Dashboard system to track cumulative exposure to dangerous sound levels during music instruction

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Abstract:

During music instruction, students and teachers are at risk of hearing loss due to exposure to unsafe sound levels, potentially reaching 120 dB. It is important to provide music instructors tools to monitor the unsafe sound intensities reached during intense and sustained music instruction to encourage more moderate sound exposure. We created a visually-appealing, user-friendly dashboard to display the accumulated time with intense sound exposure during a rehearsal. These visuals can be easily understood at a glance allowing musicians and instructors to make informed decisions about how to play music safely. The dashboard includes a collection of circular dial graphs that display the accumulated sound exposure in the provided frequency and decibel ranges, also allowing the musicians to identify the frequency and intensity of sound reaching critical exposure levels. These dials are set to display a percentage of the maximum safe daily sound exposure according to NIOSH standards. Additionally, the dashboard contains an equalizer that displays the instantaneous frequency distribution of sound, with colors tuned to indicate if sound levels at specific frequencies are too high even for short-term exposure. Less expensive than existing technology and more convenient to use, this dashboard will enable music instructors to make informed decisions on how to best adapt their teaching approaches to protect the auditory health of their students.

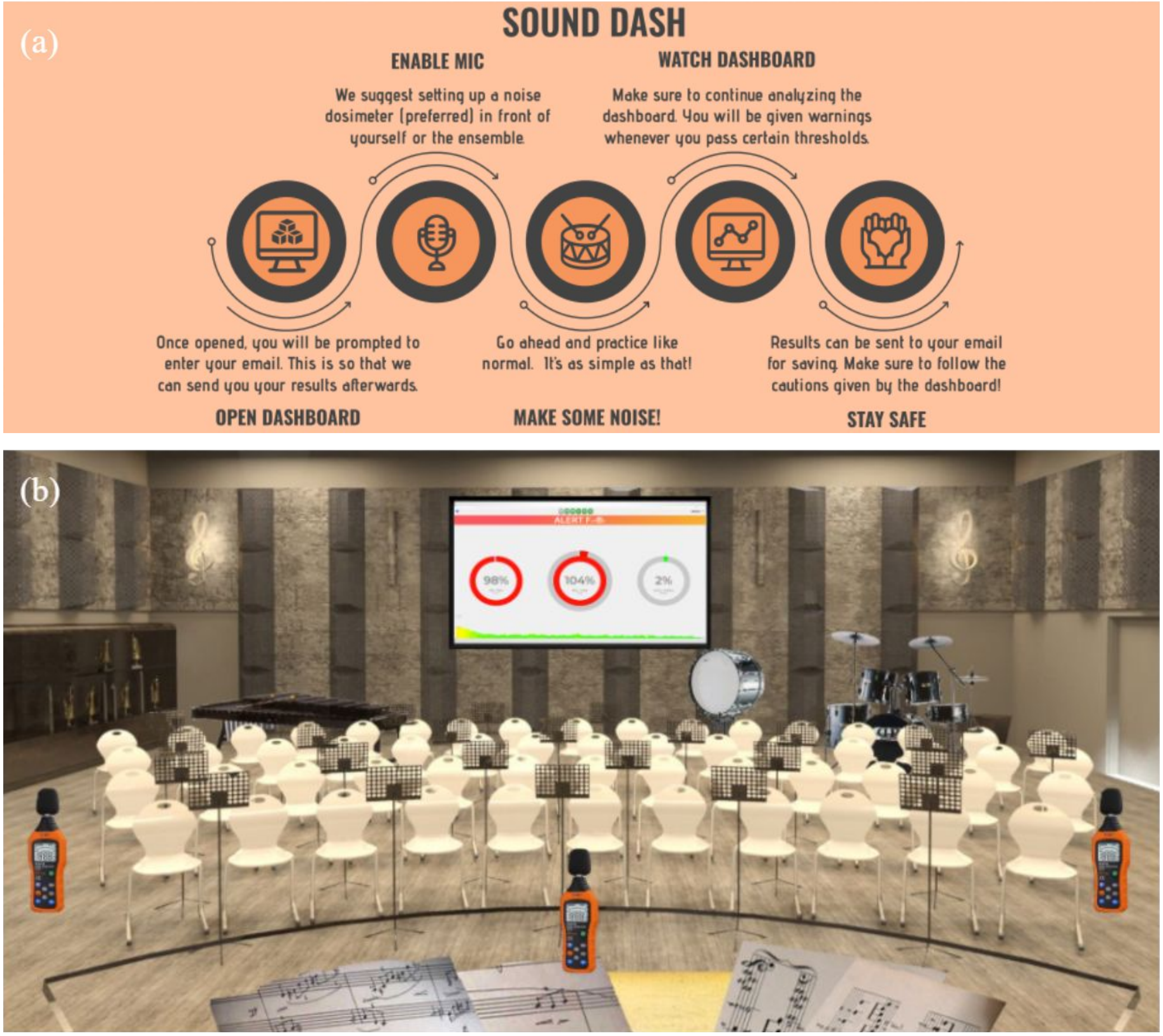

Fig. 1: *Dashboard application overview.* **(a)** Graphic describing instructions for use of Dashboard. **(b)** Example of suggested dashboard setup in an orchestra/band hall setting.

Introduction :

Excessive exposure to music can result in irreversible hearing loss. Loud music is one of the common causes of acquired hearing loss . Acquired hearing loss from exposure to loud music is an increasingly significant public health issue throughout the world (Niskar et al., 1998). Due to an increase in accessibility to music and media, more adolescents and young adults are being exposed to harmful sound levels without completely knowing and understanding the permanent risks associated with such exposure (Gopal et al., 2019). Students engaged in music education are routinely exposed to loud sounds generated by school music ensembles for extended periods, which can lead to permanent damage to the auditory system from a relatively young age. A survey conducted by Zogby International in 2006 found that 12% of adults and 17% of high school students reported tinnitus or ringing in the ears (Berg et al. 2016). The term music-induced hearing loss (MIHL) was coined to denote acquired hearing loss due to loud or sustained music exposure. Therefore, the prevention of MIHL in music students is now being addressed as a critical public health issue (Chesky, 2008; Kardous et al., 2015). While methods for treating hearing loss are available, instituting preventative measures is preferable.

One reason for the increased prevalence of MIHL is the high levels of sound exposure that musicians face. The sound levels generated during music rehearsals can range from 87– 120 dBA (Chesky, 2010). A study conducted in 2008 tested 40 music students, finding that nearly half exhibited reduced hearing thresholds at high frequencies, and a later study found that senior music students showed significantly further loss, presumably from increased sound exposure over time (Phillips and Mace 2008). The outer hair cells (OHC) of the cochlea are some of the most vulnerable components of the human auditory system, and damage to the OHC is consistent with threshold elevations, or notches, at frequencies from 3 kHz to 6 kHz (Niskar et al., 1998). This noise-induced hearing threshold shift can reduce one's ability to hear high frequency sounds at relatively young ages, though it is more common among the aged population (ibid., Sliwinska-Kowalska & Davis, 2012). Short-term hearing loss in the form of tinnitus among musicians is well documented (Berg et al. 2016). However, repeated exposure raises the possibility of permanent, long-term hearing loss.

It can be challenging to find hearing protection methods that musicians feel comfortable using. Earplugs are not viewed favorably by musicians while playing music and would only be considered as a last resort (Chesky et al., 2009). The current literature sufficiently demonstrates the risk of hearing loss in musicians (Gopal et al., 2013). Yet there are few, if any, universally accepted standards for limiting music exposure to safe levels. Based on our earlier findings that teaching methods are highly predictive of MIHL risk (Powell and Chesky, 2017) we believe that a practical, realistic, and sustainable solution is to persuade music instructors to modify their teaching methods so they can protect their hearing health better.

Several standards have been established to measure noise exposure. A noise dose, the measuring unit of noise exposure, is determined based on the aggregated acoustic energy that a person experiences in a specific acoustic environment. Such an approach focuses mainly on the assessment of the amount of energy having a direct impact on the human hearing system (Kotus and Kostek, 2008). Noise dosimeters are required to comply with the American National Standards Institute Specification for Personal Noise Dosimeters S1.25-1991 (R1997), which states that dosimeters should be suitable for measurement of impulsive, intermittent, and continuous noise. The Occupational Safety and Health Administration's (OSHA) established standards and the National Institute for Occupational Safety and Health's (NIOSH) recommended guidelines state that no unprotected impulse noise exposure should be permitted above 140 decibels peak sound pressure level (dB SPL). As a result, contemporary dosimeters designed to comply with regulations are required to operate correctly up to 140 dB (Kardous, Willson, and Murphy 2005). A noise dose might also be expressed as a percentage of "criterion exposure." The "criterion sound level", 85 dB for example, is the level of sound which has been applied continuously for a duration equal to the "criterion time." For instance, 8 hours results in a 100% criterion exposure. These calculations are completely specified in the standard and are well known in the industry (Goldberg et al. 2010).

NIOSH, OSHA, and other regulatory bodies for occupational safety use the time-weighted average (TWA), expressed as the equivalent continuous sound level in decibels (dBLeq) over a given period, as a means of tracking sound exposure in the workplace. Specifically, an 8-hour-TWA is typically used. However, the standards used in enforcing workplace safety vary. NIOSH states that the safe 8-hour-TWA is 85 dB, whereas OSHA states that the 8-hour-TWA is 90 dB. For this effort, the more stringent NIOSH standards were used (National Institute for Occupational Safety and Health, 1998; Occupational Safety and Health Administration, 1971). One advantage of using standards of these types is that they conceptualize hearing damage as proportional to sound intensity (e.g exposure to a 120 dB sound for 9 seconds causes a comparable amount of hearing damage as exposure to an 80 dB sound for 8 hours (OSHA)).

Given this, a non-restrictive method that musicians can use to limit their exposure to harmful levels of sound is needed. Existing methods are either inconvenient, too expensive, or difficult for many musicians to successfully implement during practice. This dashboard addresses each of these issues by using technology that many people already have to display information about cumulative music exposure in a dynamic, user-friendly format that musicians can use to influence their exposure to unsafe sound levels.

Methods:

This research effort focused on developing a dashboard that provides visual warnings against high levels of sound exposure, which can harm the user's hearing ability. This is done by displaying sound exposure in a series of dials (Fig. 3) that show the percentage of maximum sound exposure, defined by NIOSH, that the user has been exposed to and displaying an alert if the user has exceeded safe levels.

Development Tools:

As a web application, we used a standard web development stack. The top toolbar, its buttons, and the graphs were designed directly in HTML. The toolbar and button styles were developed using cascading style sheets (CSS). To handle the logic of the application and style of the graphs, we used JavaScript. We used a module called p5.js to handle the data collection, aggregation, and displays. Specifically, we used a branch of the library called p5.sound, which provided functions and classes to process input from the user's microphone. p5.sound acts as a layer over the web audio API (i.e., the API used by a browser for handling a host's audio).

Method for Categorizing Sound Input:

The calculations for the equalizer are handled by taking sound as input and calculating the intensity of each specific frequency range. These calculations are displayed on the equalizer at the bottom of the screen (Fig. 3), shown as a colored bar plot with frequency in hertz on the x-axis and sound intensity in decibels on the y-axis. The equalizer is updated in real-time. Each dial represents accumulated sound exposure over a different set of frequencies: the first dial shows frequencies below typical human speech (15Hz - 85Hz), the second shows frequencies at typical human speech (85Hz - 252Hz), and the third dial shows frequencies above typical human speech (242Hz - Hz). When the noise exposure for any of the dials exceeds the recommended daily limit, an alert is shown informing the user which set of frequencies triggered the alert.

Method for Accumulating Sound Exposure:

The recommended sound exposure limits from a 1998 NIOSH publication on occupational sound exposure were used to calculate the accumulation of sound for the application (Fig. 2).

Exposure level, *L* (dBA)	Duration, *T*			Exposure level, *L* (dBA)	Duration, *T*		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	–	106	–	3	45
81	20	10	–	107	–	2	59
82	16	–	–	108	–	2	22
83	12	42	–	109	–	1	53
84	10	5	–	110	–	1	29
85	8	–	–	111	–	1	11
86	6	21	–	112	–	–	56
87	5	2	–	113	–	–	45
88	4	–	–	114	–	–	35
89	3	10	–	115	–	–	28
90	2	31	–	116	–	–	22
91	2	–	–	117	–	–	18
92	1	35	–	118	–	–	14
93	1	16	–	119	–	–	11
94	1	–	–	120	–	–	9
95	–	47	37	121	–	–	7
96	–	37	48	122	–	–	6
97	–	30	–	123	–	–	4
98	–	23	49	124	–	–	3
99	–	18	59	125	–	–	3
100	–	15	–	126	–	–	2
101	–	11	54	127	–	–	1
102	–	9	27	128	–	–	1
103	–	7	30	129	–	–	1
104	–	5	57	130–140	–	–	<1
105	–	4	43	–	–	–	–

Fig. 2: *Chart of recommended daily exposure to a sound as a function of exposure level in dBA.* Taken from *Occupational noise exposure: Criteria for a recommended standard*, published in 1998 by NIOSH.

Using this data, the recommended sound exposure limit for any given sound is modeled by

$$y = 8\left(\frac{1}{2}\right)^{\frac{x-85}{3}} \qquad \text{(Equation 1)}$$

where x is the intensity of the sound in decibels, and y is the corresponding limit in hours. From there, the formula to calculate the total sound accumulation can be obtained through integration (equation 2)

$$y = \int_0^t \frac{1}{28800\left(\frac{1}{2}\right)^{\frac{x-85}{3}}} dt \qquad \text{(Equation 2)}$$

where t is the total period measured in seconds, x is the average instantaneous sound intensity in decibels over the set of frequencies being measured, and y is the total sound accumulation as a fraction of the maximum daily recommended dose. For practical implementation, we used a discrete formulation represented in equation 3.

$$y = \sum_{i=0}^{n} \frac{\Delta t}{28800\left(\frac{1}{2}\right)^{\frac{x-85}{3}}} \qquad \text{(Equation 3)}$$

where i is the index of the current update, n is the total number of updates over the duration that the dashboard runs, Δt is the time in seconds that the i^{th} update lasts, and x is the average sound intensity during the i^{th} update over the set of frequencies being measured. As was stated earlier, the industry standard for measuring sound exposure is the 8-hour-TWA; however, considering that music rehearsals vary in length and tend to be shorter than eight hours, we decided to express sound exposure as a percentage of the maximum daily sound dose defined in Figure 2 (85 dBLeq over 8 hours). This approach has the advantage of improving user-readability, as well as allowing the dashboard to be used for rehearsals of varying lengths.

Results:

We present a new method of assessing the noise-induced risk of hearing loss by creating a dashboard that provides real-time visuals related to cumulative sound exposure (Fig 3). We describe the operation of the dashboard below.

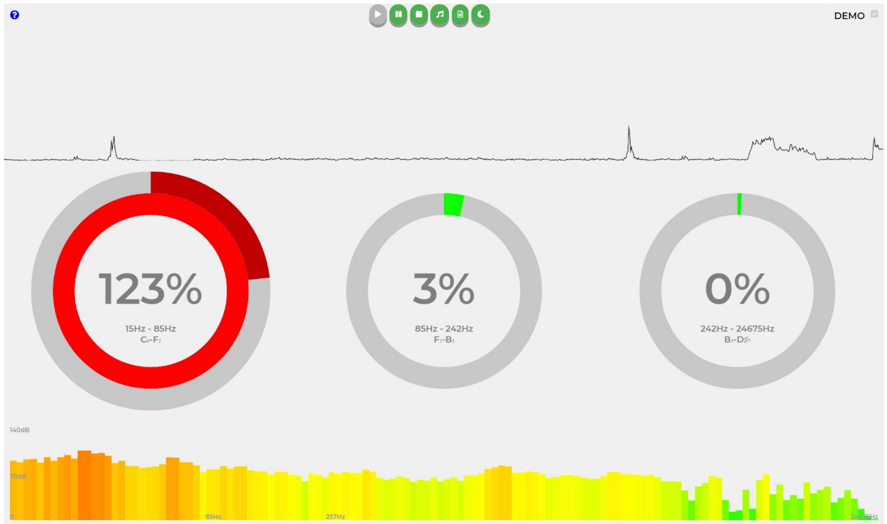

Fig. 3: *The dashboard application in operation.* At the top, there are buttons for controlling the session. Below that, we have a thin line plot showing overall sound intensity over time. Three dials display cumulative sound exposure in different frequency ranges. Note that the left dial is displaying sound accumulation over NIOSH-recommended levels. At the bottom, the equalizer shows real-time sound intensity over the entire frequency range.

Operating Procedure:

When the user first opens the web application, they are greeted with a login page (Fig. 4). There is no account creation or password required. This page requests an email address to send a report summarizing the data represented in the dashboard after each recording session. After entering their email address, a start button is located in the top toolbar, which has to be clicked at the beginning of a session. After the start button is clicked, the main dashboard screen is displayed as depicted in figure 3, with a breakdown of elements in figure 5. There is also a pause and a stop button in the top toolbar. The session ends when the stop button is pressed. The top toolbar also contains a button which takes the user to the documentation of the application, displayed as a document icon, and a button to enable dark mode, displayed as a moon icon.

The toolbar also has features to help orient a user and demonstrate the capabilities without requiring excessive sound intensity exposure. The toolbar help icon contains a tooltip advising the user to hover over buttons for clarification. The user is also able to select a checkbox in the top right corner of the application enabling “demo” mode. In demo mode, the thresholds for unsafe sound exposure are artificially lowered to demonstrate accumulation of unsafe sounds at lower intensities, since a demonstration would otherwise require high intensity exposure over time.

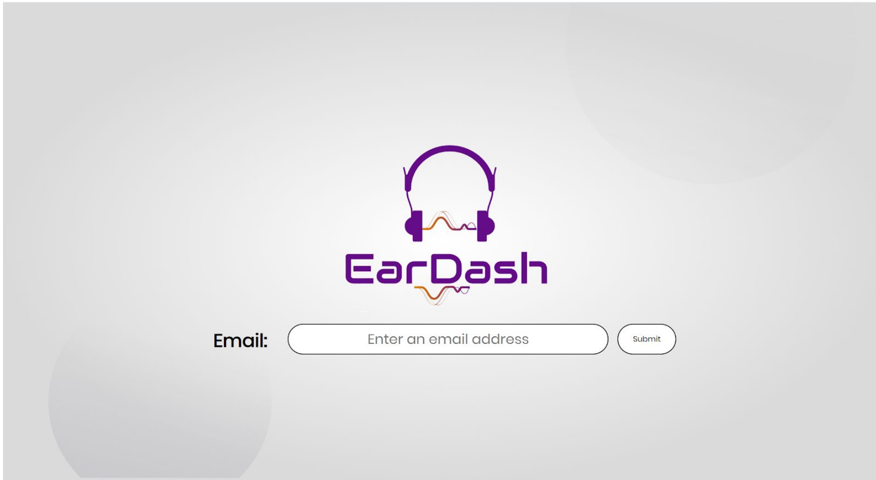

Fig. 4: *The login page for the dashboard application.*

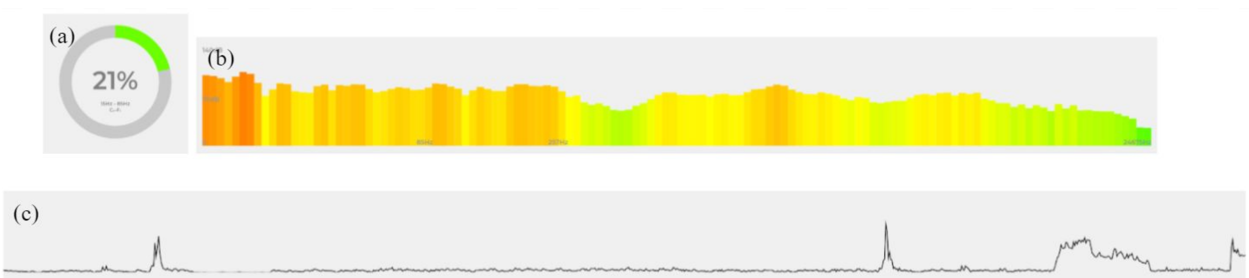

Fig. 5: *The visuals displayed in the dashboard application*: **(a)** one of the three dials representing total unsafe sound accumulation over a frequency range, **(b)** an equalizer representing finer-resolution instantaneous sound exposure over the entire frequency range, and **(c)** a line plot displaying overall sound intensity over time throughout the session.

There are three visuals on the dashboard (Fig. 5). The first visual is a dial which shows your sound exposure over a fixed range of frequencies as a percentage of the maximum sound exposure given by NIOSH standards as described in the methods, with the percentage represented by a colored bar circling the dial. The second is an equalizer that displays instantaneous sound exposure as a function of both frequency (shown along the x-axis in Hz), and intensity (shown along the y-axis in dB). The third is a line graph near the top of the screen that tracks overall intensity over time. When sounds increase in intensity, the colors change from green (relatively safe sound intensity/exposure) to orange (meaning approaching unsafe sound intensity/exposure), then finally red (unsafe sound intensity/exposure). Dials represent data in specific frequency bands at specific decibel ranges: the first dial shows frequencies below typical human speech (15Hz - 85Hz), the second shows frequencies are the band representing the fundamental frequencies of typical human speech (85Hz - 242Hz), and the third dial represents the higher frequencies (242Hz - 24675Hz). If the user exceeds their maximum dose (i.e., the percentage exceeds 100%), the original dial will turn red, an outer dial will appear and continue accumulating similarly, and an alert will pop up at the top of the page.

Once the user has ended the session by pressing the stop button, a message opens in the user's email client containing the noise dose as a percentage of the NIOSH-recommended standard, that is, its equivalent as an 8-hour-TWA.

Discussion:

Our goal with this project was to create a user-friendly, visually appealing, and accessible interface to track the cumulative level of sound exposure over a given period of music instruction. This dashboard can enable music educators to modify their teaching approach so that they can protect the hearing health of their students.

There are a number of limitations in the current version. As a web tool, the dashboard can be used with most personal devices that support standard web development protocols, therefore, variance in consumer hardware affects the readings returned by the dashboard. While existing literature suggests that mobile devices are approaching the point for industrial use in limited cases (Kardous and Shaw 2014), almost all personal mobile devices are not appropriately calibrated. For example, the positioning of the microphone on a laptop versus that of a phone might affect the decibel readings obtained, and the relative qualities of these microphones might affect the frequency readings. Additionally, one of the most significant limitations regarding the usage of the application is the lack of guidelines for positioning the host device to take accurate measurements. In similar experiments, the microphone was located approximately 10 feet above the instructor and automatically recorded the session (Powell and Chesky, 2017); however, special considerations will need to be made for consumer electronics. Under ideal conditions (i.e., a perfectly anechoic free field), sound follows the inverse square law rule: for every doubling of the distance from a sound's source, its intensity decreases by 6 dB. However, the conditions in which most music students rehearse are far from ideal. While the loss of sound intensity over distance in a setting such as a band hall may be limited, special considerations will need to be made for environments such as stadiums and performance halls (Zahorik and Kelly, 2007). Methods to measure sound intensity such as the use of two pressure microphones or an acoustic particle velocity transducer in conjunction with a pressure microphone are currently in use by acoustical professionals, with varying accuracies (Jacobsen and de Bree, 2005). However, many music programs, especially in publicly-funded schools, don't have access to these resources. Therefore, experimentation with an industry-standard dosimeter would help in developing a set of standards for the most effective use (e.g., distance from noise, the position of the device) of this application in a classroom, in a performance hall, and in other settings where music education takes place.

This application also provides many notable advantages over traditional dosimeters. Previous studies on music student sound exposure levels over a day used conventional noise dosimeters (Chesky, 2010; Washnik et al., 2016). However, these industry-standard noise dosimeters can cost thousands of dollars, which is an impractical cost for most publicly-funded school music programs. This dashboard application uses technology that most schools are already equipped with and displays its information in a format specifically designed with musicians. The display is visually appealing, enhancing the compliance of instructors. The unsafe exposures are broken down over time using the line plot and by frequency using the frequency-band dials, assisting the instructor to identify the cause of unsafe sound levels. One limitation of the separation of accumulated sound exposure into a limited set of frequency bands is that the NIOSH standards do not directly apply. The NIOSH standards referred to here were originally designed with DBleq A weighing rather than split by specific frequency ranges. Therefore, the currently reported thresholds for the application only use NIOSH standards as a guide and are not definitive. Also, although currently session information sent to instructors after the session is limited, the availability of historical information on sound exposure is critical for evaluating the effectiveness of interventions. Once released for general use, this dashboard will provide a more accessible, less financially-prohibitive tool for music educators to address the auditory health of their students. Additionally, the used unsafe exposure limits for the display are established from scientific findings and NIOSH standards for safe sound exposure (Eldred, Gannon, and Von Gierke, 1955; Burns and Robinson, 1970).

Conclusion:

Music induced hearing loss is difficult to address as many traditional interventions hinder a musician's ability to play and are viewed unfavorably (Chesky et al., 2009). Sound intensity during rehearsals has been measured so that musicians can adjust their practicing habits accordingly; however, the prevailing tool of choice, a noise dosimeter, is costly and is often used only by audiological experts. The dashboard is created using standard web development tools, enabling access to the dashboard on a variety of devices. Additionally, the dashboard provides information about both the time and frequency of intense sounds helping musicians identify the cause and address it. In summary, this dashboard system effectively provides a user-friendly, convenient, and visually appealing method that musicians and music instructors can use to track their rehearsals over time, and subtly change their behavior to limit the chance of long-term music induced hearing loss.

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