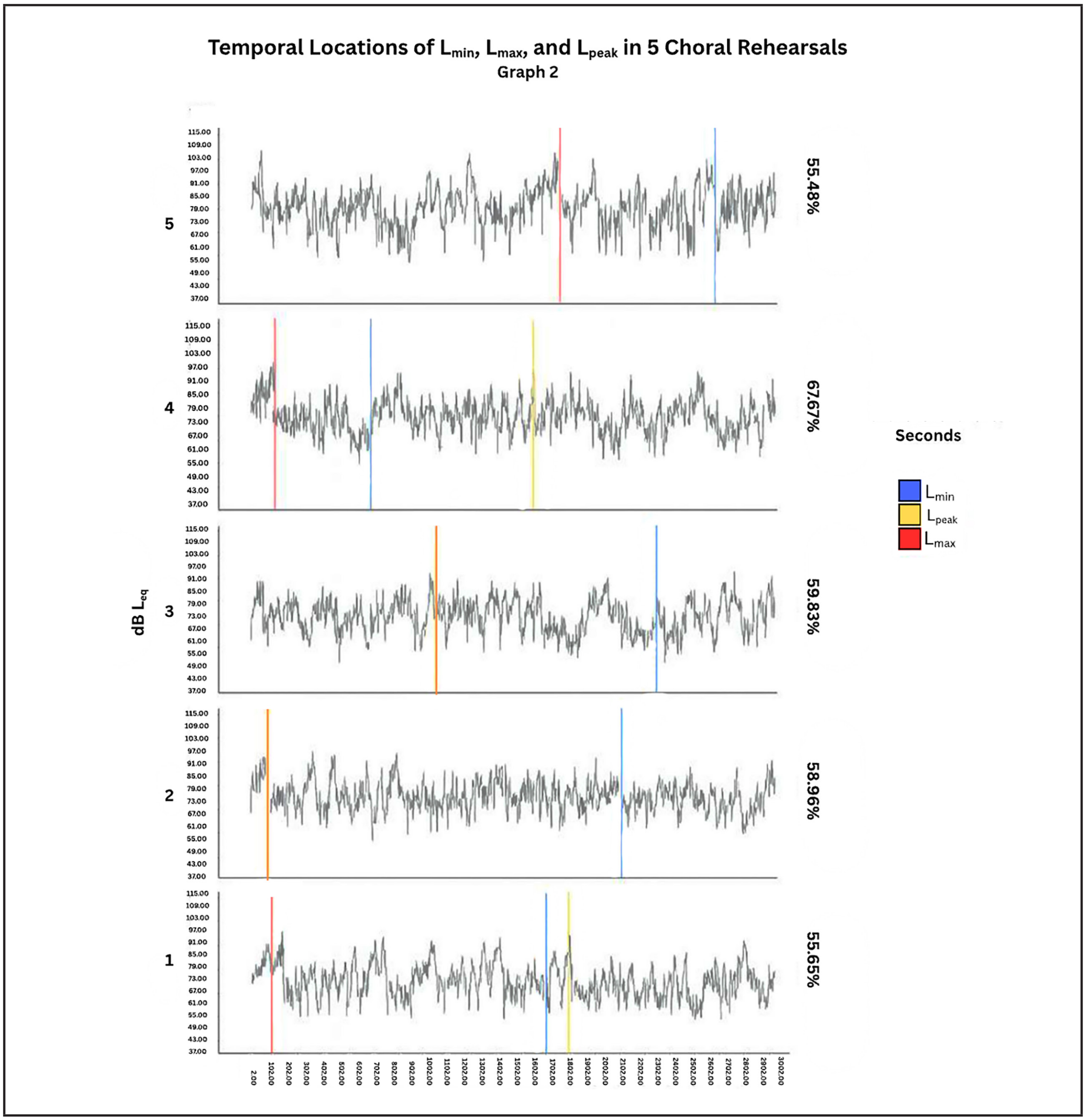


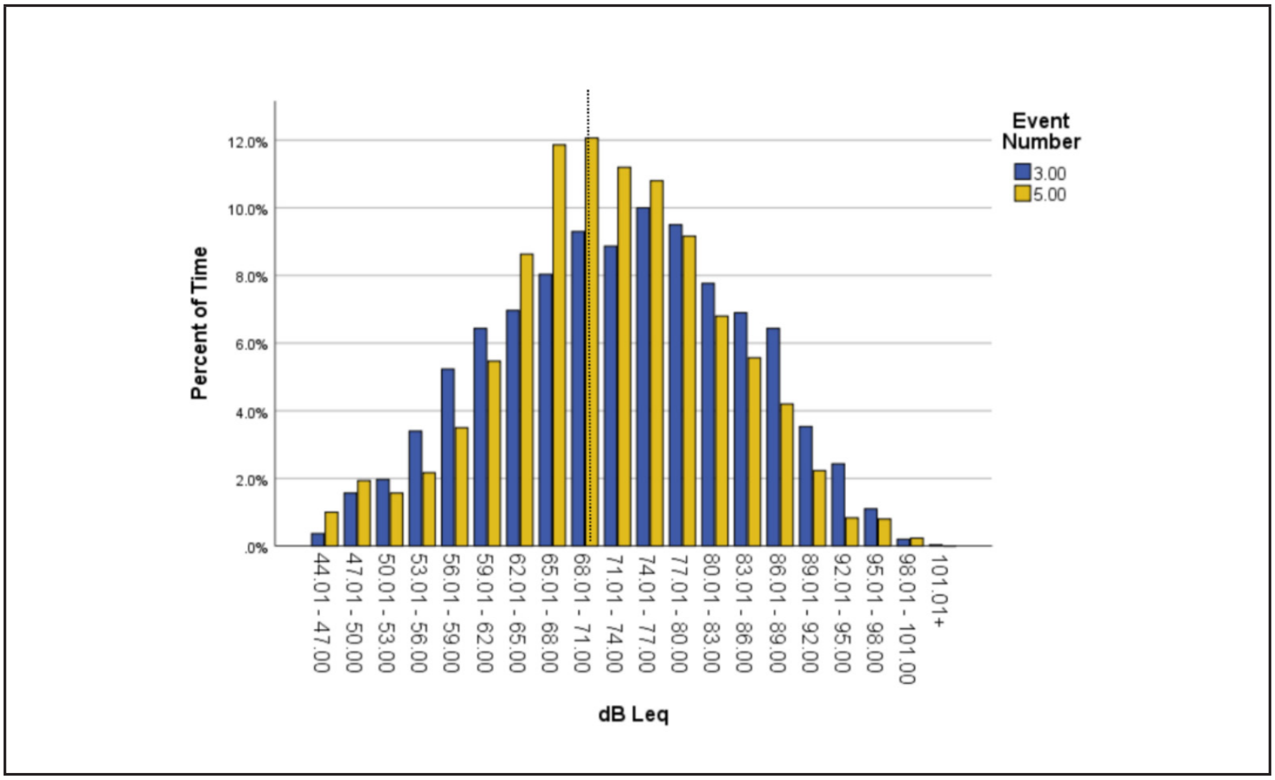
Table 3 displays the dose per event and the mean projected dose by NIOSH standards, as well as the summary data of L_{min}, L_{max}, L_{peak}, and dB L_{eq}. Collectively, the mean projected dose of the 5 rehearsal periods equaled 55.39%, ranging from 46.78% to 74.18%; meaning that on average the doses measured per rehearsal, if experienced for 8 hours, only reached half of the safe recommended dose according to the NIOSH standard. The mean NIOSH dose per event equaled 5.76%, ranging from 4.87% to 7.72%. In comparing Table 3 and Graph 1, it is interesting to note that while event 3 produced the highest average dose and projected dose, event 4 holds the highest percentage of time spent over 70dB. Measurements of 70dB and below represent spoken instruction and/or ambient noise within the space. The measurements of event 4, demonstrate that more time singing within the rehearsal period does not necessarily equal a higher average or projected dose.

Table 3
Event Dose, Projected Dose, L_{min}, L_{max}, L_{peak}, and dB L_{eq}

	NIOSH Dose/Event	NIOSH Projected Dose	L_{min}	L_{max}	L_{peak}	dB L_{eq}
Rehearsal 1	5.27%	51.37%	44.60	104.60	117.20	82.50
Rehearsal 2	5.60%	53. 77%	43.70	102.40	112.10	82.60
Rehearsal 3	7.73%	74.18%	43.90	103.30	114.10	83.90
Rehearsal 4	5.27%	50.63%	43.80	102.70	116.60	82.50
Rehearsal 5	4.87%	46.78%	43.20	101.20	111.10	82.10

Graph 3 on the next page shows the comparison in time series data between events 3 and 5, the highest and lowest dose-producing events respectively. Event 5 reflects more time spent in the 62–77dB ranges than event 5, which could reflect more time speaking or lower sound energy production across the entire choir. The data for event 3 tells us that more time was spent between the 77–98dB and the 50–62dB ranges than event 5, yet produced 27.4% more in event dose. Event 3 also produced the earliest L_{peak} across all events. Again, it is interesting to note that the highest dose-producing event contained more time spent in a lower and higher dB range overall than event 5.

Graph 3
Time Series Comparison of Rehearsal 3 and 5



Discussion

For this study, the researcher measured sound energy levels during regular choral ensemble-based instructional activities within a large college of music. In comparison with previous wind-band and jazz-band studies of exposure levels (Henoch & Chesky, 2000; Chesky, 2010), this choral ensemble did not exceed the allowable dose, as defined by NIOSH, on any single day of measurement. Measurements reflect that an ensembles' sound energy levels will vary considerably throughout the period of instruction and from day to day. For this reason and because the NIOSH and OSHA occupational-health standards exist to measure consistent exposure of sound energy levels over time, their application to music is unbefitting. The researcher's analysis of time series data adds significantly to the understanding of energy over time and to understanding music's innate variability. Afore mentioned variations could be a result of rotating repertoire, differences in energy or vocal fatigue (ex., between a Friday rehearsal and the following Monday) ensemble absences, and perhaps most importantly, the instructional methods of the director of the ensemble.

From Graph 2, one can see that the L_{max}, L_{peak}, or both occurred at the beginning portion of 3 out of 5 rehearsals. For this ensemble, these measurements occurred during the warm-up period of the rehearsal; thus, there is a tendency to sing most loudly in the opening minute to a minute and a half of the rehearsal period for this ensemble. This tendency cannot be applied as a generalization for all choral ensembles however, because each director has their own objectives for the warm-up period. Another observation from Table 2 is that the L_{min} measurement occurs in the latter half of 4 out of 5 rehearsals. This pattern could indicate that more instruction is taking place within this latter half of rehearsals and/or that the instructor may be giving the ensemble a reprieve.

Voice Range Profiles, described earlier in the paper, have served as an assessment tool for individual voices for decades, and have shown that trained vs. untrained singers have a greater dB variation in sound energy (Hunter et al., 2006). While this study did not set out to assess the dynamic range of a choir, the results indicate a potentially greater variance in sound energy than that of an individual singer. Coleman reported a 22dB range in individual singers (Coleman, 1994), and in looking at the average sound (L_{eq}) and loudest sound produced (L_{peak}) within a rehearsal, we see a range of 82.72–114.22dB, a difference of 31.5dB. Thus, it would seem that combined voices can produce a greater variance of sound energy than a single voice. In future studies, a choral ensemble could be asked to sing a fundamental pitch collectively at their softest and loudest dynamic levels for a clearer understanding on this point beyond what we've seen in the range of individual singers (Titze & Maxfield, 2017).

In recent instrumental musical studies, concern in using A-weighted L_{eq}, which is the typical protocol used to assess occupational noise exposure, has been raised (Chesky, 2010). While its sole utilization presents a challenge in studying musicians' hearing conservation due to frequency exclusion (Henoch & Chesky, 2000), measurements from this study reflect that the mean difference in LC_{eq} and LA_{eq} was 1.66dB, this is well below any level of abnormality and could be a reflection that the need for low frequency exclusion is of little concern within choral music. This observation differs from hearing health research conducted on instrumental ensembles.

The decibel level of speech typically ranges between 60 and 70dB. Using 70dB as a marker, the percentage of L_{eq} at 70dB or above for all 5 measured events was 59.6% of the time. This information tells us that roughly 40% of the average rehearsal period observed was used for instruction, questions, trouble-shooting, and demonstration. While events 3 and 5 varied significantly in dose difference, the percentage of time spent at or over 70dB was within 5% of each other; with event 5, the lower of the two events, spending more time above the marker for speech.

This study was limited in recording sound energy levels with one choir, in one room, and over only five rehearsals. No personal dosimetry measurements were taken; therefore, these measurements cannot reflect on the individual exposure risk of a person within the choral ensemble. Additionally, there were two directors (event 1 vs. events 2–5) and their position did not remain stationary, so the levels recorded from the microphone are only referencing a potential level of exposure and risk. Attendance of the choir likely fluctuated a small amount over these recordings as well. On the day of the first event, a steel drum ensemble gave a concert within the building's atrium; this interference was detectable within the choir room.

This study is a step towards recording, analyzing and understanding the cumulative sound energy levels involved in choral ensemble-based instructional activities. It serves as a start to understanding the risk of MIHL for choral directors, as well as the pedagogical implications the director has over the ensemble throughout the rehearsal period. This study serves music educators striving to meet the TEKS and NASM standards of health in music education, and should be used accordingly. While the TEKS standards apply to primary and secondary education in Texas only, there remains: 1) an ever-growing awareness of how to teach future music educators, regardless of location, to be better and healthier than those who came before them; and 2) the opportunity to implement such standards across additional states or country systems.

Conclusion

While this study's findings reflect a low risk of MIHL for the choral director instructing this ensemble, many directors instruct multiple ensembles per day. These results bode well for professional directors and/or higher-education instructors working with ensembles of a similar size. However, there are much larger ensembles, such as symphony choirs, rehearsing for longer periods of time and in spaces that are not designed to host such large ensembles; these spaces may not conducive for the sound energy produced, or provide directorial distance from the ensemble itself. The impact of distance from the ensemble source, remains uninvestigated as of this time. Considering repetitive doses rather than ensemble size or equivalent sound energy levels, many primary and secondary teachers teach back-to-back classes or rehearsals every day of the week. The sound energy variations across adolescent or less vocally mature ensembles are not yet known; understanding the impact of these factors will provide more awareness of MIHL risks to vocal ensemble-based instruction. Future studies should take all of this into consideration; likewise, research should be conducted on a variety of choirs, in a variety of spaces, and with varying rehearsal periods in order to fully understand the auditory risks of choral-based music making. Additional studies are needed to assess the sound energy levels to which members in the choir are exposed. This study takes an initial step towards understanding the conductor's role in managing the sound levels within choral ensemble-based instructional activities, potential risk to the instructor or director of such an ensemble, and the variability within the rehearsal process.

As the role of the conductor and its impact on sound levels continues to be understood, choral pedagogues can instruct future music educators to be mindful of repertoire dynamics when constructing their rehearsal plans. Additional intentionality towards rehearsing repertoire with extreme dynamic levels at lower dynamics provides another method of controlling the "dose" experienced. These rehearsal adjustments can be implemented by any given conductor, in front of any given ensemble. This data confirms the need for objective measurements to be included in choral research and promises to add relevance to the field with the pairing of objective data and subjective perceptions. This study and future research will provide a basis for educational strategies assisting choral directors striving to comply with TEKS and NASM health standards.

References

Chasin, M., Chesky, K., Fligor, B., Heche, M., Le Prell, C., Malyuk, H., Portnuff, C., Tannenbaum, L., & Wartinger, F. (2020). Clinical Consensus Document: Audiological Services for Musicians and Music Industry Personnel. American Academy of Audiology. https://www.audiology.org/guideline-topic/musicians-music-industry/

Chesky, K. (2010). Measurement and prediction of sound exposure levels by university wind bands. *Medical Problems of Performing Artists, 25*(1), 29–34.

Chesky, K., & Surve, S. (2016). Health and wellness in the music TEKS. *Southwestern Musician, 84*(9), 51–55. https://issuu.com/texasmusiceducatorsassociation/docs/may2016

Coleman, R. F. (1994). Dynamic intensity variations of individual choral singers. *Journal of Voice, 8*(3), 196–201.

Cook-Cunningham, S. L. (2014). Personal noise dosimeters: Accuracy and reliability in varied settings. *Noise and Health, 16*(70), 143–148.

Daugherty, J. F. (1996). Differences in choral sound as perceived by auditors and choristers relative to physical positioning and spacing of singers in a high school choir: A pilot study. In *A pilot study. Sesión de poster, presentado en National Biennial In-Service Conference of Music Educators National Conference, Kansas City, MO.*

Daugherty, J. F. (1999). Spacing, formation, and choral sound: Preferences and perceptions of auditors and choristers. *Journal of Research in Music Education, 47*(3), 224–238.

Daugherty, J. F. (2003). Choir spacing and formation: Choral sound preferences in random, synergistic, and gender-specific chamber choir placements. *International Journal of Research in Choral Singing, 1*(1), 48–59.

Daugherty, J. F. (2008). The effects of choir spacing and choir formation on the tuning accuracy and intonation tendencies of a mixed choir. *International Journal of Research in Choral Singing 1*(1), 48–59.

Daugherty, J. F., Manternach, J. N., & Price, K. K. (2011). Student voice use and vocal health during an all-state chorus event. *Journal of Research in Music Education, 58*(4), 346–367.

Daugherty, J. F., Manternach, J. N., & Brunkan, M. C. (2013). Acoustic and perceptual measures of SATB choir performances on two types of portable choral riser units in three singer-spacing conditions. *International Journal of Music Education, 31*(3), 359–375.

Dillard, L. K., Arunda, M. O., Lopez-Perez, L., Martinez, R. X., Jiménez, L., Chadha, S. (2022). Prevalence and global estimates of unsafe listening practices in adolescents and young adults: a systematic review and meta-analysis. *BMJ Global health, 7*(11), 1–11.

Ekholm, E. (2000). The effect of singing mode and seating arrangement on choral blend and overall choral sound. *Journal of Research in Music Education, 48*(2), 123–135.

Ford, J. K. (1999). *The preference for strong or weak singer's formant resonance in choral tone quality* [Doctoral dissertation, The Florida State University].

Fraser, C. (2016). *Wellness resources at postsecondary music schools: A survey of how this information is being offered.* [D.M.A. thesis, Arizona State University]. https://www.proquest.com/docview/1791140061/abstract/260BAA1F876B488EPQ/1

Gopal, K. V., Chesky, K., Beschoner, E. A., Nelson, P. D., & Stewart, B. J. (2013). Auditory risk assessment of college music students in jazz band-based instructional activity. *Noise and Health, 15*(65), 246–252.

Henoch, M. A., & Chesky, K. (2000). Sound exposure levels experienced by a college jazz band ensemble: Comparison with OSHA risk criteria. *Medical problems of performing artists, 15*(1), 17–22.

Hunter, E. J., Švec, J. G., & Titze, I. R. (2006). Comparison of the produced and perceived voice range profiles in untrained and trained classical singers. *Journal of Voice, 20*(4), 513–526.

Kardous, C. A., Themann, C. L., Morata, T. C., Reynolds, J., & Afanuh, S. (2015). Reducing the risk of hearing disorders among musicians.

Lowrance, R. L., Nudelman, C. J., Gonzales Redman, Y., & Bottalico, P. (2024). *Longitudinal Effect of Music Exposure on Hearing Among Vocal Performance Students. In Acoustics, 6*(4), 1047–1073). MDPI.

Morata, T. C. (2007). Young people: Their noise and music exposures and the risk of hearing loss. *International Journal of Audiology, 46*(3), 111–112.

National Association of Schools of Music Handbook 2023-2024. Reston, VA: NASM; 2009. https://nasm.arts-accredit.org/wp-content/uploads/sites/2/2024/01/M_2023-24_Handbook_Final_01-11-2024.pdf, accessed August 30, 2025.

National Institute for Occupational Safety and Health: Occupational Noise Exposure. Cincinnati; NIOSH; 1998.

Pietrzak, A. P. (2019). Musicians' daily sound exposure assessed by full-day dosimetry. *Vibrations in Physical Systems, 30*(1), 1–8.

Powell, J., & Chesky, K. (2017). Reducing risk of noise-induced hearing loss in collegiate music ensembles using ambient technology. *Medical Problems of Performing Artists, 32*(3), 132–138.

Sherburn, R., Stamper, G., & Johnson, T. (2014). Why Do We Sing So Loud?—Reflections on Reflexes That Deceive and Tendencies That Can Harm. *Choral Journal, 54*(8).

Smith, K. H., Neilsen, T. B., & Grimshaw, J. (2019). University student musician noise-dosage study measuring both ensemble and full-day noise exposure. *The Journal of the Acoustical Society of America, 145*(6), EL494-EL500.

Švec, J. G., & Granqvist, S. (2018). Tutorial and guidelines on measurement of sound pressure level in voice and speech. *Journal of Speech, Language, and Hearing Research, 61*(3), 441–461.

Ternstrom, S. (1991). Acoustical aspects of choir singing [Doctoral dissertation, KTH Royal Institue of Technology].

Ternström, S. (1994). Hearing myself with others: Sound levels in choral performance measured with separation of one's own voice from the rest of the choir. *Journal of Voice, 8*(4), 293–302.

Ternström, S. (1999). Preferred self-to-other ratios in choir singing. *The Journal of the Acoustical Society of America, 105*(6), 3563–3574.

Texas Education Agency, Texas Essential Knowledge and Skills for Fine Arts, Chapter 117 https://tea.texas.gov/about-tea/laws-and-rules/texas-administrative-code/19-tac-chapter-117, accessed on August 30, 2025.

Titze, I. R. (2008). Getting the most from the vocal instrument in a choral setting. *Choral Journal, 49*(5).

Titze, I. R., & Maxfield, L. (2017). Acoustic factors affecting the dynamic range of a choir. *The Journal of the Acoustical Society of America, 142*(4), 2464–2468.

Tonkinson, S. (1994). The Lombard effect in choral singing. *Journal of Voice, 8*(1), 24–29.

Tufts, J. B., & Skoe, E. (2018). Examining the noisy life of the college musician: weeklong noise dosimetry of music and non-music activities. *International journal of audiology, 57*(sup1), S20–S27.

United States Department of Labor, "Occupational Noise Exposure," Accessed April 4, 2019. https://www.osha.gov/Publications/OSHA3074/osha3074.html

Walter, J. S., Mace, S., & O'Connell, D. (2012). Sound exposure levels of university jazz band members. *Journal of Band Research, 48*(1), 1.

Ward, W. D. (1984). Intermittence and the equal-energy theory. *The Journal of the Acoustical Society of America, 75*(S1), S47–S47.

World Health Organization, Make Listening Safe. https://www.who.int/deafness/make-listening-safe/en/, accessed April 1, 2019.