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University student musician noise-dosage study measuring both ensemble and full-day noise exposure

Kieren H. Smith,[a] Tracianne B. Neilsen, and Jeremy Grimshaw
Brigham Young University, Provo, Utah 84602, USA
kierenhs@gmail.com, tbn@byu.edu, jeremy_grimshaw@byu.edu

Abstract: A risk factor shared by all musicians is a potential for noise-induced hearing loss. A study was conducted to explore what factors determine noise dosage during musical events experienced by college student musicians. First, noise exposure during specific activities was explored, including during ensemble rehearsal and personal practice. Next, full-day noise exposure was investigated by measuring levels experienced by student musicians during a typical daily routine. Factors such as instrument played, type of activity, location within ensemble, and room environment were related to noise dosage. Disparities in results using different standards to calculate noise dosage were also explored. Risk of noise overexposure was found to be greater in some instrument classes, such as wind instruments, than in others, such as string instruments, and can yield vastly different results depending on the metric used for noise dosage calculation.

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1. Introduction

Since professional musicians are almost three times as likely to develop hearing loss than the general population (Schink *et al.*, 2014), recent literature has addressed the topic of hearing loss and noise exposure in professional musicians—including both pop/rock/jazz (McIlvaine, 2012; Halevi-Katz *et al.*, 2015) and classical musicians (Schmidt *et al.*, 2014; Pouryaghoub *et al.*, 2017; Rodrigues *et al.*, 2014)—and in student musicians (Phillips *et al.*, 2010; Gopal *et al.*, 2013), and most report potential for noise overexposure (Jansen *et al.*, 2009). Relationships between noise exposure and hearing loss have been long evident (Royster *et al.*, 1991) and some differences in hearing thresholds have been noted between players of instrument types in professional orchestras (Kähäri *et al.*, 2001). To further explore noise exposure in a university environment, a study was conducted at Brigham Young University that takes an in-depth look at student noise exposure specifically during rehearsal and individual practice.

The study looks at how noise dosage, defined according to the guidelines of both the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH), varies within an ensemble, and how musician noise exposure varies and builds throughout the day. In addition to measurements during several large ensemble rehearsals, full-day noise exposure measurements were conducted with music major participants. This second part of the study is similar in some respects to the full-day musician noise measurements done by Washnik *et al.* (2016), but additional insights are gained through an analysis of how dosage received varies with activity duration according to both OSHA and NIOSH noise criteria. OSHA is part of the U.S. Department of Labor and is tasked with "setting and enforcing" standards for occupational safety and health (osha.gov). NIOSH is a research-based organization within the Centers for Disease Control and Prevention that aims to develop "new knowledge" pertaining to occupational safety and health and recommend safe practices based on that knowledge (cdc.gov). The parameters used to calculate dosage vary between the two organizations and reflect their unique missions. OSHA standards are less strict, as they are an organization tasked with realistic implementation of enforceable policy. NIOSH standards are more stringent as they are primarily concerned with researched evidences of how noise affects hearing health. Throughout this paper, differences between the two methods of

[a]Author to whom correspondence should be addressed.

calculation are presented with not only an expected quantity difference, but also a variation in dosage patterns across time.

2. Measurement methods

For all noise dosage measurements, Larson Davis Spark® model 703+ or 705+ noise dosimeters (PCB Piezotronics, Provo, UT) were worn by musicians and 1-min L_{eq} values were collected. IRB approval was obtained for subject testing. Noise dose was calculated using the following equation found in ANSI (1991):

$$\text{Dose} = \frac{100}{T_c}\int_{T_1}^{T_2} 10^{\left[(L_{eq}-L_c)/q\right]}\,dt, \quad \text{with } q = \frac{Q}{\log_{10}2}. \tag{1}$$

T_c is the criterion duration, typically 8 h. The criterion level (L_c) refers to the A-weighted level at which constant exposure for the entire T_c yields 100% noise exposure for that day. Levels are only considered if they are above a certain threshold level (L_T), and the exchange rate (Q) determines the amount (in decibels) above or below the L_c that would result in a doubling or halving of dosage, respectively.

In this study, both OSHA and NIOSH noise dosages are discussed. Since neither is used exclusively to discuss risks to musician hearing, both are addressed, consistent with recent literature (Miller *et al.*, 2007; Farmer *et al.*, 2014). OSHA parameters for Eq. (1) are as follows: $T_c = 8$ h, $L_c = 90$ dBA, $L_T = 80$ dBA, $Q = 5$ dB. For NIOSH: $T_c = 8$ h, $L_c = 85$ dBA, $L_T = 80$ dBA, $Q = 3$ dB.

For the ensemble portion of the study, levels during 2-h rehearsals were observed for four ensembles, each over several days. The four ensembles included a 50 member concert band and a 98 member orchestra that rehearse in a large space (1050 m^3) and a 75 member concert band and an 85 member orchestra that each rehearse in a smaller space (750 m^3). A total of 151 measurements were taken within the four ensembles. As measurement positions varied from day to day, a reference microphone was placed at the front of the room each day to normalize the data and allow for spatial mapping. Reverberation times were measured at various locations in each room (Smith *et al.*, 2016).

To observe the effect that room environment has on noise dosage, a single instrumentalist practiced in three different room environments: an anechoic environment, a reverberation chamber, and a typical practice room. The violinist wore a dosimeter and practiced for 20 min in each location, using the first 10 min for playing scales at a *mf-f* level and using the last 10 min to play the same passage from Mozart's Violin Concerto in G. Differences were observed in the three environments.

To contextualize the results found in ensemble rehearsal and personal practice, 43 musicians wore noise dosimeters for two full days each, resulting in 86 days of measurements for a variety of instrumentalists. Dosages during different activities and for the whole day were computed using Eq. (1). Participants from the study were divided into instrument classes, including brass (9 participants), woodwinds (7), strings (10), percussion (2), voice (6), piano (6), and other instruments (3).

3. Results and discussion

Results from the ensemble study are presented first, followed by results from the practice environment study. A statistical analysis of rehearsal and practice activities for the full-day study is also given.

3.1 Ensemble dosage results

Spatial maps of the noise dosage from the ensemble rehearsals (Fig. 1) show differences based on ensemble type, musician location, and room. For each ensemble, the front of the room corresponds to the bottom of the graph with the rows of musicians extending upward on the maps and backward in the rooms. Orchestra configurations were typical, with string instruments nearer to the front than wind and brass instruments in the orchestras. The bands had woodwinds in the front, followed by brass, then percussion in the far back (top of the maps). Each measurement took place over 2 h (of an 8 h T_c), and dosages were calculated. Dosages experienced by the orchestra are lower than by the band in both rooms.

Average sound levels, logarithmically averaged across locations each day and then arithmetically averaged between days, were calculated for each ensemble. Average OSHA and NIOSH dosages were also calculated within each ensemble:

(a) Band in a larger room: 90.9 dBA, 19.2% dosage (OSHA), 137.4% (NIOSH).
(b) Band in a smaller room: 92.8 dBA, 19.3% dosage (OSHA), 138.4% (NIOSH).
(c) Orchestra in a larger room: 87.4 dBA, 9.8% dosage (OSHA), 65.5% (NIOSH).
(d) Orchestra in a smaller room: 87.8 dBA, 9.5% dosage (OSHA), 46.1% (NIOSH).

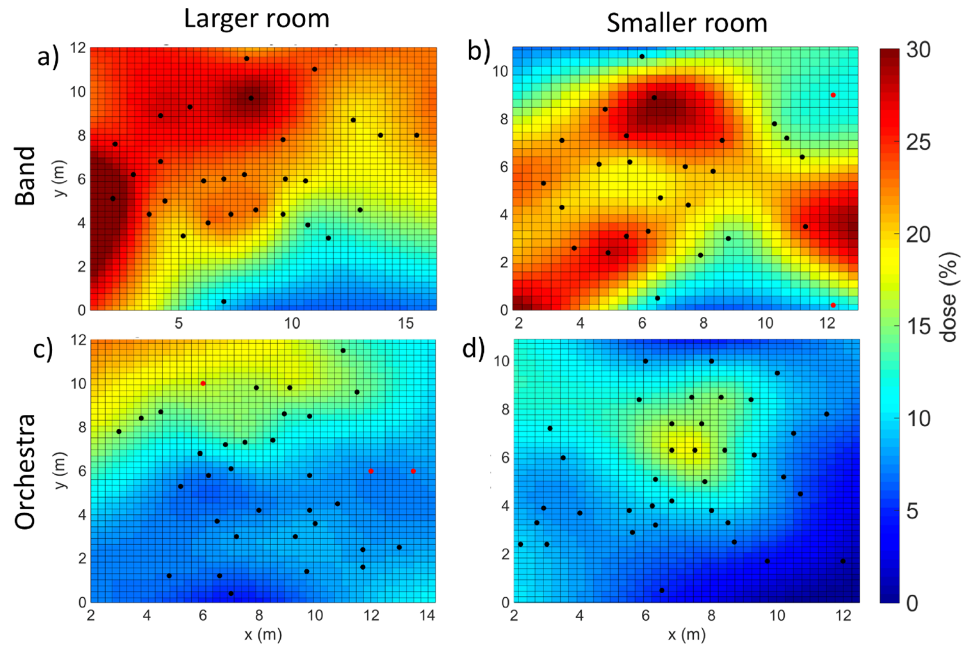

Fig. 1. (Color online) OSHA-based noise dosage maps of four ensembles, created using measurements taken during several 2-h rehearsals and normalized with a reference microphone at the conductor location, located near the bottom center of each map. Ensembles include (a) a concert band rehearsing in a large room, (b) a concert band rehearsing in a smaller room, (c) a full orchestra in the larger room, and (d) a full orchestra in the smaller room. Red points indicate values that were fabricated for interpolation purposes on graphs.

Interestingly, while the sound levels experienced by the band in the smaller room were almost 2 dB higher on average, the average noise dosage experienced was nearly identical. For the orchestras, both sound level and OSHA dosage results were comparable, although NIOSH dosage for the orchestra in the larger room was significantly higher than in the smaller room. These subtle disparities draw attention to the fact that noise dosage reflects not only the average levels experienced but also the fluctuations of level throughout the exposure time. For example, two musicians could average the same L_{eq} during a rehearsal but receive disparate dosages. One dosage may be lower because the musician experienced generally lower levels, perhaps just below the criterion level, with a few higher levels for brief periods of time pulling the equivalent average up but not significantly affecting dosage. On the other hand, the other musician could experience levels consistently above the criterion level, with no extreme levels, keeping the equivalent average level low but contributing regularly to an increase in dosage. Analysis of percent of time exceeding certain levels (e.g., criterion levels), while outside the scope of this paper, warrants study in seeking to understand the nature of musical ensemble noise and its relationship with noise dosage.

Also notable is the distribution of dosages throughout the room. Players in the back (top of spatial maps in Fig. 1) typically receiving higher dosages, most likely due to the type of instruments that play in the back, including percussionists in both bands and orchestras and brass players in bands. Other areas of high dosage include musicians sitting directly in front of traditionally louder instruments, such as the saxophone player represented by the dot near (2,5) in the band in the larger room who received an OSHA noise dosage of 34.1% and a NIOSH dosage of 323.5% during the 2 h. This instrumentalist sat directly in front of a musician playing the trumpet, an instrument known for high levels of noise production. While the instrument played by a musician is the primary contributor to their ensemble noise, proximal musicians also contribute significantly to noise exposure and louder instruments by nature are traditionally grouped together in ensembles.

Another possible contributor to spatial dosage variation is room reflection characteristics. Reverberations times were found to be slightly higher in the back of the room, especially in 1000 Hz octave band in the larger room, a spatial pattern explored in Smith *et al.* (2016).

3.2 Individual violinist practicing dosage results

To determine what effect a room has on sound levels and resulting dosage, a large number of parameters must be controlled, including the ensemble size, types of instruments, instrument spacing, and so forth. For example, a group in the Netherlands created an intricate model for predicting sound levels that members of an ensemble experience on stage, suggesting that levels were affected by the architecture of the room (Wenmaekers and Hak, 2015).

While isolating parameters that influence level within an ensemble is a fairly complex task, looking at the effect of the room on an individual musician can help better understand some of those effects. The correlation between the room reverberation time and musician noise exposure was evaluated in a more controlled way by using noise dosage for a violinist who practiced in three different acoustic environments (Smith *et al.*, 2017). The violinist experienced the following dosages in the three rooms during 20 min of practice:

(a) Anechoic chamber: 3.6% (OSHA), 10.2% (NIOSH).
(b) Reverberation chamber: 6.3% (OSHA), 25.8% (NIOSH).
(c) Practice room: 4.4% (OSHA), 14.6% (NIOSH).

As expected, noise dosage was higher in the reverberant environment than in the other two environments. The anechoic environment, due to its lack of reflections, resulted in the lowest average levels and dosage. Overall, the ranges of noise dosage in a 20 min time period, from 3.6% to 6.3% (OSHA) and 10.2% to 25.8% (NIOSH), illustrate the dramatic change caused by the room. This finding adds further evidence that the effect of room acoustics on musician noise exposure may be quite significant. Further work could explore the possibility of fitting a noise dosage vs reverberation time curve in order to more accurately predict musician noise exposure.

3.3 Full-day musician noise exposure results

To contextualize the studies done on noise dosage in ensemble rehearsals and individual practice, results from the full-day musician study are analyzed. Each musician's noise dosimeter produced 1-min L_{eq} similar to those shown in Fig. 2, which shows the levels experienced over 2 days by a trumpet player who participated in the study. First these levels were categorized according to activity type. For the purposes of this study, portions of time were labelled as "rehearsal" for a musical event in which a group of musicians assemble to play music (orchestra, band, choir, and chamber music rehearsals included), "practice" as time an individual spends playing their instrument in solitude, and "other" for loud events logged by the participant not related to their musical endeavors. Corresponding dosages were calculated for each activity. For example, the single rehearsal on the second day (red box in Fig. 2) contributed 48% of this trumpet player's daily allowed noise exposure according to OSHA and 412% according to NIOSH. Levels, similar to those in Fig. 2, were collected for 43 musicians.

This dataset provides the opportunity to investigate if the noise dosage of student musicians is linearly related to the duration of an activity. To evaluate this hypothesis, dosage vs duration plots were generated for each instrument class. An example from the string class is shown in Fig. 3. For most instrument classes, noise dosage during practice time generally followed a linear trend with higher dosages corresponding to longer practice times. Noise dosage during rehearsals often followed a somewhat linear trend, but usually less so than during practice time. Other activities were not considered because of the variety of activities that were included in that category. While OSHA [Fig. 3(a)] and NIOSH [Fig. 3(b)] standards clearly yield different dosages from the same sound levels, a difference in the linearity of dosage vs duration fit was also observed for the two standards. An example can be observed in the string class (Fig. 3): OSHA standards yielded a generally linear trend in practice dosages as a function of duration, while the NIOSH practice dosages were more scattered. Other instrument classes exhibited similar results as shown in Smith *et al.* (2017).

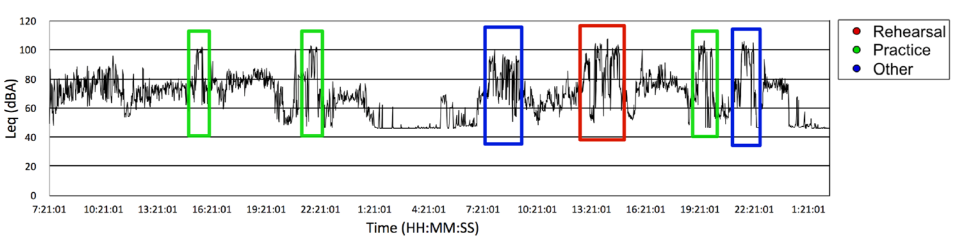

Fig. 2. (Color online) One minute L_{eq} for a trumpet player who participated in the full-day study. Data over 2 days of measurement are shown with boxes outlining significant musical activities.

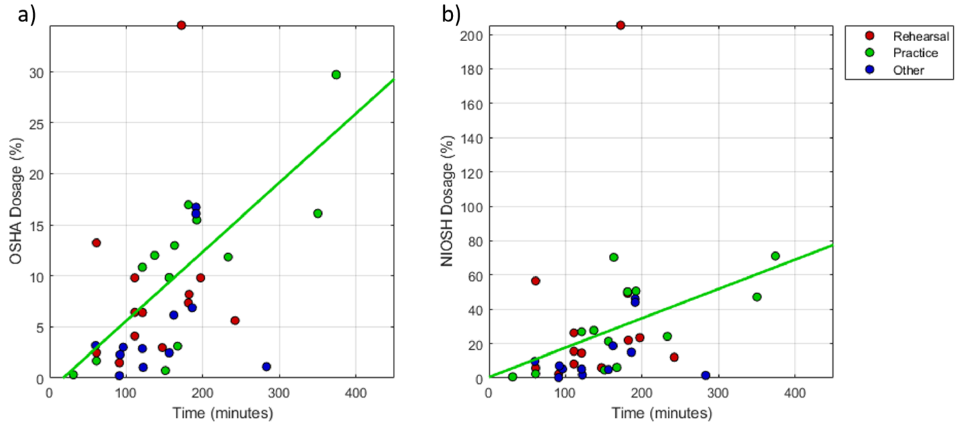

Fig. 3. (Color online) Scatterplots of activity duration vs time for the string instrument class ($n = 43$). Dosages using (a) OSHA standards and (b) NIOSH standards are shown for comparison. Regression lines for string practice are shown in each figure.

The relationship between dosage and duration for all instrument classes and activities is investigated by finding the regression line and calculating the R^2 (correlation) and *p* values (statistical significances). An example of the regression line is shown in Fig. 3(a), and R^2 values are listed in Table 1 for the practicing times. The cases where *p* indicates a significance are indicated by a *. For example, the R^2 values for the woodwind and piano practicing were higher than brass and strings. The regression lines quantify a more linear dosage-duration relationship using OSHA than using NIOSH standards. Not only are the R^2 values higher, but the *p* values for this category were significant at the 0.05 level for all four instrument classes using the OSHA standards but only two for NIOSH. One possible cause for this difference could be musicians are consistently playing above the 85 dBA NIOSH L_c but below the 90 dBA OSHA L_c, rapidly increasing their NIOSH dosage while only affecting their OSHA dosage linearly with time. Informed musicians generally understand that their risk for noise overexposure increases with time spent playing their instrument and would likely intuitively consider the relationship between time and noise exposure to be linear. While the OSHA dosage seems to be linear in this sampling of measured dosages, the NIOSH dosage, perhaps a better indicator of overall noise overexposure risks, does not. Scattered trends using this method of calculation mean that sometimes practicing longer could put a musician either above or below the exposure they might expect with that duration of playing. This variability suggests the need for better hearing loss education in musicians and better access to personal measurement devices so musicians can understand their own personal risk based on schedule, environment, instrument, and any number of other variables. With so much variability, knowledge of one's personal noise dosage is the best way to know how to implement an individual hearing protection strategy, as there is not one solution that would work ubiquitously.

In addition to patterns of dosage with duration, it is important to consider overall average values to understand the risk of noise overexposure. Differences between average dosage values per instrument type become apparent regardless of the computation method used. To evaluate the differences in noise dosage with instrument types, distributions of the dosage for all rehearsal activities and all practice activities are displayed as box and whisker plots in Fig. 4. Consistent with previous literature (Sabesky and Korczynski, 1995; Schmidt *et al.*, 2011), brass and woodwind classes

Table 1. Pearson correlation coefficients (r) and significance values (*p*) from regression of dosage received and activity duration for practicing data in four instrument classes, including woodwinds, brass, strings, and piano, where * indicates significance at the 0.05 level and ** indicates significance at the 0.01 level.

	Pearson Correlation (r)	
	OSHA	NIOSH
Woodwinds	0.77*	0.45
Brass	0.52**	0.24
Strings	0.64**	0.45*
Piano	0.72**	0.69**

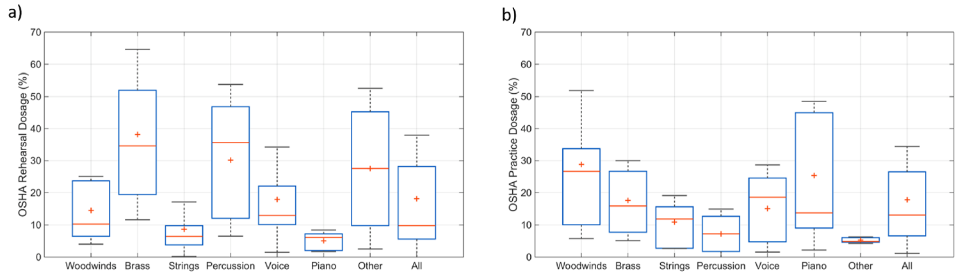

Fig. 4. (Color online) Boxplots of dosages received during (a) rehearsal and (b) practice during a given day. "+" marks the mean value, minimum, and maximum are represented by the horizontal lines, and the lower and upper edges of the box represent the 25th and 75th percentiles, respectively. Both plots report OSHA values, and sample sizes are indicated in Sec. 2.

show significant noise exposure during both activities. Notably, piano players in this sample did not receive high dosages during rehearsals but had much higher dosages and a larger distribution of dosages during practice, perhaps due to the nature of a pianist's daily routine. Additionally, percussion dosages may seem lower than some might expect. The low results from the percussion practice category may in part be due to the impulsive and sporadic nature of percussion noise especially in a symphonic environment, a type of noise that is not fully accounted for in the time-averaged dosage computation method currently employed in most standards. To fully compare instrument classes, larger samples and more diverse data are needed to strengthen these results and lead to more discoveries of nuanced differences between instrument types and noise exposure.

While musicians in this study experienced a wide range of dosages using OSHA standards, only three brass players actually exceeded 100% dosage on either day. However, several musicians exceeded NIOSH standards during either day 1 or day 2 of the study:

(a) Woodwinds: 86% of musicians exceeded full value on day 1, 42% on day 2.
(b) Brass: 56% exceeded on day 1, 89% on day 2.
(c) Strings: 10% exceeded on day 1, 0% on day 2.
(d) Percussion: 50% exceeded on day 1, 50% on day 2.
(e) Voice: 50% exceeded on day 1, 17% on day 2.
(f) Piano: 33% exceeded on day 1, 33% on day 2.

Overall, the number of musicians exceeding NIOSH standards for recommended daily noise exposure is much higher than using OSHA standards and a possible cause for concern. While high, these results are moderate in comparison with other student musician noise exposure studies, where nearly all musicians exceeded both OSHA and NIOSH recommendations such as in the work done by Miller *et al.* (2007).

5. Conclusion and recommendations

Noise exposure in musicians presents concern for those invested in musician hearing health. In this study, noise dosages during ensemble rehearsals, personal practice, and a typical musician daily routine were explored. Additionally, in a case study, a more reverberant environment was found to contribute to a significantly higher noise dosage than an anechoic environment, with nearly double the dosage received during a short practice session. Detailed measurements during ensemble rehearsals for various large ensembles in different spaces revealed a higher noise dosage for bands than for orchestras. Additionally, spatial variation of noise dosage within ensembles was observed, with musicians at the back of the room, playing louder instruments, receiving significantly higher noise dosages, highlighting the clustering effect of louder instruments together, contributing to much higher noise dosage in those areas. Since the time-tested configuration of musical ensembles with groupings of similar instruments is not likely to change, musicians in high-risk areas of the ensemble are encouraged to take extra care to wear hearing protection and to consider using sound-absorptive baffles during rehearsal to help attenuate the noise from neighboring instruments.

For the full-day noise dosage monitoring study, dosage differences in this sample between OSHA and NIOSH standards were discussed, touching not only on the obvious quantity differences but also on how dosage received varies differently with the duration of an activity. Linear fits of dosage over time were found to describe the OSHA values much better than the NIOSH values, although this does not necessarily indicate that one standard better describes actual risk for hearing loss. Finally, while most musicians did not exceed OSHA recommended limits during the measurement days, many exceeded the more conservative NIOSH recommendations, including more than half of the woodwind and brass instrumentalists and a sampling of instrumentalists from each of the categories of strings, percussion, voice, and piano. Further work could explore larger sample sizes with the individual musician measurements.

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