CDC Workplace Safety and Health

Noise Evaluation of Elementary and High School Music Classes and Indoor Marching Band Rehearsals – Alabama

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Centers for Disease Control and Prevention
NIOSH National Institute for Occupational Safety and Health

The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

Contents

Report

Abbreviations ... ii
Highlights of the NIOSH Health Hazard Evaluation ... iii
Summary ... v
Introduction ... 1
Assessment ... 1
Results and Discussion ... 2
Conclusions ... 12
Recommendations ... 12
References ... 14

Appendix A

Occupational Exposure Limits and Health Effects ... 16

Appendix B

Methods ... 19

Acknowledgments

Acknowledgments and Availability of Report ... 20

Abbreviations

AL	Action level
CFR	Code of Federal Regulations
dB	Decibel
dBA	Decibel, A-scale
HHE	Health hazard evaluation
Hz	Hertz
KHz	Kilohertz
NAICS	North American Industry Classification System
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
REL	Recommended exposure limit
SLM	Sound level meter
STS	Standard threshold shift
TWA	Time-weighted average

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received an employee request for a health hazard evaluation (HHE) at a high school in Alabama. The employee submitted the HHE request because of concerns about hearing loss from loud noise exposures during music classes and band rehearsals.

What NIOSH Did

- We evaluated the band director's noise exposures on November 1–2, 2011.
- We measured noise levels at different frequencies during marching band rehearsals.
- We calculated reverberation times for the band room and cafeteria. Reverberation time is the time it takes for a sound to go down 60 decibels from its original intensity.

What NIOSH Found

- The band director's full-shift noise exposure reached and exceeded occupational exposure limits.
- The highest noise exposure reached 110 decibels, A-scale. This level occurred in the band room during marching band rehearsal.
- The highest noise levels occurred at 125 hertz during marching band rehearsals.
- The noise levels were greater in the band room than in the cafeteria.
- Room reverberation times of the band room and cafeteria were within recommended ranges. These ranges have been recommended by other researchers.
- The band room was not a large enough rehearsal space for the number of students in the high school marching band.

What Managers Can Do

- Provide a practice space acoustically designed for musical performance. The space should also be sized appropriately for the number of students. Until such a space is available, continue to allow marching band rehearsals to occur in larger spaces that contain sound absorbent materials.
- Increase the distance between students playing musical instruments and the music instructor. This can be done by changing the set-up of the band room.
- Develop a hearing conservation program that includes annual audiometric testing and training. The band director and other music teachers should be enrolled in this program.

- Provide the band director with flat attenuation hearing protection, also known as musician ear plugs. These ear plugs should be used until an acoustically appropriate space is available for marching band rehearsals and noise monitoring results are documented at levels below occupational exposure limits.
- Teach music students, especially those involved in marching band, and their parents about noise-induced hearing loss. Include information on the symptoms of the condition and how to prevent hearing loss.

What Employees Can Do

- Wear musician ear plugs during marching band rehearsal. These ear plugs can also be worn during other music classes that are loud.
- Increase the distance between the band director and students playing instruments whenever possible.
- Hold marching band rehearsals outdoors when possible. When rehearsing indoors, use a larger space that contains absorbent materials to reduce noise levels until an appropriately designed space becomes available.
- Ask the marching band students to play softly when rehearsing in the band room.

Summary

On July 1, 2011, NIOSH received an HHE request from an employee at a high school in Alabama concerned about noise exposures, especially during marching band rehearsal. On November 1–2, 2011, NIOSH investigators evaluated the band director's exposures to noise during a typical work day in the band room and during marching band rehearsal in the cafeteria.

The band director's full-shift noise exposure exceeded the NIOSH REL, reached the OSHA AL, but did not exceed the OSHA PEL. Marching band rehearsal produced the highest noise exposures. The band director should wear musician earplugs until an area acoustically designed for musical performance is available. Administrators should educate music teachers, music students, and their parents on symptoms and ways to prevent NIHL.

We took personal noise exposure measurements on the band director during marching band rehearsal in the cafeteria on November 1, 2011 and during the entire school day on November 2, 2011. We also took area noise measurements and performed octave band frequency spectrum analyses. We measured the dimensions of the band room and cafeteria and calculated reverberation times for these areas.

The band director's full-shift TWA noise exposure reached the OSHA AL and exceeded the NIOSH REL of 85 dBA. It did not exceed the OSHA PEL. Marching band rehearsal produced the highest noise exposures, reaching 110 dBA. The TWA for marching band rehearsal in the band room was 2 dBA higher than rehearsal in the cafeteria. Octave band analysis during marching band rehearsal showed that the highest noise levels of 99 dB occurred at 125 Hz and were greater in the band room compared to the cafeteria. Room reverberation times ranged from 0.5 to 0.8 seconds in the band room and 0.7 to 1.0 seconds in the cafeteria. These reverberation times fell within ranges recommended in other studies.

Because of the high noise levels produced during marching band rehearsals, an area acoustically designed for musical performance should be used. Until such a space is available, marching band rehearsals should occur outside when possible or in larger indoor spaces, preferably areas that contain sound absorbent materials. The band director should use flat attenuation hearing protection (musician earplugs). Because noise exposures reached the OSHA AL and exceeded the NIOSH REL, a hearing conservation program is necessary. The band director and future music teachers should have yearly audiometric evaluations in accordance with the OSHA standard and NIOSH recommendations. Teachers, students, and their parents who are involved with music, especially marching band, should be educated on NIHL symptoms and prevention.

Keywords: NAICS 611110 (Elementary and Secondary Schools), noise, sound, music, band, band director, music teacher, hearing loss, NIHL, reverberation time

Introduction

On July 1, 2011, NIOSH received a request from an employee at a high school in Alabama to assess noise exposures, especially during high school marching band rehearsal. On November 1–2, 2011, NIOSH investigators evaluated the band director's noise exposures during a typical work day.

The band director taught all the music classes and rehearsals at this high school. The school day was split into 10 periods ranging from 30 minutes to 50 minutes. Music classes consisted of teaching fifth and sixth grade band and music arts and directing marching band rehearsal. Most classes consisted of approximately 15 to 30 students. However, marching band rehearsal consisted of approximately 90 students. It lasted about 50 minutes each day, and was reported to be the loudest class of the day. The marching band included woodwind, brass, and percussion instruments such as flutes, clarinets, trumpets, trombones, tubas, and drums. All classes took place in the band room, which was approximately 1,700 square feet. Marching band rehearsal took place in the band room until September 2011, when rehearsal was moved to the cafeteria because of its larger size (approximately 6,000 square feet).

In addition to regularly scheduled activities, the band director provided lessons after school prior to sectional and state auditions. These sessions contributed to his overall noise exposure.

Assessment

We held an opening meeting on November 1, 2011, with employer and employee representatives. On November 1–2, 2011, we interviewed the band director, observed classroom activities and marching band rehearsal, and measured noise. The band director wore a personal integrating noise dosimeter during marching band rehearsal in the cafeteria on November 1, 2011 and during his entire work shift on November 2, 2011. We also used two additional noise dosimeters to take full-shift area noise measurements on each side of the band room. We performed octave band frequency spectrum analysis (measurement of noise levels in different frequencies) in the cafeteria and in the band room using two integrating SLMs equipped with real-time frequency spectrum analyzers. The SLMs were mounted on tripods at a height of approximately 5 feet to represent the ear position of the standing band director. For octave band measurements in each room, we positioned one SLM at the back of the room near the percussion section and the second SLM at the front of the room near the band director. We also measured the dimensions of the band room and cafeteria and calculated reverberation times for each room. More information on occupational exposure limits and health effects for noise can be found in Appendix A. More information on sampling methodology for noise can be found in Appendix B.

Results and Discussion

The results of TWA noise exposure measurements during music classes and marching band rehearsal in the band room are listed in Table 1. The band director's full-shift TWA noise exposure in the band room did not exceed the OSHA PEL of 90 dBA, but reached the OSHA AL of 85 dBA and exceeded the NIOSH REL of 85 dBA, reaching a TWA of 90 dBA. Because the band director was the only employee who taught music classes and rehearsals, we took two additional area measurements with noise dosimeters. One dosimeter was placed on each side of the room near the storage racks. Neither area dosimeter noise measurement exceeded the OSHA AL or PEL. The area dosimeters were placed several feet further from the group of students (source of noise) compared to the distance the band director stood from the students. These results show that increasing the distance from the students decreased noise exposure. The noise measurements for the area dosimeter on the left side of the room were 3 dBA higher than on the right side; measurements on the left side showed TWA noise levels above the NIOSH REL. Most likely, this difference occurred because the area dosimeter on the left was a few feet closer to the students than the dosimeter on the right. Additionally, most of the larger percussion instruments were located on the left side of the room; the brass instruments on the right side of the room were directed toward the band director and away from the dosimeter when students were playing the instruments.

Table 1. Dosimeter noise exposure results from employee and area measurements in the band room*

Description	Duration (hours:minutes)	OSHA AL		OSHA PEL		NIOSH REL	
		TWA† (dBA)	Projected 8-hour TWA‡ (dBA)	TWA† (dBA)	Projected 8-hour TWA‡ (dBA)	TWA† (dBA)	Projected 8-hour TWA‡ (dBA)
Band director – personal	7:01	***86***	***85***	84	83	***90***	***90***
Band room area – left	6:42	80	79	78	77	***87***	***87***
Band room area – right	6:43	77	76	75	74	85	84
Occupational exposure limits			85		90		85

*Exposures at or exceeding noise exposure limits are in bold and italicized font.
†TWA noise exposures for the duration of the noise monitoring period
‡Projected 8-hour TWA noise exposures assume noise levels outside sampling period were below 80 dBA.

Results and Discussion (continued)

The band director's noise exposure time history profile during personal noise dosimeter measurements in the band room is shown in Figure 1. During fifth grade and sixth grade music and band classes and discovery rehearsal (an elementary music class), noise levels mostly ranged from 80 to 100 dBA and exceeded 100 dBA in a few instances. However, during high school marching band rehearsal, noise levels increased to 90 to 100 dBA and exceeded 100 dBA numerous times. Noise levels between music classes were below 85 dBA most of the time. Figure 2 shows the noise exposure time history profile for the 50 minutes of high school marching band practice in the band room.

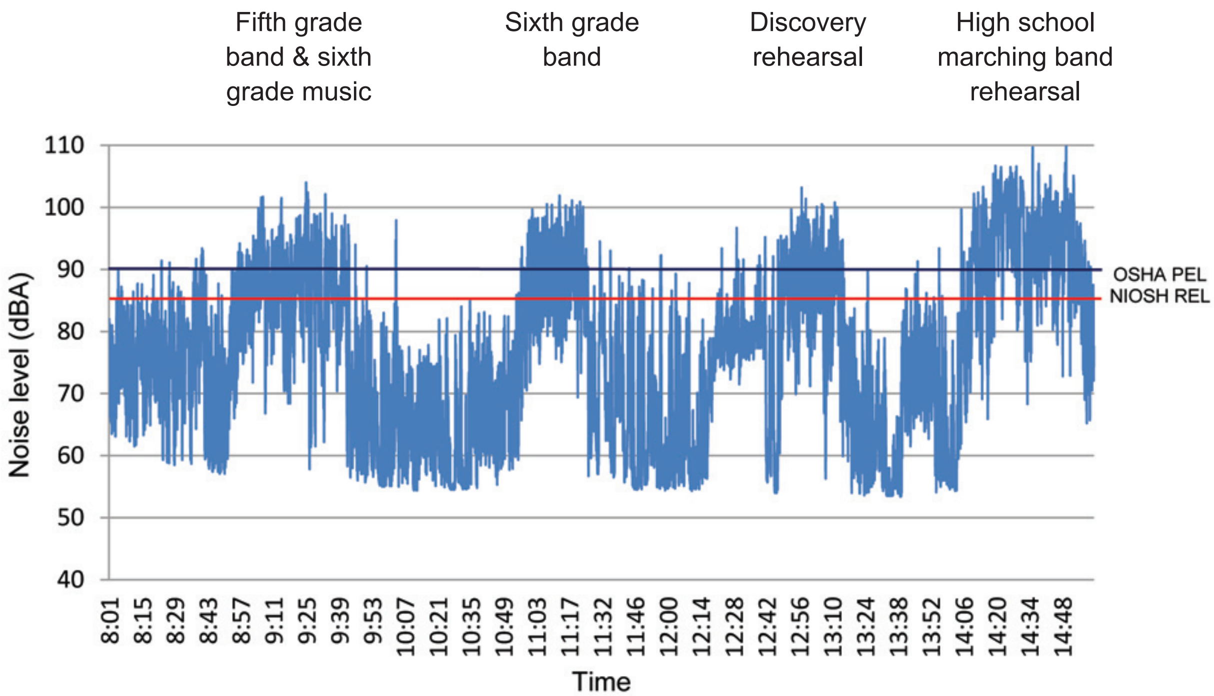

Figure 1. Noise exposure time history profile for the band director in the band room.

Table 2 compares the band director's TWA noise exposures during the loudest music classes on the basis of personal dosimeter results. Noise exposure during marching band rehearsal in the band room and in the cafeteria was substantially higher than during other music or band classes. Exposure during marching band rehearsal exceeded 90 dBA using NIOSH and OSHA measurement criteria and was the primary contributor to the band director's full-shift TWA noise exposure. If the average noise level during marching band rehearsal was reduced by 3 dBA, the band director's TWA exposure would have been less than 85 dBA on the basis of OSHA criteria.

Noise exposure during marching band rehearsal was 2 dBA higher in the band room compared to the cafeteria. The most likely reason for this difference is that the cafeteria was a much larger space with reflective surfaces located farther away from the band and band director.

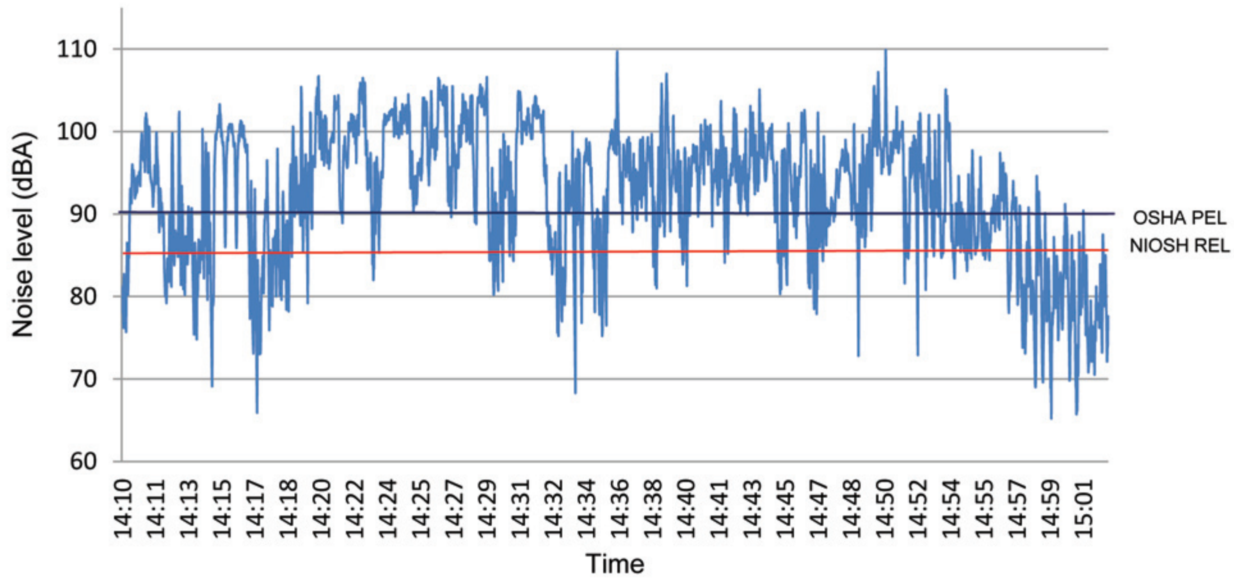

Figure 2. Noise exposure time history profile for the band director during high school marching band rehearsal in the band room.

Table 2. Band director's personal noise exposure measurement results during various music classes*

Description	Duration (hour:minutes)	OSHA AL TWA (dBA)	OSHA PEL TWA (dBA)	NIOSH REL TWA (dBA)
Marching band rehearsal in cafeteria	0:42	94	93	95
Marching band rehearsal in band room	0:51	96	95	97
Fifth grade band class	0:25	88	84	90
Sixth grade elementary music class	0:30	89	87	91
Sixth grade band class	0:30	91	89	92
Discovery rehearsal class	0:50	89	86	91

*TWA noise exposures for the duration of the monitoring period

The noise exposures measured in this evaluation were within the range reported in a previous study in which the 8-hour TWA noise exposures of 18 music teachers from 15 schools were found to range from 79 to 93 dBA [Behar et al. 2004]. In that study, band activities had the loudest continuous noise levels compared to singing, percussion, keyboard, or recorder activities. Band activities performed in the same classroom ranged from 86 to 98 dBA depending on the number of students in the class and whether they were learning, performing, or listening to examples shown by the teacher [Behar et al. 2004]. Another study of the noise exposures of high school band directors during rehearsals of jazz, percussion, or concert band ensembles reported TWA exposures that ranged from 85 to 93 dBA [Owens 2004]. The number of students ranged from 8 to 24 in the jazz ensembles and from 30 to 75 in the concert band. Maximum noise levels ranged from 101 to 115 dBA, which is similar to the maximum levels we measured. A research study of university music students found that brass instrument players had significantly higher mean average noise exposure levels (95.2 dBA) compared to woodwind players (90.4 dBA), percussion players (90.1 dBA), vocalists (88.4 dBA), or string players (87.0 dBA) [Phillips and Mace 2008]. This indicates that the proximity of the band director (and students) to specific groups of instruments can affect noise exposure levels. Our noise measurements only provided the noise exposure of the band director. Students are likely to have lower 8-hour TWA noise exposures because they spend less time in music classes and rehearsals at school. However, at a noise exposure level of 94 dBA the NIOSH REL is exceeded after 1 hour of exposure, and at a noise exposure level of 97 dBA the REL is exceeded after 30 minutes.

A study of audiometric test results from 104 music educators participating in summer music workshops found evidence that being a high school band director carried a slight risk for NIHL [Cutietta et al. 1994]. However, less than 20% of the high school band directors had NIHL, and the degree of loss was highly variable. Studies have also looked at potential hearing loss of student musicians. In one study, students had a high risk of excessive noise exposure from social and study-based music activities [Barlow 2010]. In another study, the prevalence of NIHL in 329 student musicians aged 18 to 25 years was 45% compared to 11.5% in the general population [Phillips et al. 2010]. Although these studies surveyed undergraduate student musicians, many high school student musicians pursue musical study in college, attend loud concerts or nightclubs, and listen to loud music on personal music listening devices or stereos. Music teachers may also be exposed to loud noise outside of the classroom from playing music, listening to music, or other hobbies. Therefore, it is important to educate teachers and students about the risk of hearing loss from excessive noise exposures and inform them about ways to protect and preserve hearing.

Octave Band Analysis

Octave band noise measurements provide information about the frequency distribution of noise. Because the energy from noise is usually widely distributed over many frequencies, the frequency range is broken into a smaller range of frequencies (called bandwidths), the most common being the octave band (defined as a frequency band where the upper band frequency is twice the lower band frequency). Octave band analysis allows for determination of the dominant noise frequencies and can be useful for identifying potential noise controls. For example, if low frequency noise is dominant (i.e., the highest octave band noise levels occur in frequencies of 500 Hz or less), noise is likely generated by vibration, and noise controls should focus on reducing or isolating the source of vibration. If high frequency noise is dominant (i.e., the highest octave band noise levels occur in frequencies of 2,000 Hz or greater), noise enclosures, barriers, or sound absorption systems are typically the most effective approach [Driscoll and Royster 2003].

One-third octave band noise frequency measurements were collected when students in marching band rehearsed in the cafeteria and the band room. The results are shown in Figure 3. Our measurements showed that the highest noise levels (99 dB) occurred in the band room at a frequency of 125 Hz and were greater than 90 dB across all the one-third octave bands; levels ranged from 100 Hz to 800 Hz in the band room and from 125 Hz to 200 Hz in the cafeteria. The highest noise level reached in the cafeteria was 96 dB (at 125 Hz). The dominant noise levels in the low frequencies were mostly from noise generated by percussion instruments.

Noise levels in the band room were also consistently higher than in the cafeteria for one-third octave band frequencies 125 Hz to 20,000 Hz. Interestingly, noise levels were higher in the cafeteria than in the band room across the frequencies from 12.5 Hz to 80 Hz. These differences are most likely because of the small size of the band room and the shorter wavelength of the higher frequency noise, which resulted in relatively more noise reverberation and higher noise levels for those frequencies in the band room. The large size of the cafeteria and the longer wavelength of very low frequency noise resulted in relatively more reverberation and higher noise levels for the low frequencies in the cafeteria.

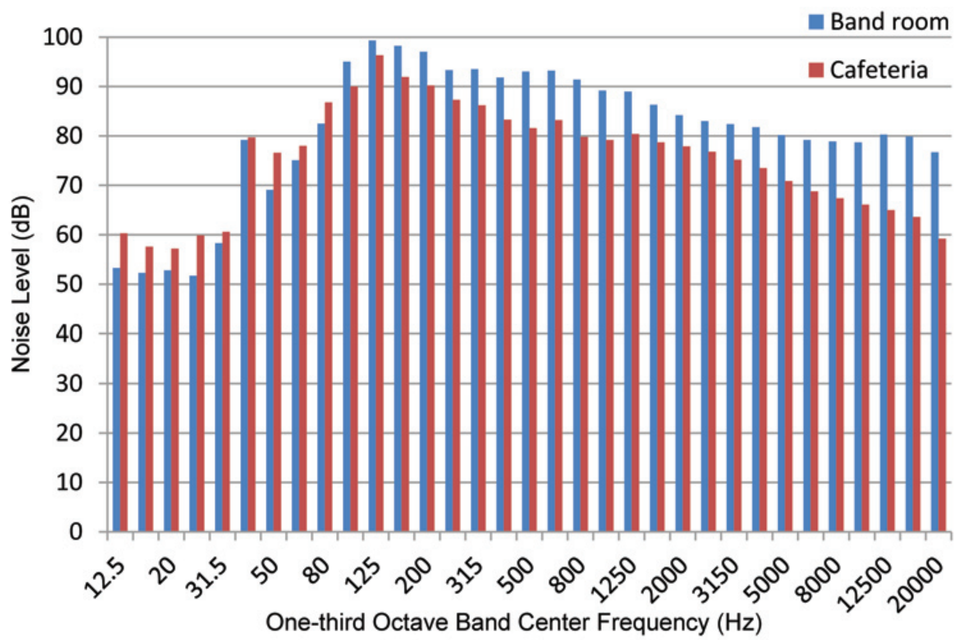

Figure 3. One-third octave band noise levels taken during marching band rehearsal in the band room and cafeteria over approximately 30 minutes.

Room Reverberation Time

Reverberation time is the time in seconds required for a steady-state sound to reach one millionth or a reduction of 60 dB of its original intensity after the sound source has stopped. Reverberation time is important because it indicates sound quality within a space for speech and music. It is based on the volume of the room, the surface area, and the sound absorbent coefficient of the materials covering the surface areas of the room.

Materials have varying abilities to absorb sound energy, also known as the sound absorbent coefficient. Materials do not absorb sound equally at all frequencies because of the wavelength differences between high and low frequencies. Most common building materials have been tested at a wide range of frequencies to determine their ability to absorb sound energy (Table 3).

We calculated reverberation time in the band room and the cafeteria (Table 4). For both areas, we did not take into account absorption by the occupants or furnishings, so our results indicate a worst-case scenario. The band room walls were constructed of painted concrete blocks. However, most of the back wall was covered with wooden storage shelves filled with instruments and with trophies on top. The side and front walls had some wooden shelves, wood or wood composite storage cabinets, metal filing cabinets, banners, and trophies. None of these materials had been tested for sound absorption coefficients. Therefore, we did two calculations, one using the painted concrete block's sound absorption coefficient and the other using the plywood paneling's sound absorption coefficient. This gave us a range of reverberation times to account for the untested materials along the walls.

Table 3. Sound absorption coefficients for common building materials*

	Frequency (Hz)						
	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	NRC†
Wall surface material:							
Concrete block (painted)	0.1	0.05	0.06	0.07	0.09	0.08	0.07
Plywood panel, 3/8 inch thick	0.28	0.22	0.17	0.09	0.1	0.11	0.15
Fabrics:							
Light velour, 10 oz/sq. yard‡ hung in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35	0.14
Medium velour, 14 oz/sq.yard draped to half area	0.07	0.31	0.49	0.75	0.7	0.6	0.56
Heavy velour, 18 oz/sq.yard draped to half area	0.14	0.35	0.55	0.72	0.7	0.65	0.58
Glass – Ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04	0.16
Sprayed-on acoustic material – 1" cellulose applied to metal lath, 2.5 pounds per cubic foot	0.47	0.9	1.1	1.03	1.05	1.03	1.02
Floor surface material:							
Vinyl tile or linoleum on concrete	0.02	0.03	0.03	0.03	0.03	0.02	0.03
Carpet, heavy on concrete	0.02	0.06	0.14	0.37	0.6	0.65	0.29
Carpet, heavy, on 40-ounce hair felt or foam rubber	0.08	0.24	0.57	0.69	0.71	0.73	0.55
Wood	0.15	0.11	0.1	0.07	0.06	0.07	0.06
Ceiling surface material:							
Acoustic tile – suspended§	0.5	0.7	0.6	0.7	0.7	0.5	0.64
Other:							
Opening, stage depending on furnishings			0.25 to 0.75				

*Source: Berger et al. 2003, Table 9.10
†NRC – noise reduction coefficient; average of coefficients between 250 Hz and 2000 Hz.
‡oz/sq. yard – ounce per square yard
§Source: Hall 2002, Table 15.1

During our evaluation, the food service area of the cafeteria was caged off so we could not take dimensional measurements. For our calculations of this area, we used the sound absorption coefficient of "openings: stage depending on furnishings." Our reverberation time estimates were based on calculated values; these results could differ from values obtained using equipment specifically designed to measure reverberation.

Table 4. Calculated reverberation time estimates (seconds) for the band room and cafeteria at various sound frequencies

	Room Volume (cubic feet)	Frequency (Hz) 125	250	500	1000	2000	4000	NRC*
Band room†	17,500	0.6	0.5	0.6	0.6	0.6	0.8	0.6
Band room‡		0.8	0.7	0.7	0.6	0.6	0.8	0.7
Cafeteria§	63,000	0.9	0.7	0.8	0.7	0.7	1.0	0.8

*NRC – noise reduction coefficient; average of coefficients between 250 Hz and 2000 Hz
†Calculated with plywood paneling sound absorption coefficient
‡Calculated with painted concrete block sound absorption coefficient
§Best estimate of room volume because separation of the service area prevented the dimensional measurement of the food service area

Recommended reverberation times for music rooms and halls depend on the type of music being performed and the size of the room. Recommended ranges are based on multiple tests in a variety of environments and on determining the reactions of different people at measured reverberation rates. Large rooms where music will be played, such as concert halls, are designed to have longer reverberation times (1.2 to 2.3 seconds) [Beranek 2006]. For rooms designed for music education where clear recognition of speech and changes in instrument nuances need to be heard, a shorter reverberation time is preferred [Hunecke 2011].

Examples of recommended reverberation rates are shown in Figure 4 [Hemond 1983] and Figure 5 [Hall 2002]. A series of case studies led researchers to recommend that band rooms have reverberation times of 0.6 to 0.8 seconds and a ceiling height of 16 to 24 feet [Paek et al. 2003]. Hemond recommended music room reverberation times of 1.0 to 1.2 seconds, whereas a classroom should have a 0.7-second reverberation time so speech can be heard clearly [Hemond 1983]. Sheaffer determined room reverberation times using a model and calculated that music practice rooms require 0.3 to 1 second of reverberation time depending on room volume [Sheaffer 2007]. Estimated reverberation times ranged from 0.5 to 0.8 seconds for the band room and from 0.7 to 1.0 second in the cafeteria we evaluated; these times are within the recommended ranges.

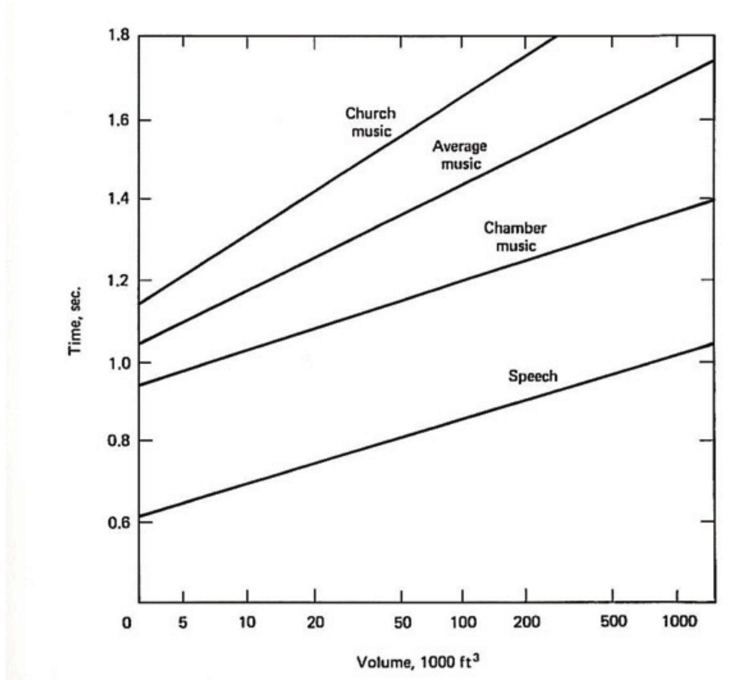

Figure 4. Recommended reverberation times [Hemond 1983].

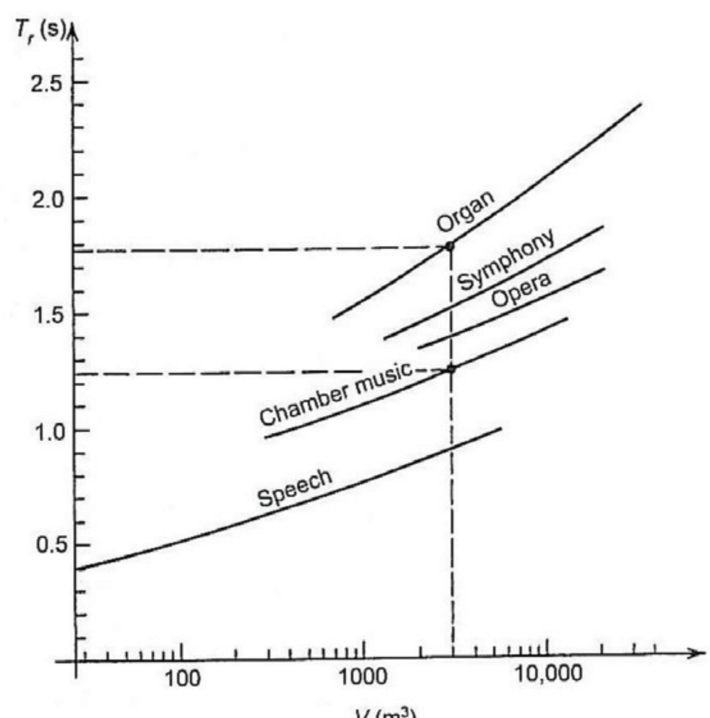

Figure 5. Recommended reverberation times [Hall 2002].

In a study at a music institute in Finland, researchers measured reverberation times before and after installing sound absorbent materials in six classrooms and a music hall and administered a questionnaire to music teachers before and after the installation. The authors concluded that reducing the room reverberation times did not significantly decrease the teachers' noise exposure levels; however, teachers perceived the quality of sound to have improved and reported higher job satisfaction [Toppila and Olkinuora 2010].

Installing sound absorbent materials in the band room might reduce reverberation time, but this alone may not significantly reduce the band director's noise exposure because of the relatively small size of the band room, the large number of students in the space, and the band director's proximity to the students during rehearsal. It may be possible to reduce the band director's noise exposure in the band room through a combination of approaches including increasing the distance of the band director from the students during rehearsal, installing sound absorbent material on the wall in the front of the classroom, and instructing students to play more quietly during rehearsal in the band room. Because the band room was designed as a classroom and not for musical performance purposes, and because it was not designed for the large number of band students in the room for rehearsals, these noise reduction approaches would likely be more effective in a properly sized practice space. Adequate room volume is necessary to allow sound energy to dissipate, and higher ceiling heights reduce the loudness of high energy brass and percussion instruments [Paek et al. 2003]. Additionally, the room size should be appropriate for the number of students practicing or performing in the space. It has been observed that some music instructors teach in rooms designed too small for the numbers of students actually present [Paek et al. 2003]. A guideline is that a high school band room for 60 to 75 musicians should have a floor space of 2,500 ft^2 and a ceiling height of 18 to 22 ft. [Wenger 2001].

Conclusions

Personal noise measurements taken during the band director's work day did not exceed the OSHA PEL but reached the OSHA AL of 85 dBA and exceeded the NIOSH REL, reaching a TWA of 90 dBA. His short-term exposure during high school marching band rehearsals exceeded 90 dBA. Noise exposures were highest during marching band rehearsal in the band room, but noise exposure levels during rehearsal in the cafeteria were also high. Calculated reverberation times in the band room were appropriate for teaching music classes, but the band room was not designed for use as a music rehearsal or performance space and was too small for the number of students in the marching band. Marching band rehearsal should take place outside, when possible, or in an area appropriately sized for the number of students and acoustically designed for musical rehearsals or performances. Until an acoustically designed and properly sized space can be constructed, marching band rehearsals should take place in alternative rehearsal spaces such as a larger room with sound absorbent materials or in the cafeteria. Because of the high noise levels during marching band rehearsal, a hearing conservation program is needed for the band director, including hearing protection, yearly audiometric evaluations, and training on noise exposures. Music students and their parents should also be educated on the potential hazards of loud music and ways to protect their hearing.

Recommendations

On the basis of our findings, we recommend the actions listed below to create a more healthful workplace. Our recommendations are based on the hierarchy of controls approach (refer to Appendix A: Occupational Exposure Limits and Health Effects). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate the hazard or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and/or personal protective equipment may be needed. Personal protective equipment is the least effective means for controlling employee exposures. Proper use of personal protective equipment requires a comprehensive program, and calls for a high level of employee involvement and commitment to be effective.

1. Hold marching band rehearsal outside or in a room appropriately sized for the number of band students and acoustically designed for musical rehearsals and

performances. Until an acoustically designed space can be constructed, marching band rehearsals should take place in alternative rehearsal spaces such as the cafeteria or a larger room with sound absorbent materials. If marching band rehearsal must take place in the band room, all students should be asked to play softly and focus on technique, and practice louder dynamics when rehearsals take place outside or in the larger rehearsal areas.

2. Stand away from high sound reflective surfaces, such as blackboards, when leading music classes and marching band rehearsal. If this is not possible, then cover such surfaces with sound absorbent material.

3. Move the students slightly farther back in the classroom to create more distance from the band director.

4. Provide the band director with flat attenuation "musician" ear plugs until an acoustically appropriate space is available and noise monitoring results are documented to be below occupational exposure limits. These hearing protectors attenuate sound levels evenly across frequencies to maintain sound quality. Administrators should provide training for the proper fit, use, and care of the ear plugs.

5. Establish a hearing conservation program to include the band director and future music teachers in accordance with the OSHA hearing conservation standard [29 CFR 1910.95] and NIOSH recommendations. This program should provide guidelines for reducing the risk of hearing loss, include annual audiometric testing and follow-up, and include training on using hearing protectors. Audiometric testing allows for the early detection of hearing loss and provides opportunities for interventions. More information on establishing a hearing conservation program can be found at http://www.osha.gov/dts/osta/otm/noise/hcp/index.html and http://www.osha.gov/Publications/osha3074.pdf.

6. Share information on the symptoms and prevention of NIHL with band students and their parents.

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NIHL is an irreversible condition that progresses with noise exposure. It is caused by damage to the nerve cells of the inner ear and, unlike some other types of hearing disorders, cannot be treated medically [Berger et al. 2003]. More than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009]. NIOSH estimates that workers exposed to an average daily noise level of 85 dBA over a 40-year working lifetime have an 8% excess risk of material hearing impairment. This excess risk increases to 25% for an average daily noise exposure of 90 dBA [NIOSH 1998]. NIOSH defines material hearing impairment as an average of the hearing threshold levels for both ears that exceeds 25 dB at frequencies of 1,000, 2,000, 3,000, and 4,000 Hz.

Although hearing ability commonly declines with age, exposure to excessive noise can increase the rate of hearing loss. In most cases, NIHL develops slowly from repeated exposure to noise over time, but the progression of hearing loss is typically the greatest during the first several years of noise exposure. NIHL can also result from short duration exposures to high noise levels or even from a single exposure to an impulse noise or a continuous noise, depending on the intensity of the noise and the individual's susceptibility to NIHL [Berger et al. 2003]. Noise-exposed workers can develop substantial NIHL before it is clearly recognized. Even mild hearing losses can impair one's ability to understand speech and hear many important sounds. In addition, some people with NIHL also develop tinnitus, a condition in which a person perceives hearing sound in one or both ears, but no external sound is present. Persons with tinnitus often describe hearing ringing, hissing, buzzing, whistling, clicking, or chirping like crickets. Tinnitus can be intermittent or continuous, and the perceived volume can range from soft to loud. Currently, no cure for tinnitus exists.

The preferred unit for reporting of noise measurements is the decibel, A-weighted (dBA). A-weighting is used because it approximates the "equal loudness perception characteristics of human hearing for pure tones relative to a reference of 40 dB at a frequency of 1,000 Hz" and is considered to provide a better estimation of hearing loss risk than using unweighted or other weighting measurements [Earshen 2003]. The dB unit is dimensionless, and it represents the logarithmic ratio of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, which is defined as the threshold of normal human hearing at a frequency of 1,000 Hz). Decibels are used because of the very large range of sound pressure levels audible to the human ear. Because the dB is logarithmic, an increase of 3 dB is a doubling of the sound energy, an increase of 10 dB is a tenfold increase, and an increase of 20 dB is a hundredfold increase in sound energy. Noise exposures expressed in decibels cannot be averaged by taking the arithmetic mean.

Workers exposed to noise should have baseline and yearly hearing tests to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location, such as an audiometric test booth where background noise does not interfere with accurate measurement of hearing thresholds. In workplace hearing conservation programs, hearing thresholds must be measured at 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz. Additionally, NIOSH recommends that 8,000 Hz should also be tested [NIOSH 1998]. For workers covered by the OSHA hearing conservation standard, changes from baseline hearing thresholds must be analyzed to determine if the change is substantial enough to meet OSHA criteria for an STS. OSHA defines an STS as a change in hearing threshold relative to the baseline hearing test of an average of 10 dB or more at 2,000, 3,000, and 4,000 Hz in either ear [29 CFR 1910.95]. If an STS occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA 300 Log of Injury and Illness [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines a significant threshold shift as an increase in the hearing threshold level of 15 dB or more, relative to the baseline audiogram, at any test frequency in either ear measured twice in succession [NIOSH 1998].

Hearing test results are often presented in an audiogram, which is a plot of an individual's hearing thresholds (y-axis) at each test frequency (x-axis). Hearing threshold levels are plotted such that fainter sounds are shown at the top of the y-axis, and more intense sounds are plotted below. Typical audiograms show hearing threshold levels from −10 or 0 dB to about 100 dB. Lower frequencies are plotted on the left side of the audiogram, and higher frequencies are plotted on the right. NIHL often manifests itself as a "notch" at 3,000, 4,000, or 6,000 Hz, depending on the frequency spectrum of the workplace noise and the anatomy of the individual's ear [ACOM 1989; Osguthorpe and Klein 2001; Suter 2002; Schlaucha and Carneya 2011]. A notch in an individual with normal hearing may indicate early onset of NIHL. For NIOSH HHEs, a notch is defined as the frequency where the hearing threshold level is preceded by an improvement of at least 10 dB at the previous test frequency and followed by an improvement of at least 5 dB at the next test frequency.

NIOSH has an REL for noise of 85 dBA, as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Using this criterion, an employee can be exposed to 88 dBA for no more than 4 hours, 91 dBA for 2 hours, 94 dBA for 1 hour, 97 dBA for 0.5 hours, etc. Exposure to impulsive noise should never exceed 140 dBA. For extended work shifts NIOSH adjusts the REL to 84.0 dBA for a 10-hour shift and 83.2 dBA for a 12-hour work shift. When noise exposures exceed the REL, NIOSH recommends the use of hearing protection and implementation of a hearing loss prevention program [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an AL of 85 dBA, both as 8-hour TWAs. OSHA uses a less conservative 5-dB exchange rate for calculating the PEL and AL. According to the OSHA criterion, an employee may be exposed to noise levels of 95 dBA for no more than 4 hours, 100 dBA for 2 hours, 105 dBA for 1 hour, 110 dBA for 0.5 hours, etc. Exposure to impulsive or impact noise must not exceed 140 dB peak noise level. OSHA does not adjust the PEL for extended work shifts. However, the AL is adjusted to 83.4 for a 10-hour work shift and 82.1 dBA for a 12-hour work shift. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [29 CFR 1910.95].

An employee's daily noise dose, on the basis of duration and intensity of noise exposure, can be calculated according to the formula: Dose = $100 \times (C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n)$, where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference exposure duration for which noise at that level becomes hazardous. A noise dose greater than 100% exceeds the noise exposure limit.

To calculate the noise dose using NIOSH criteria, the reference duration (T_n) for each time period must be calculated using the following formula: $T(min) = 480/2^{(L-85)/3}$, where L = the measured noise exposure level for each time period. To calculate noise dose using OSHA criteria, the reference duration (T_n) for each time period must be calculated using a slightly different formula: $T(min) = 480/2^{(L-90)/5}$,where L = the measured noise exposure level for each time period.

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Appendix B: Methods

A noise dosimeter (Larson Davis, Provo, Utah, Spark™ model 706RC) was attached to the wearer's belt, and a small remote microphone was fastened to the wearer's shirt at a point midway between the ear and outside of the shoulder. For area noise measurements, a dosimeter was placed on each side of the room near the storage racks. Windscreens provided by the dosimeter manufacturer were placed over the microphones to reduce or eliminate artifact noise, which can occur if objects bump against unprotected microphones. The dosimeters were set up to collect data using different settings to allow comparison of noise measurement results with the three different noise exposure limits referenced in this HHE, the OSHA PEL and AL and the NIOSH REL (Table B1). During noise dosimetry measurements, noise levels below the threshold level are not integrated by the dosimeters for accumulation of dose and calculation of TWA noise level.

The dosimeters averaged noise levels every second. At the end of the sampling period, the dosimeters were removed and paused to stop data collection. The noise measurement information stored in the dosimeters was downloaded to a computer for interpretation with Larson Davis Blaze® software. The dosimeters were calibrated before and after the measurement periods according to the manufacturer's instructions.

Table B1. Dosimeter settings

Parameters	OSHA AL	OSHA PEL	NIOSH REL
Response	Slow	Slow	Slow
Exchange rate	5	5	3
Criterion level	90	90	85
Threshold	80	90	80

Area noise levels and octave band noise frequency analysis (measurement of noise in different frequencies) were measured with System 824 SLM real-time frequency analyzers (Larson-Davis, Provo, Utah). The SLMs were equipped with 0.5-inch random incidence Type 1 microphones. Noise and octave band frequency spectrum measurements were collected at a sample rate of 51,200 times per second and averaged eight times per second. The SLMs were calibrated before and after the measurement periods according to the manufacturer's instructions. SLMs were mounted on a tripod at a height of approximately 5 feet.

Acknowledgments and Availability of Report

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found. HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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