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Noise Exposures of High School Marching Band Students

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NOISE EXPOSURE OF HIGH SCHOOL MARCHING BAND STUDENTS

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Abstract

Objective: The aim of this study is to examine research studies related to marching band noise (sound) exposure, to examine the sources and potentially hazardous effects of sound levels on hearing and describe best practices for prevention as reported in the literature.

Methods and Materials: A literature search was performed to identify original research articles describing noise exposure, noise-induced hearing loss and hearing conservation programs applicable to university and high school marching bands and related staff members. The databases Web-of-Science, Google Scholar, and PubMed were searched using a set of 15 key words in combination.

Results: A total of 14 studies were identified as relevant to the risk of hearing loss from marching band activities and strategies for the prevention of noise-induced hearing loss in this group.

Conclusion: The literature review revealed that marching band members are at risk of noise-induced hearing loss. Multiple studies reported that marching band members often exceeded 100% daily noise dose, according to NIOSH criterion (Edwards; Miller, Stewart, & Lehman; Walter). Additional research suggests that hearing loss conservation programs are effective in these populations, as after receiving education, earplug usage increased by 54% (Auchter & Le Prell) and concern for NIHL increased by 39.5% (Seever et al.). The literature supports the need for further research in the noise exposures of young adults and the implementation of hearing conservation programs targeting students and staff that participate in marching bands.

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Introduction

High school marching band participants may be at risk of noise-induced hearing loss (NIHL). Research has shown that musicians have shown evidence of NIHL caused by excessive sound exposure (Emmerich, Rudel, and Richter, 2008; Jansen, Helleman, Dreschler, & de Laat, 2009; Halevi-Katz, Yaakobi, and Putter-Katz, 2015). Young musicians in marching bands are exposed to hazardous sound levels during rehearsals (Walter, 2011). About 12.5% (approximately 5.2 million) of children in the United States, ages 6-19, are estimated to have a noise-induced threshold shift in either one or both ears (Niskar et al., 2001). Despite the large number of youths showing signs of irreversible cochlear damage, the number of adolescents that wear hearing protection devices is low (Edwards, 2019). One approach to address these concerns is the implementation of educational hearing conservation programs for students high school marching bands (Auchter & Le Prell, 2014). The purpose of this literature review is to summarize the current prevalence of NIHL in young musicians, determine sound exposures of marching band members, and outline the best practices for effective hearing conservation programs.

Review of the Literature

The present literature review investigates the physiological effects and early detection of noise-induced hearing loss (NIHL). This condition has been documented in people who work in occupational settings with excessive sound levels, including professional musicians.

Noise-Induced Hearing Loss

Auditory Damage

Noise-induced hearing loss can occur after years of hazardous sound exposures or after a single/multiple high-level impulse noise exposure. NIHL is characterized as a bilateral or unilateral sensorineural hearing loss, due to auditory damage to the inner ear (Henderson, Bielefeld, Hu, Nicotera, 2007, p. 217). The cochlea is most vulnerable at the basal end, which is responsible for high frequency sound transduction. Although most structures within the cochlea may be damaged by hazardous levels of noise, the outer hair cells are at the greatest risk of damage (Henderson, Bielefeld, Hu, Nicotera, 2007, p. 217). The stereocilia of the outer hair cells are responsible for transducing mechanical energy to electrochemical signals that are sent to the brain (Hudspeth and Jacobs, 1979). High noise exposure can damage the connections between these stereocilia (Mulroy and Curley, 1982). Permanent auditory damage can also occur to the inner hair cells (Zwislocki, 1974) and the capillaries (Wang, Hirose, and Liberman (2002). NIHL not only causes a permanent reduction in hearing ability but can also result in tinnitus and hyperacusis (Laitinen & Poulsen, 2008).

Audiometric Characteristics of NIHL

Audiometric testing can determine the presence of hearing loss. Early noise-induced hearing loss may present as a notched configuration on an audiogram. The presence or absence of a “notch” has been defined differently by various researchers. In general, a “noise notch” is typically defined as a decrease in hearing thresholds at 3 to 6 kHz when compared to lower frequencies and exhibits recovery in hearing thresholds at 8

kHz. Table 1 summarizes the various approaches that have been used in the peer-reviewed literature.

Table 1

Definitions of Audiometric Notch Configurations used in Peer-Reviewed Literature

Author(s)	Audiometric Notch Configuration Definition
Agrawal, Platz, & Niparko (2008)	A high frequency pure tone average at 3, 4, and 6 kHz of 25 dBHL or more.
Hsu, Wu, Chang, Lee, & coles (2013); Wilson & McArdle (2013);	The difference between threshold at the notch frequency (3, 4 or 6 kHz) and the threshold at 2 and 8 kHz are both greater than or equal to 10 dBHL.
Coles, Lutman, & Buffin (2000)	A decline in hearing sensitivity of at least 10 dB at 3, 4, or 6 kHz when compared to those at 1 or 2 kHz and 6 or 8 kHz
Bauch (1981); Chung (1980); Loch (1943)	A 15-dB decline in hearing sensitivity at both an octave above and below the maximum hearing loss.
Lees, Lees, Roberts, & Wald (1985)	A 10 dBHL or greater "notch" at 6 kHz.
McBride & Williams (2001)	Narrow or V-shaped notch: • Only one frequency in the depth of the notch and the depth is at least 15 dB. Wide or U-shaped notch: • More than one frequency in the depth of the notch, depth of 20 dB, thresholds better by at least 10 dB at the high frequency end."
Niskar, Kieszak, Esteban, Rubin, Holmes, & Brody. (2001)	In at least one ear: • Hearing sensitivity at .5 and 1 kHz that are greater than or equal to 15 dBHL, and • The worst hearing threshold at 3, 4, or 6 kHz is 15 dB or poorer than the worst threshold at .5 and 1 kHz, and • The hearing threshold at 8 kHz that are 10 dB or better than the poorest threshold value for 3, 4, or 6 kHz.
Phillips & Mace (2008)	A decreased hearing threshold of at least 10 dB between 1, 2, or 3 kHz when compared to 4 kHz, or from 1, 2, 3, or 4 to 6 kHz, with a 5 dB recovery at 8 kHz.
Phillips, Henrich & Mace (2010)	A 15 dB or more difference when comparing the thresholds at 4, or 6 kHz to 2 and 8 kHz.
Renick, Crawford, and Wilkins (2009)	A notch occurs from 3 kHz to 6 kHz. There must be at least a 15-dB difference between the hearing thresholds measured at 0.5 kHz and 1 kHz and measurements taken at 3 kHz to 6 kHz.

Noise-Induced Hearing Loss in Professional Musicians

Emmerich, Rudel, and Richter (2008) investigated the prevalence of noise-induced hearing loss in both student musicians and professional musicians. The participants included 110 students at a music training academy, ages 11-19 years. There were also 109 professional musicians in this study, and they were categorized into four age groups, 30-39 years, 40-49 years, 50-59 years, and 60 years and older. The professional musicians were employed by German orchestra groups. Sound exposure was assessed by measuring area sound levels and noise dosimetry. Demographic information was obtained by having participants complete a questionnaire, and auditory status was assessed with pure-tone audiometry (0.25 to 16 kHz) and distortion product otoacoustic emission (DPOAE) testing (2-6 kHz). Sound level measurements were recorded by an integrating-averaging sound level meter (type 118, class 1) during a rehearsal of a professional orchestra in 12 different positions, including positions within the brass section, in front of the drums, between the violins and contrabasses, and in front of the French horns and piccolos. Noise dosimetry was conducted by having musicians wear a noise dosimeter for a maximum of 4 hours during rehearsal sessions [sampling according to German Law]. The questionnaire was completed via an interview format, and questions included age, duration of years spent practicing music, instruments played, duration of training time per week, use of hearing protection devices, prevalence of tinnitus, and recreational noise exposure. The hearing testing and DPOAE measurement were conducted at least 24 hours after a performance or practice session. Area sound level measurements averaged 92.9 dBA for the entire orchestra. The highest sound levels were measured in the brass sections, reaching “peak levels” of 100 dBA or more. The

authors reported sound “peaks” exceeded 109 dBA in frequency ranges up to 6.3 kHz in front of the piccolos. Noise dosimetry exceeded the German law limit of 85 dBA eight-hour time-weighted average or 100% noise doses for the musicians playing the piccolo, trombone, violin, French horn, bassoon, clarinet and contrabass and ranged from 111% to 172%. Audiometric testing showed a “permanent threshold shift” in the mid-frequency range, or speech frequency range (2-6 kHz), larger than “15 dB SPL” in over 50% of professional musicians. A greater hearing loss was more commonly found in the 60 years and older age group. When the music students were tested, 12 students were found to have a permeant threshold shift of “15 dB(A)”. [Note: this article did not report hearing thresholds in dBHL as would be typical, so the actual measurement technique is unknown, and results were reported as PTS, even though a baseline test was not available for comparison]. Distortion product otoacoustic emissions generally revealed reduced amplitude with age and were poorest for brass musicians. The questionnaire revealed that 50% of professional musicians reported tinnitus, and 63% of musicians had never worn hearing protection. These results indicate that music in orchestral performances is reaching hazardous levels and negatively affecting hearing ability in student and professional musicians. Based off the results of this study, Emmerich, Rudel, and Richter (2008) recommend that musicians should be allowed noise-free periods between musical performances, and hearing protection should be implemented early in music training programs. Emmerich, Rudel, and Richter insist that NIHL must be recognized as an occupational disease in order to protect hearing function in musicians.

Jansen, Helleman, Dreschler, & de Laat (2009) studied the prevalence of NIHL and related conditions in musicians. The researchers distributed surveys about prevalence

of hearing-related problems and attitudes towards noise to 241 musicians, ages 23 to 64 years old, in professional orchestras. Audiological testing was conducted on the participants, including testing the audiometric thresholds, speech perception, and otoacoustic emissions. The number of samples that were found to have normal hearing sensitivity was 48% (n=230) of ears. Normal hearing was defined as hearing thresholds better than or equal to 15db HL at 0.5, 1, 2, 3, 4, 6, 8, kHz. Although the majority of samples were found to have normal hearing, 11% (n=53) of ears were found to demonstrate a moderate notched configuration on the audiogram, which was defined as a maximum threshold level at 3, 4, k kHz that is between 15 and 20 dB poorer than thresholds obtained at 0.5, 1 and 2 kHz. A profound notch was found in 9% (n=41) of ears, which was defined as a maximum threshold level at least 25 dB poorer at 3, 4, and 6 kHz than the other tested frequencies, which include 0.5, 1, and 2 kHz. The researchers did find a hearing loss in a number of participants, as 13% (n=64) of ears were found to have a "sloping" high frequency loss and 12% (n=57) of ears were found to have a "flat" loss across all frequencies. The questionnaire disclosed that 52% (n=152) of participants wore hearing protection during rehearsals and 29% (n=70) wore hearing protection during concerts. The participants also reported conditions related to NIHL, with 79% (n=190) experiencing hyperacusis, 7% (n=17) experiencing diplacusis, and 51% (n=121) experiencing tinnitus. Based on the reported health issues and prevalence of notched audiograms, the researchers conclude that musicians are susceptible to hearing damage from high sound levels.

Halevi-Katz, Yaakobi, and Putter-Katz (2015) investigated the prevalence of variables related to hearing loss status in professional pop/rock/jazz musicians. The study

consisted of 44 professional musicians, aged 20-64 years. The researchers distributed a questionnaire (Pop/Rock/Jazz Musician's Questionnaire (PRJMQ) which included questions regarding general demographics and health information, use of hearing protection devices, understanding sound levels produced by instruments and understanding loudness on a decibel scale. The questionnaire contained both yes/no questions and scaled questions. Audiometric testing was conducted on 41 of the 44 participants to determine hearing thresholds from 1-8 kHz using a portable audiometer. The average weekly exposure to music was 23.55 hours. Tinnitus was reported in 31.8% of the participants. Audiometric testing revealed that both the left and right ears of the participants were shown to have an average decrease in hearing thresholds of 2.8-5 dB at 3-6 kHz from hearing thresholds obtained at 1, 2, 8 kHz after adjustment for age and gender. The 10 drummers in this study were found to have higher hearing thresholds (M = 10.33, S.D. = 11.48) than non-drummers (M = 2.16, S.D. = 8.15). This study has shown that professional musicians experience symptoms and evidence of NIHL. The extent of these symptoms can be predicted by reported exposure to music. Halevi-Katz, Yaakobi, and Putter-Katz (2015) recognize that research with a larger sample, particularly a larger sample of drummers, would be more beneficial in determining the prevalence of NIHL in musicians.

Auditory Damage Risk Criteria

Since the extent of auditory damage is affected by the intensity and duration of the sound, laws and guidelines have been implemented to protect workers' hearing. Noise dosimeters are used to quantify noise/sound exposures and determine if they are safe or hazardous to the auditory system. Noise dosimeters can measure sound levels and

durations to determine if noise exposure reaches hazardous levels. The noise dosimeters must be calibrated to ensure that sound level readings are accurate. Noise dosimeters are typically worn near ear level (within a 2-foot radius of the head) to determine personal sound exposure data. This data is then used to determine a person's daily time-weighted average and noise dose.

Occupational Safety and Health Administration (OSHA)

The Occupational Safety and Health Administration (OSHA) is a government agency that creates legal limits on sound exposure in the workplace. OSHA permits workers to be exposed to 90 dBA for eight hours a day (OSHA, 1983). This is called the "permissible exposure level" or PEL. As the level of the noise increases by 5 dB, the permissible exposure time is halved (exchange rate). For example, a worker exposed at 95 dBA would have an equivalent exposure at 4 hours, and a worker exposed at 100 dBA would have an equivalent exposure at 2 hours. For workers exposed at 85 dBA for eight hours a day (action level - AL), they must be enrolled in a hearing conservation program. Hearing conservation programs require that employer's measure noise levels, implement noise controls when feasible, and provide hearing protection, audiometric testing and training to the workers that are over-exposed to noise.

National Institute of Occupational Safety and Health (NIOSH)

The National Institute for Occupational Safety and Health (NIOSH) has a recommended exposure level (REL) of 85 dBA and integrates the exposure time using a 3-dB exchange rate (ER), rather than a 5 dB ER (NIOSH, 1998). When determining sound exposure, a noise dosimeter is attached to the participant who is being measured.

The ideal location for the noise dosimeter is placing the microphone on the person's more exposed shoulder, and the microphone should be oriented parallel to the plane of the shoulder (NIOSH, 1998). NIOSH recommends a noise dosimeter that measures from 80 to 140 dBA.

Even with the noise exposure regulations set by OSHA and the noise exposure recommendations from NIOSH, there will still be a number of people who develop a material hearing loss due to occupational noise exposure. A material hearing impairment is defined as when a person's average hearing threshold level for both ears exceeds 25 dB at the frequencies of 1000, 2000, 3000, and 4000 Hz. Prince et al. (1997) developed estimates of the percentage of workers that are still at risk. These estimates are summarized in Table 2.

Table 2

Estimated percentage of people at risk of material hearing impairment at age 60 after 40 years of exposure to noise from Prince et al. (1997).

	Exposure Level (dBA)	Percentage at Risk
OSHA PEL	90	25
OSHA AL	85	8
NIOSH REL	80	1

World Health Organization (WHO)

The World Health Organization (WHO) recommends a sound level of 75 dBA or less for 8 hours a day (Berglund, 1999). The WHO does not regulate noise levels but does

produce guidelines for countries to reference. Most recently, the WHO has published a monograph on recommended noise exposures for children (WHO, 2018) and these outcomes were subsequently peer-reviewed in a publication by Roberts and Neitzel (2019). In this recent publication, the WHO recommends a maximum exposure of 80 dBA for 8 hours a day for children. The WHO (2018) recognizes that this value may need to be reduced to 75 dBA if there is a large percentage of children still at risk of developing hearing loss at 80 dBA. Roberts and Neitzel (2019) examined the factors affecting hearing loss and determined that an average recreational noise exposure level of 80 dBA for 8 hours day will protect 99% of children from developing more than a 2.1 dB hearing loss at 4kHz during childhood. The 80 dBA for 8 hours a day is equivalent to 75 dBA for 24 hours.

Methods

The aim of this study is to examine and summarize research studies related to marching band noise (sound) exposure, to examine the sources and potentially hazardous effects of sound levels on hearing and describe best practices for prevention as reported in the literature.

Study Selection

A systematic literature search was performed using three databases, PubMed, Web of Science, and Google Scholar. Only English articles were reviewed. Searches were performed with combinations of the following key words: marching band, student musician, hearing protection, hearing protection device, noise control, hearing loss, noise-induced hearing loss, music-induced hearing loss, sound level, sound exposure,

noise exposure, noise dosage, hearing conservation, hearing loss prevention, and hearing loss prevention program. Studies related to school-based marching bands, the measurement of noise exposure, and the usage of hearing protection were included in this review. Studies related to orchestral musicians were excluded from this review study. The relevant studies are then summarized with regard to outcomes and relevancy towards hearing loss prevention in students participating in school-based marching band activities.

Results

A total of 24 articles were found using these search terms. The literature search found 14 of these articles specifically related to noise exposures of high school and university marching bands. The designs and major findings of these studies are summarized in Table 5.

Prevalence of Noise-Induced Hearing Loss

Three studies were found to relate directly to detecting early NIHL in student musicians. Phillips, Henrich, & Mace (2010) investigated the prevalence of NIHL in a group of 329 collegiate student musicians. The participants completed a survey on their daily exposure to sound, including questions regarding type of instrument played, number of hours spent practicing their instrument, and ensemble participation. Pure-tone thresholds were obtained to determine the prevalence of audiometric notches suggestive of NIHL. The results of this study concluded that 45% of participants were found to have a notch in at least one ear at 4 or 6 kHz. Of these, 11.5% of participants showed a bilateral audiometric notch. Although these studies suggest that student musicians are

demonstrating signs of early NIHL, there are certain factors that may affect the results, such as genetic predisposition.

Lüders et al. (2014) similarly focuses on the use of audiometric testing as a diagnostic tool for NIHL. Both conventional and extended high-frequency audiometry were performed on 84 total participants, 42 being music majors and 42 being non-music majors. There was a significant difference between the two groups at .25 kHz in both ears and .5 kHz in the left ear. The mean thresholds in the musician group were lower at 2, 3, 4, 6, 8, 9, 10 and 11.2 kHz in the left ear. Although the presentation of NIHL occurs over time, this study suggest that extended high-frequency audiometric testing may be a reliable method of detecting early signs of NIHL. In order to prevent NIHL in vulnerable populations, the prevalence of the condition and the early signs of hearing loss must be studied.

Researchers Hatheway and Chesky (2013) explored the prevalence of NIHL hearing loss through subjective measures, rather than quantifiable measures used in Phillips, Henrich, & Mace (2010). This study involved a total of 246 collegiate marching band students. The participants completed a survey on habits related to participation in marching band, attitudes, and self-reported levels of pain. While the survey revealed that the demands of marching band participation affects all aspects of health, participants frequently reported symptoms related to NIHL, including ear pain, decrease in hearing quality, and ringing of the ears known as tinnitus.

Noise Dosimetry and Sound Measurements

A total of eight articles were found to relate to noise dosimetry and measuring the sound exposure of student musicians at both the high school and collegiate levels. Three of these studies recorded the daily noise exposure of collegiate musicians. Barlow found that music students participated in rehearsals were noted to have a mean duration of 2 hours and 13 minutes. The sound levels recorded reached a mean of 98 dB LAEQ. Barlow further explored noise exposure outside of the classroom by surveying 100 undergraduate music students. The results of this survey suggest that music students participate in noisy leisure activities, as 94% reported attending a concert at least once a month and 38% reported attending a nightclub once a week. Washnik, Phillips, & Teglas (2016) used noise dosimeters to record 2 full day noise exposures for 57 music students. The amount of exposure was calculated with NIOSH criteria. The results of this study found that 28 of the participants exceeded 100% daily noise dose on at least one of the two days, and eleven students exceeded 100% daily noise dose for both days. Smith, Neilsen, and Grimshaw (2017) similarly documented the daily noise exposure of music students. A total of 47 music students wore noise dosimeters for two days while participating in music-related activities. The researchers found that several musicians exceeded NIOSH daily dose criteria. The results of this study are summarized in Table 3. Overall, these studies conclude that further research is needed on noise exposures and the implementation of hearing conservation strategies to protect student musicians from potential NIHL.

Table 3

The percentage of students who exceeded NIOSH daily dose recommendations during full day noise measurements

	Percentage of students exceeding NIOSH REL	
Type of Musician	Day One	Day Two
Woodwind	86%	42%
Brass	56%	89%
Strings	10%	0%
Percussion	50%	50%
Voice	50%	17%
Piano	33%	33%

A total of 4 studies were found relating to investigating noise exposures in collegiate marching band students and related professionals. A study by Miller, Stewart, & Lehman (2007) uses a survey and noise dosimeters to evaluate the habits and knowledge of students related to hearing conservation and the amount of noise that collegiate musicians are exposed to. Two noise dosimeters were used to capture sound during practices and a sporting event. The daily dose values ranged from 200% to 700% when compared to OSHA criteria and 1600% to 17,000% when compared to NIOSH criteria. Despite these findings, the survey revealed that 21 out of the 27 participants surveyed reported never using hearing protection devices. Jin, Nelson, Schlauch, & Carney (2013) measured sound levels at several locations during an indoor marching band practice session with a sound level meter. The highest levels were recorded at the percussion section, with sound levels between 110-120 dBC, the cymbal section, with

sound levels between 105-110 dBC, and the brass section, with sound levels between 106-109 dBC. These results from Miller et al. and Jin et al. suggest that collegiate marching band members are at risk of NIHL, as sound levels have the potential to reach dangerous levels.

Russell and Yamaguchi (2018) investigated the noise exposure of athletic trainers working directly with a collegiate marching band. Eight athletic trainers wore noise dosimeters during outdoor rehearsals, and outdoor performances during sporting events. The athletic trainers typically stood directly in front or directly behind the band. The daily noise dose was calculated according to NIOSH criteria. When measuring the noise exposure of outdoor rehearsals, 25 out of 65 observations (38%) were found to exceed 100% daily dose recommendations. The mean LAeq reported for outdoor rehearsals was 84 dBA. For performances, 34 out of 38 observations (89%) were found to exceed 100% daily noise dose recommendations. The mean LAeq reported for outdoor performances was 91 dBA. Although this study used athletic trainers as the sample populations, the implications of this study suggest that both marching band members and professionals in close proximity to the marching band may be at risk of NIHL.

Edwards (2019) examined noise exposure in marching band members and the members' perceptions of hearing protection and hearing loss. Two students, one saxophone player and one trombone player, wore noise dosimeters that were programmed to use the NIOSH sampling protocol and two different types of hearing protection, CVS Health foam earplugs and Etymotic Research ER-20XS earplugs, during nine basketball games. The noise dosimeters collected data from when the participants entered the basketball arena to the moment, they exited the arena. Additionally, the participants

completed a survey on their experience wearing hearing protection. The average equivalent continuous sound levels across all basketball games for the season was 104.4 dBA for the trombone player and 107.7 dBA for the saxophone player. The average daily dose values were 4,033% for the trombone player and 8,444% for the saxophone player. The trombonist, who wore ER-20XS earplugs during every basketball game, reported difficulties communicating with other band members and difficulties detecting intonation. While wearing the foam ear plugs, the trombonist subjectively reported difficulties communicating with other band members and inadequate fit. Overall, the noise dosimeter measurements indicate that the pep band participants are exceeding their 100% daily dose.

While the previous studies explored noise exposure for musicians in college, the literature search did result in one study relating to noise exposures at the high school level. Walter (2011) investigated the daily noise exposure of high school students by measuring sound levels during a summer marching band camp. The marching band was comprised of 100 student members. Sixteen participants, ages 14 to 18 years, wore doseBadge noise dosimeters that were pinned to clothing or sun visors near the ear. The sound-dose values were determined according to NIOSH 1998 recommendations. Participants were chosen from every section of the marching band. This group included one drum major, one color guard member, two piccolo players, one clarinet player, two alto saxophone players, one mellophone, two trumpet players, one trombone player, one baritone player, one sousaphone player, one snare drummer, one tenor drummer, and one bass drummer. The data was collected over two days, for a total of 20 total hours measured. The measurements were taken during breaks, during outside rehearsals with all

band members, and during indoor sectional rehearsals. On both rehearsal days, fifteen subjects (N=16) reached 100% of their daily dose. The snare drummer recorded the highest mean decibel level, reaching 102.7 dBA on day one and 99 dBA on day two. The color guard member recorded the lowest sound levels with values of 80.5 dBA and 79.9 dBA. Table 4 summarizes the mean decibel values and NIOSH daily dosage values for both day one and day two of the study. Although the participants in this study exceeded NIOSH recommended exposures, Walter (2011) recognizes that more research is needed on the external factors that may have affected the noise dosimetry measurements, such as the acoustic environment, type of instrument, and size of the group.

Table 4

Mean sound levels and daily dose percentages for marching band members during day one and day two practice sessions as reported in Walter (2011) with dose based on NIOSH REL criteria.

	Day One Measurements		Day Two Measurements	
Participant	Mean dBA	Dose Percentage (%)	Mean dBA	Dose Percentage (%)
Drum Major	98.4	2,722	91.5	519
Guard	80.5	44	79.9	36
Piccolo 1	93.8	941	92.1	596
Piccolo	93.1	800	93.8	883
Clarinet	94.3	1,000	92.0	583
Alto Sax 1	93.8	941	93.4	805
Alto Sax 2	93.2	819	93.7	863
Mellophone	96.5	1,755	95.8	1,402
Trumpet 1	95.9	1,528	92.2	610
Trumpet 2	93.4	857	92.1	596
Trombone	95.6	1,426	94.0	925
Baritone	95.5	1,393	94.1	895
Sousaphone	93.6	898	91.3	496
Snare Drum	102.7	6,158	99.0	2,916
Tenor Drum	99.5	1,459	97.5	2,077
Bass Drum	95.7	1,459	93.2	796

Attitudes Towards Noise

Chesky, Pair, Lanford, & Yoshumura (2009) investigated college students' attitudes towards noise. A modified version of the YANS was distributed to a total of 467 students, both music majors and non-music majors. The YANS consists of 12 statements related to noise in leisure activities and the effects of environment sound. The participants are instructed to respond on a five-point scale that ranges from "completely agree" to "completely disagree." A higher score indicates more positive attitudes towards hearing conservation. Overall, researchers found that music majors have healthy views towards sound than non-music majors. The music students scored higher on each of the questions, indicating more awareness of the dangerous of excessive noise.

Interventions to Prevent NIHL

Auchter & Le Prell (2014) investigated the efficacy of hearing loss prevention programs for high school students. The 60 participants were gathered from two different schools. The training procedures consisted of a discussion about hearing loss and an informational DVD presentation from the *Adopt-a-Band* program on how the auditory system works and how excessive sound levels can damage the ear. The students completed a pre- and postsurvey on their experience with the program, and a third survey at the end of the season recorded long-term effects. Earplugs were distributed to all of the participants. A total of 54% of participants increased their usage of earplugs from survey one to survey three. Comfort and sound quality were noted as being the main reasons the participants chose not to wear earplugs. About 60% of the participants planned to wear hearing protection after the end of marching band season.

Seever et al. (2018) reported similar results in a collegiate population. A total of 48 band members were divided into two study groups. Both groups received a presentation from *Adopt-a-Band* curriculum, but one of the two groups received additional training on the possibility of developing hidden hearing loss. The curriculum for both groups covered topics relating to anatomy of the ear, how sound levels are measured, which sound levels are considered safe, and hearing protection devices. The participants completed a pre- and post-survey on their attitudes towards hearing conservation and concern of NIHL. Although there were no significant differences between the two study groups, the overall concern of NIHL increased by 39.5% between the pre- and post-survey.

Table 5

Summary of the major findings of the studies gathered in the literature review

Reference	Primary Purpose	Sample	Methods	Conclusions	Limitations
Auchter & Le Prell (2014)	To investigate the effects of hearing loss prevention education on earplug usage in high school marching bands.	Participants included 69 students gathered from two different high schools	Participants completed a pre-training survey, a post-training survey, and a follow-up survey at the end of the season. The training program included a discussion and DVD presentation on how the auditory system works and how sound can damage the ear. Earplugs were distributed to the participants	A total of 54% of participants increased their usage of earplugs from survey one to survey three. Comfort and sound quality were noted as being the main reasons the participants chose not to wear earplugs. About 60% of the participants planned to wear hearing protection after the end of marching band season.	The researched noted that the study's questionnaire may have been confusing for some students. Further research is needed on the potential hazardous levels of sound in the classroom.
Barlow (2010)	To determine if students in popular music courses were exposed to hazardous sound level.	Participants included 100 undergraduate students studying popular music, audio performance, electronic music, and music production.	Participants completed a survey on participation in musical activities. Noise dosimeters were used to record sound levels in studios and music venues.	A total of 76% of participants had experienced symptoms of hearing loss, while only 18% reported wearing hearing protection. Results found hazardous levels of sound in both recreational and educational settings.	Further research is needed on the factors affecting hearing protection usage.
Chesky, Pair, Lanford, & Yoshumura (2009)	To assess the attitudes towards noise of music majors, compared to non-music majors.	A total of 467 college students were recruited for this study.	A questionnaire assessing attitudes towards music and earplugs was distributed to the participants.	Music majors are more likely to participate in healthy listening habits. They are generally more aware of the dangers of excessive noise.	This study is limited by the lack of diversity in the sample population, as the participants were only pulled form one school.
Edwards (2019)	To determine the noise dosages of pep band members and the perceptions and knowledge of the members of the pep band on hearing loss and hearing loss prevention.	The primary participant group consisted of 2 participants who wore noise dosimeters. The secondary participant group consisted of 72 collegiate pep band members who did not wear noise dosimeters.	The participants in the primary group wore earplugs and noise dosimeters on their shoulder for the entirety of every basketball game in the season. This group also completed a survey on their experience wearing hearing protection. The secondary group completed a survey on hearing loss knowledge.	The noise dosages exceeded NIOSH daily noise allowances. The scores of the secondary participants indicated that they are familiar with hearing loss prevention concepts. The lowest scoring questions were about effectiveness of hearing aids and the permanent nature of hearing loss.	The researcher mentions that the choice of using NIOSH standards to determine dosage and the specific environment tested may not accurately reflect actual noise exposure.

Hatheway & Chesky (2013)	To determine the prevalence of health-related issues of a collegiate marching band.	246 marching band students were recruited for this study.	A survey was distributed at the end of the semester. The survey gathered information on habits related to participation in marching band, attitudes, and self-reported levels of pain.	Participation in a collegiate band affects all aspects of health. In regard to audiologic health, participants frequently reported ear pain, decrease in hearing quality, and ringing of the ears.	Sample was gathered at one school. The measures were subjective, as no numerical data measurements were gathered.
Jin, Nelson, Schlauch, & Carney (2013)	To investigate the risk of NIHL in marching band members.	Group one consisted of 350 members of the University of Minnesota marching band over three years. Group two was a control group consisting of 348 young adults	Group one received annual audiometric testing before and after band season. Marching band members were given earplugs at the first hearing evaluation. Thresholds for group two were measured once a semester. Sound levels were measured during an indoor practice session with a sound level meter. A questionnaire was distributed to both groups.	Sound levels during the indoor rehearsal suggested an increased risk of NIHL. Over half of marching band members reported never using hearing protection. No significant difference in thresholds or audiograms was found between the two groups.	The lack of audiometric evidence for NIHL may be due to the young age of participants and the fact that rehearsals were outside. The researchers recommend musicians monitor their hearing and practice safe listening habits.
Lüders et al. (2014)	To determine if audiometry is an effective tool in detecting early hearing loss.	A group of 42 undergraduate music students was compared to a control group of 42 participants.	Air-conduction testing was conducted on both groups at .25 kHz to 8 kHz. Extended high-frequency testing was conducted at 9, 10 and 11.2 kHz.	There was a significant difference between the hearing thresholds in both groups. The greatest differences were found during the extended high frequency testing, suggesting this testing is effective in detecting early NIHL.	Differences in music education programs may affect one's exposure to noise.
Miller, Stewart, & Lehman (2007)	To explore the habits and knowledge related to hearing conservation of music students.	The participants included 27 collegiate student musicians.	A survey was distributed to the participants. Noise dosimeters were placed on students during a practice and sporting event performance.	The results suggest that student musicians are at risk of NIHL. Twenty-one participants reported never wearing hearing protection. Noise dosimetry showed that the students exceeded both OSHA and NIOSH 100% daily dose.	The difference between OSHA and NIOSH recommended levels resulted in varying daily doses. Further research is needed into hearing conservation programs to prevent risk of NIHL.
Phillips, Henrich, & Mace (2010)	To quantify the prevalence of NIHL in student musicians.	A total of 329 collegiate music students participated in this study.	The participants completed a questionnaire and audiometric testing was completed.	Audiometric testing revealed 45% of participants had a notch in at least one ear at. About 11.5% of students were found to have notches in both ears.	Additional factors, such as genetic predisposition, may affect these results.

Russell & Yamaguchi (2018)	To determine the noise exposure of professionals working in close proximity to marching bands.	The participants included 8 athletic trainers working with a university marching band.	Participants wore a noise dosimeter during indoor and outdoor rehearsals, and outdoor performances. The daily dose was calculated according to NIOSH criterion.	The amount of noise exposure exceeded the recommended daily dose. The sound levels at the performances were higher than the levels recorded during rehearsals.	Crowd noise and public address systems may influence the amount of exposure. Further research is needed on exposures of professionals related to marching band.
Seever et al. (2018)	To investigate the effects of an *Adopt-A-Band* program on students' prevention of NIHL	Participants included 48 collegiate marching band members.	Participants were separated into two groups- one received education and one was a control group. Participants completed a pre- and postsurvey	The education program increased concern for NIHL by 39.5%.	Further research is needed on the long-term effects of education programs
Smith, Neilsen, & Grimshaw (2017)	To investigate the factors affecting noise exposure in a variety of musical settings.	This study included music students from Brigham Young University.	Sound levels were recorded during rehearsals from four different ensembles. A single student played in different room environments and noise dosage was recorded. Full day measurements were taken from 43 students.	Factors such as type of instrument, type of activity, arrangement of ensemble, and room acoustics all affected noise dosage. Many musicians exceed 100% NIOSH daily dose recommendations. The woodwind and brass instrumentalists were particularly at risk.	Further research should is needed on individual musician measurements.
Walter (2011)	To examine sound exposure of high school marching band students.	The marching band was made of 100 students. Sixteen of the students wore noise dosimeters.	Participants wore noise dosimeters for two full days of summer band camp.	Ten participants exceeded their daily noise on day one, when compared to NIOSH recommendations. Fifteen participants exceeded their daily dose on day two.	Further research is needed on the usage of earplugs in these populations and the use of breaks to reduce the risk of NIHL.
Washnik, Phillips, & Teglas (2016)	To determine noise exposure during both individual practice and ensemble rehearsals.	The participants included 57 collegiate marching band members.	Sound levels were measured for two full days using noise dosimeters. Daily dose percentages were calculated according to NIOSH criterion.	About 49% (n=28) of students exceeded their daily noise dose during at least one out of the two days of measurements, according to NIOSH recommendations.	Further research is needed on education programs for students to prevent NIHL

Discussion

This literature review provides evidence that music students have been exposed to excessive sound levels and show evidence of NIHL. Although there are noise regulations governing occupational settings, there are no requirements or guidelines for sound over-exposure for marching bands at the collegiate or high school levels. Due to the lack of regulations, voluntary hearing conservation programs are recommended for these populations. The implementation of hearing conservation programs for collegiate music students suggests that education on NIHL has a positive effect on attitudes and promotes earplug usage (Auchter & Le Prell, 2014; Seever et al., 2018). A consensus regarding how hearing conservation programs for marching band students should be implemented is lacking and there is no guidance regarding the structure and content of the program in the literature.

Therefore, it may be necessary to rely on outcomes from hearing conservation program interventions targeting professional musicians as a comparable population of musicians. For these musicians, it appears that the execution of education and training programs is an effective strategy in the prevention of NIHL (Auchter & Le Prell, 2014; Seever et al., 2018). O'Brien, Ackermann, & Driscoll (2015) implemented a best-practice hearing conservation program that was delivered to orchestral musicians and assessed the successes, difficulties, and practical viability of the program. The program components consisted of 1) noise exposure monitoring with noise dosimetry, 2) provision of high-quality earplugs 3) investigation and application of engineering controls, 4) annual audiologic screenings planned by the ensemble's hearing conservation management committee, 5) annual education and discussion of NIHL with musicians and management

and 6) research into emerging technologies. Overall, the researchers found that the program was successfully integrated into the orchestra's daily operations and contributed to managing the risk of hearing loss in orchestra musicians. Specifically, earplug usage and awareness of NIHL was more prevalent in the group receiving the hearing conservation program intervention when compared toother ensembles. O'Brien et al. concluded that the study provides a basis for those wishing to implement or evaluate similar paradigms targeting musicians.

With this in mind, Figure 1 provides a potential adaptation of the O'Brien et al. hearing conservation strategies to conceptualize a potential approach to hearing conservation program targeting marching bands. In this scenario, the hearing conservation program would be administered by the school district health and safety staff with support from the educational audiologist.

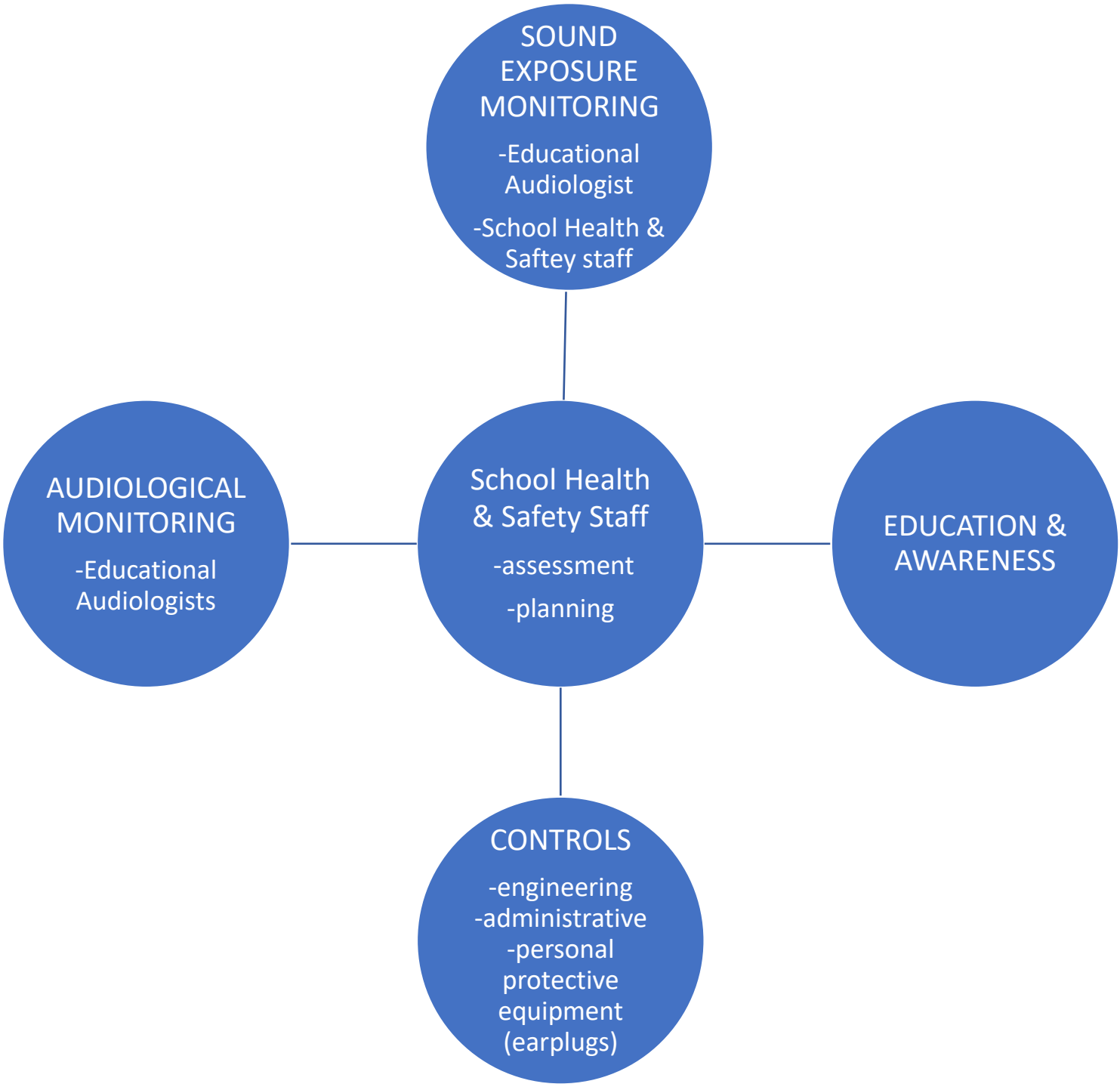

Figure 1. Structure and Elements of a School-Based Hearing Conservation Strategy for Marching Band Students

Measurement of Noise Exposure

In order to evaluate risk of NIHL, noise dosimetry can be implemented to help monitor sound levels and exposures. These devices are able to be clipped to one's shoulder and worn during rehearsals and performances. Best practice would suggest that the measurements from the dosimeters should calculate the daily dose value, according to NIOSH criteria or more conservative WHO standards (Edwards, 2019; Miller, Stewart, & Lehman, 2007). These noise dosages would inform the potential risk of NIHL and the need for the hearing conservation program.

Sound Control

There are a number of strategies that can be used to modify student's amount of exposure to hazardous sound levels. There were many variables that could have affected the calculated daily noise dosage. Researchers note that the type of instrument, the arrangement of the ensemble, and the room acoustics, and the size of the marching band are additional factors that affected the noise dosage experienced by the participants (Smith, Neilsen, & Grimshaw, 2017; Walter, 2011). Engineering controls, such as increased spacing between marching band members, reducing reverberation in rehearsal spaces, and utilization larger rehearsal spaces can help to minimize exposure. Sound measurements taken during outdoor rehearsals were found to be lower than indoor rehearsals (Walter), suggesting practices should be performed outside when possible. Russell & Yamaguchi also recognize that additional noise sources, such as crowd noise and public address systems, are important factors when evaluating noise exposure during performances. Administrative controls would potentially include scheduling rest periods

between practices and performances and/or limiting the number of practices and performances.

Hearing Protection

Hearing protection (earplugs) is a type of personal protection equipment designed to reduce the sound exposure of the wearer. Despite music students being aware of the dangers of excessive sound exposure (Chesky, Pair, Lanford, & Yoshumura, 2018), a small percentage of students actually wear hearing protection devices (Barlow, 2010). Marching band members reported difficulties with communication and detecting intonation while wearing hi-fidelity musicians' earplugs, and difficulties with communication and self-perceived inadequate fit when wearing foam earplugs (Edwards, 2019). Despite these challenges, Auchter & Le Prell (2014) found that the number of students wearing earplugs increased after they received education on the proper use hearing protection devices and were provided hi-fidelity "musicians" earplugs.

Audiometric Monitoring

Hearing testing is one tool that can be used to detect and monitor NIHL, aiding in the early prevention of hearing loss. Although different researchers have specific definitions for an audiometric notch, Phillips, Henrich, & Mace (2010) defined NIHL generally presents as a decrease in hearing at 3, 4, and 6 kHz. Almost half of music students were found to have some degree of an audiometric notch evident in at least one ear (Phillips, Henrich, & Mace). Music students were also found to have a greater amount of hearing loss at high frequencies than non-music students (Luders et al., 2014). In additional to audiometric testing, students frequently reported signs of NIHL, including

ear pain, tinnitus, and a decrease in hearing quality (Hatheway & Chesky, 2013). These results support the need for frequent audiometric testing in students. Audiologists should perform pure-tone audiometry at 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz to establish a baseline reference audiogram and perform annual audiometry in order to detect a change in high-frequency hearing status that might be suggestive of NIHL. These tests should be performed annually to ensure the opportunity for intervention in order to preserve hearing function, as NIHL is a progressive condition that occurs over time. Students with complaints of tinnitus or hyperacusis may need further audiological evaluation.

Education and Motivation

Research shows that music students have positive attitudes towards hearing conservation, suggesting they are motivated to learn about the dangers of excessive sound exposure and strategies to protect their hearing (Chesky, Pair, Langford, & Yoshumura, 2009). Comprehensive presentations, such as PowerPoint presentations and videos, are shown to be an effective method in increasing knowledge and concern for NIHL in high school and collegiate marching band members. (Auchter & Le Prell, 2014; Seever et al., 2018). An effective hearing conservation educational effort should cover anatomy and physiology of the ear, how sound exposure affects the ear, how sound is measured, and which levels are dangerous (Auchter & Le Prell, 2014; O'Brien, Ackermann, & Driscoll, 2015; Seever et al., 2018). In order to increase earplug usage, the research suggests that hearing conservation education programs should additionally cover information regarding how hearing protection devices can prevent NIHL (Auchter & Le Prell, 2014; O'Brien, Ackermannm & Driscoll, 2015).

Research Needs

Further research is needed on the variables that effect one's risk of developing NIHL and the implementation of successful hearing conservation programs in this population. Multiple studies noted that external variables, such as type of instrument played, room acoustics, marching band arrangements, and additional crowd noise, may have affected the reported noise dosages (Edwards, 2019; Rusell & Yamaguchi, 2018; Smith, Neilson, & Grimshaw, 2017; Walter, 2011). Research suggests that students may benefit from hearing conservation programs (Auchter & Le Prell, 2014; Seever et al., 2018), but additional research is needed to determine if these effects are consistent over longer periods of time. Additionally, it may be useful to adapt evidence-based interventions such as the Dangerous Decibels® program for marching band musicians and assess the effectiveness of the modification (Griest et al., 2007).

Overall, there is a lack of research regarding the noise exposures of high school marching band students. This literature review shows that professional musicians often develop NIHL to some degree, while collegiate marching band members are exposed to excessive sound levels and demonstrate signs of early NIHL. Research from Walter (2011) suggests that high school marching band students may be exposed to similar sound levels, but there is lack of research on the risk of NIHL younger musicians which can be substantiated by linking noise exposure data with longitudinal audiometric data. Further research on the sound exposures of high school marching band members to both music and recreational activities is needed, and linking audiometric outcomes to the sound exposures can inform how best to protect young musicians from the effects of excessive sound exposure both during school-based music activities, but also during

participation in other recreational activities (e.g., attending concerts, riding motorized vehicles such as motorcycles or snowmobiles, shooting firearms etc.).

Conclusion

Marching band students are at risk of NIHL (Edwards, 2019; Jin, Nelson, Schlauch, & Carney, 2013; Miller, Stewart, & Lehman, 2007). Collegiate marching band students typically exceeded daily dose limits (Edwards; Miller, Stewart, & Lehman). The findings from Jin, Neilson, Schlauch, & Carney (2013) suggest that playing in the percussion section, cymbal section, and brass section presents the greatest risk of NIHL, due to sound measurements being the highest at these locations, with measurements ranging from 105-120 dBC. Although studies show that collegiate marching band members are exposed to excessive levels of sound, research from Walter suggests that younger musicians at the high school level are exposed to similar sound levels. In order to prevent risk of NIHL, marching band students should be enrolled in a hearing conservation program, which would include the provision of proper hearing protection devices, audiometric monitoring, and training regarding the risk of NIHL and strategies to prevent NIHL. Sound or “noise” control strategies should also be implemented during rehearsals and performances (Auchter & Le Prell, 2014; O’Brien, Ackermann, Driscoll, 2015; Seever et al., 2018). The findings from this literature review outline strategies that are critical for the prevention of NIHL in high school marching band members and elucidate the need to inform the broader school and musical community regarding the risk and the need for intervention.

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