6-2-2017

A Systematic Review of Occupational Music-Induced Hearing Loss

Lilach Gez Saperstein
The Graduate Center, City University of New York

A SYSTEMATIC REVIEW OF OCCUPATIONAL MUSIC-INDUCED HEARING LOSS

by

LILACH GEZ SAPERSTEIN

A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology, The City University of New York

2017

A SYSTEMATIC REVIEW OF OCCUPATIONAL MUSIC-INDUCED HEARING LOSS

by

LILACH GEZ SAPERSTEIN

This manuscript has been read and accepted for the Graduate Faculty in Audiology in satisfaction of the capstone project requirement for the degree of Au.D.

	Adrienne Rubinstein, Ph.D
___________	________________________
Date	Faculty Mentor
	John P. Preece, Ph.D
___________	________________________
Date	Executive Officer

THE CITY UNIVERSITY OF NEW YORK

Abstract

A SYSTEMATIC REVIEW OF OCCUPATIONAL MUSIC-INDUCED HEARING LOSS

by

Lilach Gez Saperstein

Advisor: Dr. Adrienne Rubinstein

The prevalence of noise induced hearing loss (NIHL) is a public health concern with government regulations (i.e. OHSA, NIOSH) in place to protect employees in occupational settings. Sound pressure levels (SPL) of various industries have been measured and exposure dosages monitored as per the national regulations. Previous research has demonstrated that *occupational* exposure to loud noise has led to audiometric evidence of NIHL. Thus, it raises the question about the impact of occupational exposure to music on hearing. For the purposes of this capstone, literature pertaining to occupational music exposure levels, and the effects on both hearing threshold levels and otoacoustic emissions (OAEs) were systematically reviewed. The evidence provides some support that musicians and other workers in music environments are indeed exposed to occupational noise in the form of music at levels which are consistent with those considered to be potentially damaging, as delineated by regulatory agencies. However, the exposure dose and duration is highly variable, dependent on the particular type of music, setting, schedule, and instrumentation. There are limitations in the way noise exposure can be measured; nevertheless, the use of dosimetry presents representative data that needs to be taken into account when evaluating the occupational noise level that musicians face. Areas of further research need

to encompass the highly diverse nature of musicians' employment. Results also revealed decreased hearing thresholds in those exposed to music occupationally in a number of studies. Furthermore, otoacoustic emissions were shown to be an effective clinical and research tool in evaluating NIHL susceptibility and signs of auditory damage post music exposure. Longitudinal studies are needed to determine if the hearing loss endured by musicians can be causally linked to their music exposure. Risk reduction measures, including educational initiatives, hearing protection, and audiometric monitoring, are recommended in nearly all of the studies examined.

Acknowledgements

First, I would like to thank my mentor and advisor Dr. Adrienne Rubinstein, who has walked me through, not only this project, but every step of these last four years. For imparting a great body of audiological knowledge and skills, and more importantly for cultivating my passion for patient-centered and evidence-based care, I thank Dr. Rubinstein and the members of the audiology faculty at the CUNY Graduate Center including Dr. Shlomo Silman, Dr. Carol A. Silverman, Dr. Susan Wortsman, Dr. Dorothy DiToro, Dr. Barbara Weinstein and Dr. John Preece. I feel blessed to have studied alongside my talented, outspoken, and cohesive cohort, and I owe a particular debt of gratitude to Chanie Lindenbaum, whom I am proud to call both my colleague and my friend.

It is impossible to sufficiently thank my devoted parents, Rabbi Hanoch and Naomi Gez, for their immense love, encouragement and support and for teaching me about what is truly important in life. I thank my parents-in-law, Drs. Avi and Adena Saperstein, without whom the combination of graduate school and parenthood would have been near impossible. And to the rest of my family and friends, near and far, I count you in my many blessings.

All my love and appreciation go to my husband Yona; I maintain "it is a miracle I have found you." And to my sweet daughters Raananit and Levona who inspire me each day to care for others. Thank you all for sharing in my journey.

Table of Contents

List of Figures and Tables

Introduction

Noise-induced hearing loss (NIHL) is a sensorineural hearing loss that results from overexposure to loud sound. Exposure to loud noises over time can lead to outer hair cell death and dysfunction of the peripheral auditory system, as well as other symptoms, including tinnitus and distortions of auditory perception. The proposed mechanism of outer hair cell dysfunction falls into one of two categories; either due to metabolic exhaustion of outer hair cells in response to continuous acoustic input, or cellular trauma in response to a transient high-intensity sound, such as a gunshot. Audiometrically, NIHL typically presents as a decrease in hearing sensitivity thresholds that generally centers around 4000 Hz, and gradually affects hearing thresholds at surrounding frequencies, corresponding to cochlear damage in adjacent regions. Decreases in audiometric thresholds can be temporary in nature, known as a temporary threshold shift (TTS), although depending on the intensity and duration of the stimulus may also lead to irreversible cochlear damage, or a permanent threshold shift (PTS). In addition, other symptoms of auditory system dysfunction may occur, such as tinnitus, which is experienced as noises heard by the patient that have no external source in the environment. Tinnitus may manifest as a bothersome, sometimes intermittent, buzzing, hissing, roaring, or most commonly, as a high-pitched ringing sound. Aside from the physiologic damage to the auditory system, NIHL can affect communication efficacy and quality of life (Zhao, Manchaiah, French & Price, 2010).

The prevalence of NIHL is a public health concern with government regulations in place to protect employees in occupational settings. These regulations were based on noise measurement studies that quantify noise levels in a variety of ways. The average sound level exposure over an eight-hour session known as the L_{eq} or L_{eq8h}, can be extrapolated from sound level measurements collected by dosimeters, portable sound level meter devices that record and analyze the intensity level of noise in an environment over time. A permissible exposure level (PEL) describes what an employee can be exposed to with the reasonable expectation that no damage will result. The PEL for noise exposure is a time-weighted average (TWA) of eight-hour daily shifts within a 40-hour work week (OSHA). The peak level is the maximum sound pressure level measured within a recording session.

Various governmental agencies, such as the Occupational Safety and Health Administration (OSHA) and The National Institute for Occupational Safety and Health (NIOSH) in the United States, the European Agency for Safety and Health at Work (EASHW) in Europe and the Australian Workplace Health and Safety (WHS) in Australia, develop and maintain standards and guidelines for occupational safety standards. Among the two U.S. standards, OSHA is a regulatory body which mandates laws that employers must follow, while NIOSH presents evidence-based recommendations, which are more stringent than the OSHA standards. OSHA standards require that if an employee is exposed to an 8-hour TWA of at least 85 dBA in his or her work environment, employers must provide hearing conservation training and hearing protection devices (HPD) to their employees, as well as obtain baseline and subsequent annual audiograms (OSHA, "Occupational Noise Exposure 1910.95"). Whereas the NIOSH allowable exposure time is only 8 hours at high sound pressure levels (Noise and Hearing Loss Prevention, NIOSH, 2017), the OSHA standard would allow a total of 16 daily hours of noise exposure at the same level. Additionally, OSHA decreases the allowable duration with 5 dB increments, whereas NIOSH uses a 3 dB exchange rate, thus the NIOSH recommendations allow for much shorter exposure durations at higher levels than do the OSHA regulations. These standards are put in place to protect workers exposed to potentially damaging levels of noise such as jobs involving construction, factory machinery and other industries where employees are exposed to loud work conditions. Lutman (2000) reported that a lifetime occupational exposure of noise at a level of 85dBA affects a significant margin of people who are susceptible to NIHL and a level of 90 dBA poses significant risk of developing NIHL in most people. Noise measurement studies attempt to quantify the noise levels by measuring the L_{eq}, noise dosage, and peak. L_{eq} is the average of the sound levels that exceed a certain threshold across a measurement period. Measurements include only sound levels that exceed a given threshold. Noise dosage refers to the amount of actual exposure relative to the amount of allowable exposure, and for which 100% and above represents exposures that are hazardous (NIOSH, 1998). The maximum level reached by the sound pressure at any instant during a measurement period (recorded in dB) is called the peak.

Sound pressure levels (SPL) of various industries have been measured and exposure dosages monitored as per the national regulations. For example, Neitzel, Seixas, Camp & Yost (1990) evaluated the noise levels of four different construction-related vocations and found that the TWA means ranged from 82.2 dBA to 85.3 dBA among carpenters, laborers, ironworker and operating engineers (1990). Root et al. (2013) found that mean exposure levels of firefighter training sessions that lasted approximately 70 minutes were 78 dBA, although mean levels as high as 91 dBA and 92 dBA were measured when using the sirens and water pumps. Another study that measured the noise exposure levels of fisherman and mechanics on small- and medium-sized ocean vessels revealed average exposure levels of 91.2-94.3 dBA for the mechanics in the engine room and slightly lower levels of 84.7-88.4 dBA for other crewmen (Zytoon, 2013). Among New York City mass transit workers, mean exposure levels ranged from 75.1 dBA on the Metro-North commuter rail to 80.4 dBA on the MTA subway, with maximum levels as high as 102.1 dBA on the MTA subway when taking into account noise levels both inside the train and on platforms (Neitzel, Gershon, Zeltser, Canton, & Akram, 2009).

Studies have also shown that occupational exposure to loud noise has led to audiometric evidence of NIHL. For example, police officers are at risk for developing NIHL in their line of work, due mostly to transient noise exposure to gunshots, both in training and in the field. A cross-sectional study comparing French police officers with civil servants was conducted to evaluate the association between police employment and noise-induced hearing loss (Lesage, Jovenin, Deschamps & Vincent, 2009). When adjusting for extraneous factors such as smoking status, medical history, age and gender, there was a significant decrease in hearing thresholds at 4kHz in the police officer group as compared with the control group, indicative of a NIHL. Pilots, too, are at risk due to the engine noise they are exposed to for many hours at a time. Mil'kov and Gofman (2006) reviewed the medical records of 609 pilots who had worked between 2 and 40 years. Over 400 of the participants studied had some form of sensorineural hearing loss. Firefighters are also at risk of developing NIHL as they are exposed to very high intensity sounds such as sirens, horns, alarms, and fire truck engines as well as power tools used during emergencies (Hong & Samo, 2007). A study by Kales et al. (2001) evaluating the hearing sensitivity of 340 firefighters, found that even when controlling for age-related factors, older firefighters were more likely to have high frequency hearing loss, consistent with NIHL, than young firefighters. Thus, the older firefighters demonstrated greater than expected age-related hearing loss (Kales et al., 2001).

Whereas the stimuli discussed above involve noise, it is also important to consider other loud sounds, such as music. In fact, past research has already investigated the impact of music exposure for *recreational* purposes and its potential effect on hearing. Kim et al. (2009) evaluated the relationship between use of personal music players and hearing thresholds in 490 adolescents and found that there was a significantly elevated threshold in those who reported use of in-ear headphones, increased usage time (1-3 hours per day) and those who reported such a usage pattern over the last 3 years. A similar study by Abdi (2011) evaluated pure-tone audiometric thresholds from 250-8000 Hz in 60 participants aged 15-30 years. Two testing sessions were conducted, an initial evaluation and another after six months. All participants' initial results revealed hearing thresholds and tympanometry within normal limits and present acoustic reflexes, and all had unremarkable otologic histories. The participants were divided into two groups based on their reported duration and levels of music exposure, as well as their mode of listening, i.e. through speakers or through ear-worn devices such as headphones. The results of the study demonstrated a decrease in hearing sensitivity in the 4000-8000 Hz region in both groups at the six-month re-evaluation, more so among the headphone users (Abdi, 2011). These, and other similar studies, have given support to the intuitive notion that loud sound exposure, even in the form of music, can be damaging to the peripheral auditory system and lead to decreased hearing sensitivity, as indicated by elevated pure-tone thresholds in the above and similar studies. It is not only continuous, steady-state noise, such as those produced by machinery in factories, or transient, impulse sounds, characteristic of firearms, that can damage the peripheral auditory system, but even music.

While there is evidence that occupational noise exposure can lead to NIHL and that recreational music exposure may be associated with hearing loss, it certainly raises the question of the impact of occupational exposure to music on hearing as well. Therefore, those who are exposed to high intensity music for many hours each day vocationally, such as professional musicians, music students, disk jockeys and other nightclub employees, may also be at risk of developing NIHL. Despite the risk of noise exposure that exists for musicians, there are no formal protective guidelines for musicians or music venues as an industry in the United States, among other countries. The current paper will investigate the literature available regarding occupational noise exposure in the form of music.

Unlike other defined regulated industries, there is a conglomerate of workers who are occupationally exposed to noise: professional musicians, recording artists and production staff, and venue staff among others, for whom it is difficult to quantify the number of employees exposed to music at risk of NIHL. The Bureau of Labor Statistics reports that there are 37,090 musicians in the U.S., although this does not include self-employed musicians of which there are invariably many. Additionally, many jobs in the music industry are unreported and highly variable in terms of hours of work and venues etc., such as disk jockeys, who may work between 2-8 hours at a time, working anywhere from 1-4 nights per week (Santos et al., 2007).

In order to fully evaluate the risk that musicians and other workers face, the levels and durations of music to which they are exposed must first be measured and quantified. Such quantification studies have been undertaken by numerous researchers, collecting data of various types of music, from different professional venues, and patterns of exposure. A systematic review of such articles is included in the body of this capstone research paper and will lead to the elucidation regarding the L_{eq} to which musicians are exposed. Given the variability of duration inherent in music exposure, as opposed to continuous noise, the second research question focuses on whether there are any noticeable differences in hearing thresholds in those exposed to music.

Clinical pure-tone audiometry is utilized to evaluate hearing thresholds from 250-8000 Hz, and NIHL is conventionally measured in this manner; hearing thresholds are measured with a subjective response from the patient. However, subclinical changes to the auditory system can go undetected by conventional methods of audiometric testing. Otoacoustic emissions (OAE), an objective measure of outer hair cell function or dysfunction proposed to originate from the outer hair cells (Kemp, 2002), may be used as a tool to detect early cochlear damage, such as those thought to be a result of noise exposure. Distortion-Product otoacoustic emissions (DPOAE), in particular, can be used to differentially diagnose NIHL, separating high-frequency hearing loss from other etiologies such as ototoxicity and age (Sliwinska-Kowalska & Kotylo, 1996). Marshall, Miller and Heller (2001) reviewed the use of DPOAEs in determining individual changes in outer hair cell function in relation to noise exposure; they discuss the feasibility of using DPOAEs as a clinical screening tool for NIHL susceptibility or subclinical/preclinical hearing loss (Marshall et al., 2001). Previous research has investigated the effect of occupational noise on OAEs. For example, in a study of airline pilots, the number of flight hours was inversely correlated with DPOAE amplitudes, implying that DPOAEs decrease with increased noise exposure (Zhang, Zhang, Zhu, Zheng & Deng, 2004). Another study evaluated the noise exposure of construction workers and found that for every additional year of work experience i.e. noise exposure, there was a 0.2dB decrease in DPOAE amplitude, even when controlling for other variables (Seixas et al., 2004). OAEs may also be thought of as a glimpse into the efficacy of cochlear mechanics in processing the volume of acoustic input. Musicians have been a population of interest in OAE research, as they are exposed to auditory input and training in their daily work.

Research questions:

The purpose of the current study was designed to answer the following research questions:

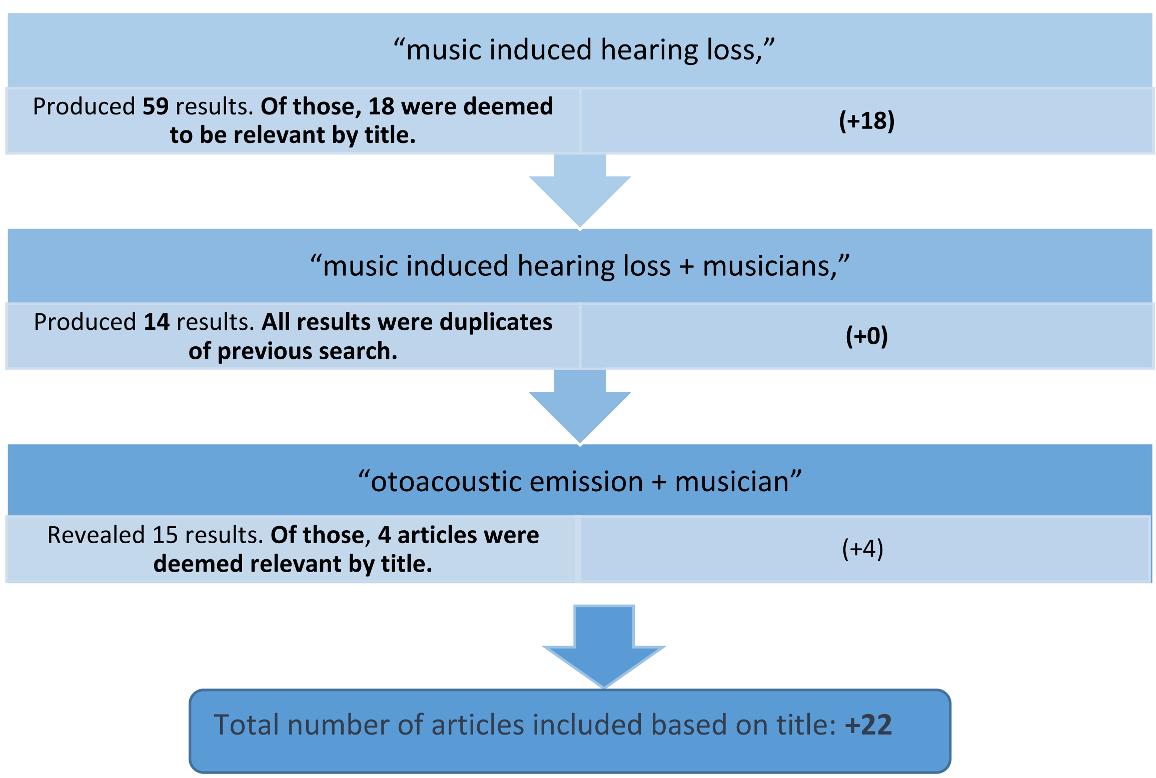
1. What are the levels of music exposure to which professional musicians and other workers in the music industry are exposed? Do these exposure levels exceed current protective guidelines?

2. Can occupational music exposure lead to temporary or permanent threshold shifts as evidenced by audiometric testing?
3. Does evidence exist regarding OAEs and early detection of hearing loss in this population?

Methods

For the purpose of this review the following databases were searched for relevant literature: CINAHL complete, psychINFO, Health Source: Nursing/Academic Edition, and Medline Complete. The search terms that were utilized are represented in the chart below, along with the results produced from those searches. Studies were assessed by title, by abstract and by complete reading to determine inclusion in this review. Figure 1 summarizes the inclusion process for retaining studies for this systematic review.

Figure 1. Flowchart of inclusion process



Eight additional articles were found by related results or from other studies by the same author of a previously identified article. A sum total of **+33** articles were read and reviewed. Articles were then excluded if their focus was not on musicians, but rather on attendants of music venues exposed to recreation exposure of music. Additionally, any research papers addressing the effectiveness or usage of hearing protective device were excluded.

TOTAL:	Questions 1 & 2 (Leq/threshold): **8 articles**	Question 3 (OAE): **5 articles**

Results

Table 1 summarizes the eight studies chosen for this systematic review to answer the first two research questions. All studies measured the SPL of music in different settings and of differing music genres. The studies measured the sound exposure of musicians and employees who were involved with professional orchestras, jazz bands, and recreational music venues. The method of measurement in each of the studies was dosimetry recordings, which sample the environment at a particular rate over time.

Table 1. Summary of studies reviewed to answer first two research questions

Authors, publication date	**Title**	**What Was Measured**	**Average Levels/ Leq**	**Range of Exposure Levels**	**Peak Level**
Bray, Szymanski, & Mills (2004)	Noise induced hearing loss in dance music disc jockeys and an examination of sound levels in nightclubs.	Dosimeter recordings on 23 disc jockeys (DJs)	96 dBA average	97.8 to 107.9 dBA	108 dBA

Gopal, Chesky, Beschoner, Nelson, & Stewart, (2013)	Auditory risk assessment of college music students in jazz band-based instructional activity.	Dosimeter recording on 14 college students participating in a routine 50 min jazz ensemble-based instructional	95 dBA Leq 99.5 dBA average	95 to 105 dBA	-
Gunderson, Moline, & Catalano, (1997)	Risks of developing noise-induced hearing loss in employees of urban music clubs.	Dosimeter recordings of sound levels at eight live-music clubs	-	94.9 to 106.7 dBA (during performances) 91.9 to 99.8 dBA (performances + ambient levels)	Exceeding 115 dBA peaks at some performances
Henoch, & Chesky, (2000)	Sound exposure levels experienced by a college jazz band ensemble: Comparison with OSHA risk criteria	Dosimeter measurements on five different positions within a jazz ensemble	Averages in dBA: ~91 (string bass) ~96 (drums) ~96 (lead trumpet) ~99 (lead trombone) ~98 (lead alto sax)	-	-
Kelly, Boyd, Henehan &, Chamber, (2012)	Occupational noise exposure of nightclub bar employees in Ireland.	Dosimeter recording on 19 bar employees	92 dBA Leq8	77 to 98 dBA	135.6 dBC
O'brien (2008)	Nature of orchestral noise	1608 Dosimeter readings from different instrument positions within a professional orchestra	81.2 dBA Leq (violin) 89.4 dBA Leq (1st Trumpet)	77.4 to 95.9 dBA	146.9 dBA (percussion)

Rodrigues, Freitas, Neves, & Silva, (2014)	Evaluation of the noise exposure of symphonic orchestra musicians	Dosimeter recordings of Portuguese orchestra players	79.7 (strings) 85 (woodwinds) 87.7 (brass) 84.3 (percussion /tympani) 76.5 (conductor)	77.2 to 92.7 dBA	135 dBA (percus sion)
Santos, Morata, Jacob, Albizu, Marques, & Panini (2007).	Music exposure and audiological findings in Brazilian **disc jockeys (DJs)**.	Dosimeter readings from 21 DJs	-	93.2 to 109.7 dBA	-

Table 2 provides the types of dosimeters used for each study. Data from the dosimeters were then analyzed and extrapolated to produce various measures of noise exposure, such as the average SPL, the range of SPL throughout the recording period, and peak SPL. As noted earlier, extrapolated measures were calculated to approximate the exposure over an eight-hour workday, referred to as an L_{eq} or L_{eq8}.

Table 2. Dosimeters Used for Sound Pressure Level Recordings in Studies Reviewed

Bray, Szymanski, & Mills, (2004)	Ametek Mk-3
Gopal, Chesky, Beschoner, Nelson, & Stewart, (2013)	Quest Q-400
Gunderson, Moline, & Catalano, (1997)	TK-3 portable
Henoch, & Chesky, (2000)	Quest Model 400
Kelly, Boyd, Henehan &, Chamber, (2012)	Brüel and Kjaer 4445E
O'Brien, Wilson & Bradley (2008)	Cassella USA CEL-460
Rodrigues, Freitas, Neves, & Silva, (2014)	Quest NoisePro, CESVA DC112
Santos, Morata, Jacob, Albizu, Marques, & Panini (2007)	Bruel & Kjaer, model 4431

O'Brien, Wilson and Bradley (2008) and Rodrigues, Freitas, Neves, and Silva (2014) measured orchestra noise levels. Gopal, Chesky, Beschoner, Nelson, and Stewart, (2013) and

Henoch and Chesky (2000) evaluated the noise exposure levels in student jazz band ensembles. Bray, Szymanski, and Mills, (2004) and Santos et al. (2007) measured levels in nightclubs to which DJs are exposed. Gunderson, Moline, & Catalano (1997) and Kelly, Boyd, Henehan and Chamber, (2012) also evaluated measures in nightclub venues, however they focused on the exposure to employees other than musicians such as bartenders and security personnel.

Sound Exposure in Orchestras:

Orchestra musicians are necessarily exposed to high levels of noise exposure throughout the course of their professional activities. Rehearsals and performances consist of continuous exposure to not only the musician's own instrument, but to those of their surrounding co-performers. There have been numerous studies evaluating the levels of exposure, as well as studies examining the relationship between noise exposure and otologic complications. In this section, a review of the results of three noise level studies will be outlined.

An analysis of 12 studies, in which orchestra sound levels were measured, was undertaken by O'Brien et al. (2008). However, the study was severely limited in providing adequate data as many flaws of previous studies were noted, including insufficient data points and incomplete reporting of microphone placement or orchestra setup. Different instruments among the orchestra produce varying levels of noise and are highly directionally dependent, such that microphone placement affects the levels measured. Due to the limitations of position and variability among orchestras, O'Brien et al. (2008) concluded that previous results could not be generalized to other orchestras and attempted to explore the nature of orchestra sound with a systematic and position-specific approach.

The authors proceeded to perform a more detailed and specific study, measuring exposure levels of the Queensland Orchestra over a period of three years. They systematically took into account venue, repertoire, instrument, position within a section, and distance between dosimeter and instrument. Careful analysis was performed to remove any artifacts. They concluded that SPLs varied greatly depending on venue, repertoire, instrument, position, and duration, and that musicians in close proximity do not necessarily share the same risk profile.

Orchestral recordings made over a period of three years by O'Brien et al. (2008), revealed the mean SPL ranged from 85.1 dBA L_{eq} for first violinist to 86.7 dBA L_{eq} for tympani player. However, the variability of levels within one position also varied across instrument positions. Overall, brass players were at greatest risk of overexposure, specifically trumpet, horn and trombone players. Percussionists and timpani players were exposed to highest peak noise levels of 144 dBC (O'Brien et al., 2008). Most importantly, they caution that the nature of orchestra noise is complex and individualized, and that any further risk assessments for the purpose of noise protection or legislation will have to be meticulously detailed when it comes to orchestra musicians.

Rodrigues et al. (2014) based on the work of O'Brien et al. (2008), conducted a study measuring the exposure levels of an orchestra in Portugal in order to compare sound pressure levels of different positions in the orchestra over varying repertoires to the current European guidelines for occupational noise exposure, referred to as the ISO 9612:2009. While the string musician and the conductor were exposed to eight-hour equivalent exposure levels, L_{eq8}, below the legislative cutoff of 85 dBA L_{eq}, the woodwinds and brass exceeded it with mean L_{eq8} of 85 dBA L_{eq} and 87.7 dBA L_{eq} respectively. The percussion levels were just under the upper limit at 84.3 dBA L_{eq}. It is important to note however, that all the instrument groups exceeded the lower limit of 80 dBA L_{eq}. Peak sound pressure levels fell within the lower actionable limit of 135 dB, for all instrument groups aside from the percussion and tympani, with a maximum peak measurement of 135 dB. The authors noted two significant differences in how the extrapolated sound exposure levels were calculated in their study compared to previous studies. Firstly, an eight-hour equivalence was calculated to estimate a daily exposure rather than using data to extrapolate for SPL for a year, which does not take repertoire changes into account. Secondly, they used a baseline of 70dB instead of 0, pointing to the many hours of individual practice exposure that musicians are exposed to as part of their profession.

Music Levels in Jazz Bands

Jazz is a particular genre of music that is characterized by the use of brass instruments and a relatively wide dynamic range compared with other genres of music. Gopal et al. (2013) measured the sound exposure of music students studying jazz in a typical instructional session, required as part of a student's collegiate training. The study included 24 participants, an experimental group consisting of 14 music major students, and a control group consisting of 11 students who were in a non-music classroom setting. Dosimeters were placed on all the participants in both the control and experimental group, and measurements were taken over 50-minute classroom sessions. The authors noted that a typical jazz band practice session includes moments of verbal instruction in addition to music playing, therefore results may vary across different sessions due to instructor stylistic differences. Recordings were made and averaged over two separate sessions to attempt to account for variability.

The results of the study revealed that the noise exposure levels in the control group ranged from 46.4 dBA to 67.4 dBA with a mean of 49.9 ± 10.6 dBA. In contrast, the experimental group, the students in the jazz practice sessions, were exposed to levels ranging from 95 dBA to 105.8 dBA with a mean of 99.5 ± 2.5 dBA. This stark contrast implies that music students are consistently exposed to nearly double the exposure levels of noise throughout their schooling when compared with students of non-musical disciplines. Based on these results, the researchers calculated the equivalent daily dose, as set forth by NIOSH, that students were exposed to during the 50-minute jazz session; dosages ranged from 100.1% to 825%, greatly exceeding the daily dosage limit recommended for protection of 100%. It is important to note that a dosimeter reading of 90 dBSPL over a period of eight hours is considered a noise dose of 100%, as per the OSHA (1983) criteria. The authors recognized that this study is limited to recordings from one jazz-instruction class and one control classroom. Noise exposure levels will vary across classes, professor instructional style, choice of music and ratios of instrumentation. Nevertheless, they present these findings in an effort to bring awareness to the potential risks of developing NIHL associated with jazz band practice and the lack of protective regulations.

Henoch and Chesky (2000) also conducted a study measuring the equivalent level of noise exposure in school jazz bands to determine the noise exposure of young school musicians. They then compared their dosimeter findings with the damage risk criteria developed by OSHA (OSHA, 1983). The authors discussed the potential risk presented to students who play in ensemble jazz orchestras, specifically noting the overall high intensity (wide dynamic) achieved during rehearsals and performances of ensembles in this genre, the close proximity of players to the multiple instruments surrounding them, and the extended register, including high-frequency input, that are associated with NIHL notches.

Dosimeter measurements were taken during 50-minute rehearsal sessions over a three-day period in the typical arrangement, with the student musicians wearing the dosimeter microphone on the right shoulder. There were 15 different dosimeter measurements taken, including the average SPL of the 50-minute recording time and equivalent noise doses of three hours, the typical length of a jazz performance, and eight hours, to compare results relative to the OSHA criteria of a typical work shift.

The resulting measurements showed that there were differences across the different musicians' instruments, with the alto sax and trombone having the highest SPL, followed by the trumpet, percussion and bass, for the length of the recording session. The lead players of the alto sax and trombone were exposed to the highest levels of noise and also exceeded the OSHA criteria for the 3-hour equivalent doses. When extrapolating the equivalent 8-hour dose, the noise levels of all the ensemble sections exceeded the OSHA criteria.

The researchers noted that given the hours of practice, rehearsal, and performance of the typical college jazz musician, it is likely that he or she is exposed to the 8-hour equivalent dose extrapolated from the dosimeter readings, thus far exceeding the OSHA damage risk criteria. They petition that a standard of noise exposure risk includes musicians, *and* student musicians, as the equivalent noise levels they measured exceeded the current definition of occupational damage risk criteria. Moreover, they point out that the jazz ensemble is an unamplified band, as opposed to heavy metal or rock bands, suggesting that levels of exposure to musicians of those genres likely surpass those measured, and would benefit from standardization of risk criteria.

DJ/Nightclub Music Levels

Bray et al. (2004) recorded the exposure levels of DJs in a variety of settings in a number of Edinburgh nightclubs. Dosimetry recordings were taken over 11 music sessions, ranging from 56 minute to approximately four hours in duration, at various locations, thus representing the variability in venue and time that DJs are exposed to loud music. Recordings were made in both the main room of the venue as well as in the smaller, back rooms, with music of varying nightclub genres represented. The range of exposure levels was found to be 97.8 to 107.9 dBA, with peak values as high as 108 dBA. The extrapolated average of 96.1 dBA with no additional noise exposure outside the set, was calculated (Bray et al., 2004).

Santos et al., (2007) obtained dosimeter recordings from 21 Brazilian DJs across 5 club locations to serve the purpose of their study's aim of demonstrating damage-risk relationships. Audiometric data, including audiometric thresholds, tympanometry, OAEs and self-report of tinnitus and other perceptual measures, were also obtained from all the participants. Measurements ranging from 93.2 dBA to 109.7 dBA, using a 5-dB exchange were obtained, all vastly exceeding the 85 dBA legislative limit in Brazil. No extrapolated measures were reported. The authors noted that DJs report variability in their schedules and exposure levels from week to week, thus making it difficult to evaluate the overall exposure levels of DJs and to recommend appropriate protection guidelines.

Musicians, disk jockeys (DJs), and other nightclub employees may indeed incur dangerous levels of noise in their work environment in the form of music. A study conducted by Kelly et al. (2012) examining the noise levels experienced by nightclub bar employees in 9 nightclubs in Ireland found that the average bar employee is exposed to 4 times the accepted legal limit. The average L_{eq} they recorded was 92 dBA. Furthermore, they also assessed the employees' knowledge base and awareness of existing legislation which they found to be sorely lacking and ignorant of both the dangers of noise exposure and the legislation surrounding employee protection. Only one of the nine clubs they studied had mandated hearing protection for its employees.

A digital sound level meter (SLM) was utilized to obtain recording of the average noise level. It was placed in a fixed position behind the dance floor at nine different bars/discotheques in Ireland. Three eight-minute recordings were taken at 45 minute intervals from 11:30 pm to 1:00 am, the time period in which these venues have the highest number of patrons and thus the subjectively loudest time period. The total L_{eq} ranged from 77 dBA to 98 dBA across the different venues, with a trend toward increased L_{eq} throughout the night at all 9 clubs measured (Kelly et al., 2012).

Additionally, bar employees had attached dosimeters that they wore to obtain specific measurements of individual exposures throughout the work shift. Of the 17 employees who wore the dosimeters, 86% (13) of them were exposed to levels that exceeded the exposure limit of 87 dBA. All the employees exceeded both the lower and upper limits of 80 dBA and 85 dBA under the 2007 Noise Regulations set by the Irish Government's "Safety, Health and Welfare at Work."

The noise exposure of servers, bartenders, and sound and lighting crews at music venues such as nightclubs was also examined. Although these individuals are not musicians, they are continuously exposed to noise levels in the form of music in their occupational setting. Gunderson et al. (1997) used dosimeter recordings to assess these levels. Measurements were taken in eight New York music venues, playing music of differing genres, in specific locations that approximate the location of these employees, such as behind the bar. The average sound level (L_{eq}) was calculated and revealed levels of noise ranging from 91.9 dBA to 99.8 dBA which surpass the OSHA standard. Venues playing hard rock, rock and blues all exceeded the peak measurements of 115 dBA.

In summary, O'Brien et al. (2008) and Rodrigues et al. (2014) who both measured orchestra noise levels found that noise levels varied greatly among the different orchestra musicians' position and instrument. The recorded range of averages had relatively wider spreads when compared with the other studies examined, by virtue of the wide range of dynamics characteristic of orchestras. In addition, L_{eq} values were sometimes less than and sometimes slightly above the OSHA legislative limit of 85 dBA. Contrary to that, Gopal, et al. (2013) and Henoch and Chesky (2000) who evaluated the noise exposure levels in student jazz band ensembles far exceeded the standard, with L_{eqs} of 95 dBA and 91-98 dBA, respectively. Similarly, in the studies that measured noise exposure levels of DJs, Bray et al. (2004) found an L_{eq} average of 96 dBA, and Santos et al. (2007) measured noise levels ranging from 93.2 dBA to 109.7 dBA. Gunderson et al. (1997) noted that exposure levels far exceeded standards for nightclub employees even when accounting for ambient levels between performances. Kelly et al. (2012) measured an L_{eq} of 92 dBA for non-musician nightclub and bar employees. The above data show that extrapolated exposure levels were below or slightly above the allowable exposure limit for orchestra musicians, but far exceeded those safety standards among Jazz ensembles, DJs and nightclub employees.

Effects on Hearing Thresholds

To address the second research question, an additional metric was reviewed, that of audiometric hearing thresholds. Decreases in pure tone thresholds were measured, both by determining their presence in a sample of DJs, or by measuring pre- and post- exposure thresholds. In the study noted by Gopal et al. (2013), pure tone audiometry was conducted in order to obtain thresholds for the 14 jazz band students and 11 non-music control participants before and after exposure to the jazz ensemble session and the non-music instructional session, respectively. Testing of 250-8000 Hz was conducted in a sound-treated room with a calibrated GSI-17 audiometer and associated equipment, i.e. headphones. The pre-exposure thresholds were within normal limits for all the participants from 250-8000 Hz, with one exception- a jazz student with a threshold of 30 dBHL at 6000 Hz in one ear. Whereas post-exposure threshold testing revealed no difference in the control group after being exposed to a non-music instructional session, there was a significant decrease seen in hearing thresholds at the 4000 Hz frequency in the experimental group. The decrease had a mean of 1.9 dBHL in the right ear and a mean of 4.1 dBHL in the left ear. This decrease was not seen when testing was repeated in half of the test participants one week after, suggesting that the decrease was evidence of a TTS following exposure to band ensemble practice (Gopal et al., 2013).

Santos et al. (2007), measured pre- and post- audiometric threshold data from 500-8000 Hz, using an Interacoustic AC 40 audiometer, in the 30 participant DJs before and after performance sets lasting an average of 2 hours. Mean group thresholds were reported, revealing a significant decrease for all post exposure thresholds in both ears. The maximum decrease in thresholds was centered around 4000 Hz, from 3000-6000 Hz (Santos et al., 2007).

Bray et al. (2004) obtained audiometric thresholds from 500-8000 Hz, including 3000 and 6000 Hz, of 23 DJs who had a mean of 8 years of experience working as DJs. Of the 18 males and 3 females tested, three subjects were found to have decreased hearing thresholds at and around 4000 Hz, indicative of NIHL, and another four subjects had decreased air and bone conduction thresholds indicative of sensorineural hearing loss. Hearing thresholds were considered to be within normal limits for 14 of the DJs, and two others had unilateral hearing loss thought to be secondary to childhood middle ear pathology and tympanic membrane perforations. A majority of the DJs reported experiencing TTS, as well as tinnitus, after work. While this study did not measure pre- and post- exposure thresholds as did the above studies, this data presents evidence of PTS seen in a subset of DJs who are exposed to noise levels that exceed safety limits on a regular basis (Bray et al., 2004).

Music Exposure and OAEs

Musicians, as a group, represent a population that is necessarily exposed to music for many hours each week over many years. What evidence exists of alterations in the auditory system of musicians compared with non-musicians? OAEs may be able to evaluate different aspects of auditory function in an objective manner. OAEs are thought to originate in the outer hair cells as a result of cochlear nonlinearity of the response to incoming sounds. In order to evoke OAEs, a sound stimulus is introduced through a probe that also has a very sensitive microphone which records the resulting emissions. Table 3 summarizes the studies that were included in this review to determine the relationship between music exposure with OAE's

Table 3. Summary of Studies Reviewed to Answer the Third Research Question

Authors, publication date	Title	Subjects, Variables	Results
Bhagat & Davis, (2008)	Modification of otoacoustic emissions following ear-level exposure to MP3 player music.	-20 normal-hearing adults - DPOAEs were acquired before and after a 30-minute MP3 player music exposure.	**DPOAE levels in half-octave bands centered from 1.4 6.0 kHz were significantly reduced** following the music exposure.
Bockstael, Keppler, & Botteldooren, (2015)	Musician earplugs: Appreciation and protection	-59 (age 18-30) NON MUSICIANS -Five different types of commercially available hearing protectors used. -During five different test sessions of 30 min each, participants **not professionally involved in music** wore one particular type of protector. Otoacoustic emissions (OAEs) were measured directly before and after music exposure.	The changes in OAE amplitude before and after noise exposure were small in terms of clinical standards. Nevertheless, the observed temporary shifts differed systematically for the different types of hearing protectors, with two types of musician earplug showing a more systematic decline than the other three types.
Brashears, Morlet, Berlin, & Hood, (2003)	Olivocochlear efferent suppression in classical musicians.	-29 members of the Louisiana Philharmonic Orchestra and 28 non-musician control subjects matched for age and gender. -Suppression of transient-evoked	Results showed **musicians to have significantly more suppression than non-musicians** for both the right and left ears.

		otoacoustic emissions were measured.	
Gopal, Chesky, Beschoner, Nelson, & Stewart, (2013)	Auditory risk assessment of college music students in jazz band-based instructional activity.	-14 college jazz students and 11 non-music students -50-min jazz session compared to 50 minutes of regular classroom activity (control) -Measured and compared pre- to post-auditory changes associated with these two types of classroom exposures.	A significant decrease in the amplitude of transient-evoked otoacoustic emission response in both ears ($P < 0.05$) after exposure to the jazz ensemble-based instructional activity.
Santos, Morata, Jacob, Albizu, Marques, & Panini (2007).	Music exposure and audiological findings in brazilian disc jockeys (DJs).	**-30 DJs** **-Transient and distortion product otoacoustic emissions** before and after their exposure to music during their work.	Transient **otoacoustic emissions showed a significant difference in bilateral amplitude and reproducibility at all frequency bands tested**.

In the absence of significant audiometric threshold shifts following music exposure, decreases in OAEs have been shown to occur post music exposure in numerous studies. Bhagat and Davis (2003), evaluated DPOAEs in half-octave frequency bands of 20 normal hearing listeners after exposing them to 30 minutes of music via a personal music player, i.e. MP3 player. Real-ear probe microphone measurements were utilized to ensure that the exposure level remained at 85 dB ±3dB in the ear canal. In line with previous studies, significant decreases in DPOAEs occurred in the post-exposure evaluation of 50-65% of participants, differing at different frequencies. The authors posit that OAEs can be used as a reliable measure of changes to the auditory system as a result of music, not only steady-state continuous noise.

In another study done by Bockstael, Keppler and Botteldooren (2015), in which the aim was to evaluate different attenuated earplugs, one of the dependent variables was OAEs measured pre- and post- exposure to music. The research room was equipped with speaker systems to mimic a bar, and continuous contemporary style music was playing. Participants spent 30-minute blocks of time in the room exposed to the music, measured at 90 to 95 dBA L_{eq}. While this study did not perform any analysis of OAEs before and after music exposure without ear protection (in order to adhere to protective legislation), the five earplugs tested did have variable OAE shifts in the pre- and post- conditions. This study represents another way in which OAEs are used as a research tool to evaluate changes to the auditory system in response to music.

With regard to occupational music exposure, studies have also shown changes to the auditory system that can be detected by OAE measurements. In two of the studies mentioned above (Gopal et. al., 2013; Santos et. al., 2007), OAEs were measured pre- and post- exposure to music, demonstrating shifts in OAE amplitude. In the study by Gopal et. al. (2013), the OAEs of the jazz band musicians were measured before and after an ensemble practice. A significant negative difference in OAE amplitude was noted in the experimental group compared with the control group of non-music students. Santos et al. (2007) in the study of Brazilian disk jockeys, reported decreased response amplitudes in the post-exposure TEOAE's signal-to noise ratio and a decrease in reproducibility. Changes in OAE amplitude and reproducibility are consistent with disordered cochlear function, illustrating the damaging effects of occupational music exposure on outer hair cell function.

Furthering the idea that occupational music exposure can lead to changes in OAEs, Brashears, Morlet, Berlin and Hood (2003) measured the specific OAE suppression pattern in orchestra musicians. The researchers examined the phenomenon of otoacoustic emission suppression in response to broadband noise stimuli. Previous studies employed a protocol in which broadband noise is presented to one ear, while OAEs are measured in the contralateral ear.

Suppression of the emissions typically results, and previous studies have shown that this suppression is greater among musicians. The medial olivocochlear system in the lower brainstem is presumed to be responsible for this phenomenon. Building on the work of previous studies, the researchers created a testing paradigm that presented broadband noise stimulation to both ears simultaneously in order to take into account both the ipsilateral and contralateral pathways of the medial olivocochlear pathways, while measuring OAEs. Their study included an experimental group of orchestra musicians and a matched control group. The results were consistent with previous studies, showing a significantly greater suppression of OAEs in the musicians group than in the control group (Micheyl, Carbonnel, & Collet, 1995). Based on this result, the researchers discussed the effects of cumulative exposure to music on auditory pathways. While it is known that OAEs are negatively impacted by continuous exposure to noise, the specific deviations in OAEs in response to occupational music, which has great variability in its loudness, duration of exposure and frequency range, have also been demonstrated (Brashears et al., 2003).

In summary, OAEs have been used as an objective measure of cochlear dysfunction, as a result of noise exposure. Bhagat and Davis (2003) showed that changes in DPOAE amplitude were measured after controlled music exposure in at least half of the participants. Similarly, Bockstael et al. (2015) utilized OAE measurements as a dependent variable when comparing the efficacy of various ear plugs, demonstrating the sensitivity of OAEs in response to music as an acoustic stimulus. Changes in OAEs have also been demonstrated with occupational music exposure; Gopal et al. (2013) and Santos et al. (2007) performed OAE testing before and after exposure to jazz ensemble session and DJ sets respectively, with noted differences in OAE amplitude and reproducibility in both. Further delineating the specific OAE suppression pattern, Brashears et al. (2003) measured greater suppression of OAEs in the experimental group of musicians compared to their non-musician counterparts. Changes in OAEs that are consistent with cochlear dysfunction have been demonstrated in the cases where noise exposure has been occupational music.

Discussion

The review of the included studies demonstrates the great variability that exists in the area of music-induced hearing loss research. The term “music” itself encompasses a very wide range of acoustic inputs, across various genres (i.e. classical, jazz, rock, metal etc.), production methods (string instruments, woodwinds, brass, electronic, etc.) and exposure settings (performance hall, at-home practice, nightclub, classroom etc.). The review of measured L_{eq} levels from the body of research serves to highlight this spread.

There are a number of difficulties that arise when noise dosimetry is undertaken and L_{eq8} levels are extrapolated. Dosimetry data is typically collected for a relatively short duration time, with the L_{eq8} then extrapolated. This leads to the possibility of over- or under-estimating intensity levels of overall exposure depending on the levels obtained within the time recorded. The L_{eq8} may therefore not be a true representation of one’s actual noise exposure dosage. As seen in the above reviewed articles, the wide range of intensity levels within a recording session depicts the dynamic nature of music, in contrast to the steady-state noise typical of industrial machinery.

Another confounding factor in obtaining dosimetry readings that are accurate depictions of music exposure levels is the diversity of levels present even within one venue or stage. O’Brien et al. (2008) discuss the great variability in noise exposure within an orchestra based not only on the musician’s instrument of choice, but also on their surrounding instruments and even their position within their section. Henoch and Chesky (2000) concluded that the lead saxophone and trombone players within the jazz ensemble are exposed to the highest concentration of noise energy by virtue of being surrounded by musicians on all sides. Similarly, in Kelly et al. (2012), the exact location of the employee within the bar was a very significant factor in the level of noise exposure; being nearer to the speaker system, working the main/front room rather than the back room, and the structure of shifts all have an effect on the noise exposure dose. Gunderson et al. (1997) suggest that further research is needed in order to delineate the noise exposure levels of waiters, as well as sound and lighting personal who are typically closer to the sound source than bartenders.

Additionally, musicians' schedules are often variable and unpredictable, working as independent contractors, as opposed to stable employees. For example, the work structure of a DJ is rather unlike traditional occupations that have employees work eight-hour shifts in a predictable pattern; DJs typically work 2-4 nights per week, for 4-8 hours, although many report staying at the venue for longer periods of time even when they are not working (Santos et al., 2007). Performance musicians, such as jazz band musicians or orchestra musicians, also have atypical work structures that involve 3- or 4-month alternating seasons of practice and performance. Furthermore, L_{eq} values do not take into account hours of personal practice or recreational noise exposure that is expected and inherent to this population of musicians and those exposed to music professionally. Not only does this complicate research methods, it also places many musicians who are self-employed outside the reach of legislative bodies, making it difficult to monitor and regulate exposure levels and hearing sensitivity as well as provide protective guidelines. It is recommended that musicians and music students be included as an at-risk population under the purview of OSHA (Henoch & Chesky, 2000).

Zhao et al. (2010) conducted an extensive review of research that evaluated the relationship between music exposure and hearing loss. One of the most striking conclusions from that review was the differentiation between studies which found a relationship and those which did not is the use of sensitive audiologic measuring tools. The use of pure-tone averages (PTA) as a definition of hearing loss is not nearly as sensitive to cochlear damage as are OAEs, and high frequency audiometric testing, among others. Carter et. al. (2014) also examined a large body of research relating to how recreational noise exposure affects hearing and related auditory function. In discussing the methodological weaknesses that were present in some of the studies, they mention the inherent imprecision of pure-tone audiometric testing. When determining the hearing threshold of a subject, many factors play a role in obtaining the patient’s response, including the patient’s motivation, the expertise of the tester, the equipment, testing conditions and calibration. Furthermore, the issue of operationally defining NIHL is discussed on two fronts. First, the intensity that operationally defines hearing loss is subject to debate as to whether it is a pure tone average of 20 or 25 dBHL. Second, the configuration of audiometric results in which a notch between the 2-4 kHz region is typically associated with NIHL is neither sensitive nor specific in defining NIHL. For example, Gopal (2013) measured pre- and post-exposure audiometric thresholds and found a group mean difference in the experimental group of ~2-4 dBHL at 4000 Hz and no difference in the control group. The skepticism posed by Carter (2014) regarding the imprecision of pure tone audiometry and the debatable threshold of normal hearing may mitigate the clinical significance of this result.

The use of OAEs as a measure of inner ear function is utilized in many studies, and has been demonstrated as a promising research tool in determining NIHL susceptibility or preclinical damage, i.e. dysfunction of the outer hair cells that precedes decrease in hearing thresholds. The noninvasive, rapid and objective nature of OAE testing is regarded as superior to the time-consuming, labor-intensive, subjective method of pure tone audiometry (Mehrparvar et al., 2012). Often decreased or absent OAEs precede threshold changes, thus allowing for early detection and the possibility of prevention of music-induced hearing loss (Zhao et al., 2010). In line with previous studies that showed that OAEs were a reliable method of measuring NIHL, the results from studies reviewed above (Bhagat & Davis 2003, Gopal et al. 2013, and Santos et al. 2007) provided evidence that supports the use of OAEs in a music-exposed population, revealing measurable decreases in OAE amplitude after music exposure.

While OAE studies do provide a causal relationship, it is nonetheless difficult to provide high quality evidence to bolster the claim that noise exposure leads to dysfunction of the auditory system due to the many extraneous variables that may exist. Even when it is established that a population, in this case musicians, are exposed to hazardous levels of noise, the leap towards directing a causal relationship is confounded by the multifactorial nature of hearing loss and dysfunction. For instance, the presence of middle ear pathology, impacted cerumen, exposure to solvents, smoking, age-related hearing loss among others, may all prove relevant when examining the correlation. Longitudinal studies are necessary in order to support that NIHL can be caused by music exposure (Carter et. al., 2014).

The legislative guidelines relating to noise exposure in industrial settings enforce hearing conservation programs which include serial audiograms, mandating use of hearing protective devices, and implementing work hours to limit exposure doses. Musicians are at a unique disadvantage in that they are often outside of the jurisdiction of regulatory bodies such that no such measures are implemented or enforced. Even if hearing conservation programs were enforced for musicians, compliance may be limited as noise exposure is a requirement for the musician, and hearing protection may distort the frequency response that the musician needs to perform his occupation. Nevertheless, it is still worthwhile for the protection of musicians to at least establish awareness that there is evidence that occupational music can lead to NIHL, and provide information about the preventable nature of NIHL along with actionable steps to protect hearing.

Whereas NIHL has been studied on an epidemiologic basis in occupations with known exposure to sounds (including police, firefighters, farmers, pilots), there is a paucity of research in this regard in relation to musicians. The studies reviewing other industries are useful in helping guide further necessary research on musicians, since the challenges faced by these industries in adhering to and implementing noise conservation initiatives for their employees in some ways mirror those of the music industry. For example, there is a great range of work environments and worker mobility in both construction and music industries. In addition, construction workers are often employed per diem or with highly variable schedules, much like musicians. In a review of construction workers' exposure to noise conducted by Suter (2002), the greatest perceived barrier of hearing protective devices among construction workers was the fear of missing an important communication or warning signal on the job site. This is somewhat comparable to the perceived barrier of musicians who often report that a barrier of HPD use is distortion of the music and not being able to hear the music they, or their co-performers, are creating in real time (Suter, 2002).

Conclusion

- There is evidence which provides support that musicians, music professionals, and those working in music environments are exposed to occupational music at levels that are consistent with those that are considered to be potentially damaging, as delineated by regulatory agencies. This was found to be particularly true with regard to those working in jazz ensembles, and working as DJ's and in clubs.

- Decreased hearing thresholds have been demonstrated in those exposed to music occupationally in a number of studies.
- OAEs are an effective clinical and research tool in evaluating NIHL susceptibility and signs of auditory damage post music exposure.
- Due to limitation in the design of many studies in this area, future research is needed to address research design issues, including:
  - Exposure dose and duration is highly variable, dependent on the particular type of music, setting, schedule, and instrumentation, among many other variables. There are limitations in the way noise exposure can be measured; nevertheless, the use of dosimetry presents representative data that needs to be taken into account when evaluating the occupational noise level that workers exposed to music face.
  - Areas of further research need to encompass the highly diverse nature of musicians' employment.
  - Longitudinal studies are needed to determine if the hearing loss sustained by musicians can be truly causally linked to their music exposure.
- Until more definitive findings can be ascertained, risk reduction measures, including educational initiatives, hearing protection, and audiometric monitoring**,** are recommended, as noted in nearly all of the studies examined.

References

Abdi, S. (2011). Music induced hearing loss... 10th european federation of audiology societies (EFAS) congress. *Journal of Hearing Science, 1*(1), 118-118.

Bhagat, S. P., & Davis, A. M. (2008). Modification of otoacoustic emissions following ear-level exposure to MP3 player music. *International Journal of Audiology, 47*(12), 751-760. doi:10.1080/14992020802310879

Bockstael, A., Keppler, H., & Botteldooren, D. (2015). Musician earplugs: Appreciation and protection. *Noise & Health, 17*(77), 198-208 11p. doi:10.4103/1463-1741.160688

Brashears, S. M., Morlet, T. G., Berlin, C. I., & Hood, L. J. (2003). Olivocochlear efferent suppression in classical musicians. *Journal of the American Academy of Audiology, 14*(6), 314-324 11p.

Bray, A., Szymanski, M., & Mills, R. (2004). Noise induced hearing loss in dance music disc jockeys and an examination of sound levels in nightclubs. *Journal of Laryngology & Otology, 118*(2), 123-128.

Gopal, K. V., Chesky, K., Beschoner, E. A., Nelson, P. D., & Stewart, B. J. (2013). Auditory risk assessment of college music students in jazz band-based instructional activity. *Noise & Health, 15*(65), 246-252. doi:10.4103/1463-1741.113520

Gunderson, E., Moline, J., & Catalano, P. (1997). Risks of developing noise-induced hearing loss in employees of urban music clubs. *American Journal of Industrial Medicine, 31*(1), 75-79.

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

Hong, O., & Samo, D. (2007). Hazardous decibels: Hearing health of firefighters. *AAOHN Journal : Official Journal of the American Association of Occupational Health Nurses, 55*(8), 313-9.

Kales, S. N., Freyman, R. L., Hill, J. M., Polyhronopoulos, G. N., Aldrich, J. M., & Christiani, D. C. (2001). Firefighters' hearing: a comparison with population databases from the International Standards Organization. *Journal of Occupational and Environmental Medicine, 43*(7), 650-656.

Lesage, F., Jovenin, N., Deschamps, F., & Vincent, S. (2009). Noise-induced hearing loss in French police officers. *Occupational Medicine,* 483-486.

Lutman, M. (2000). What Is the Risk of Noise-Induced Hearing Loss at 80, 85, 90 dB(A) and Above? *Occupational Medicine,* 274-275.

Micheyl, C., Carbonnel, O., & Collet, L. (1995). Medial olivocochlear system and loudness adapation: Differences between musicians and non-musicians. *Brain and Cognition, 29*(2), 127-136. doi:10.1006/brcg.1995.1272

Mil'kov, A. A., & Gofman, V. R. (2006). [Hearing loss as an occupation pathology in civil pilots]. *Aviakosmicheskaia i ekologicheskaia meditsina= Aerospace and environmental medicine*, *41*(3), 52-56.

Kelly, A. C., Boyd, S. M., Henehan, G. T. M., & Chambers, G. (2012). Occupational noise exposure of nightclub bar employees in ireland. *Noise & Health*, *14*(59), 148-154. doi:10.4103/1463-1741.99868

Kemp, D. T. (2002). Otoacoustic emissions, their origin in cochlear function, and use. *British Medical Bulletin, 63*223-241.

Kim, M. G., Hong, S. M., Shim, H. J., Kim, Y. D., Cha, C. I., & Yeo, S. G. (2009). Hearing Threshold of Korean Adolescents Associated with the Use of Personal Music Players. *Yonsei Medical Journal Yonsei Med J, 50*(6), 771. doi:10.3349/ymj.2009.50.6.771

Marshall, L., Miller, J. A. L., & Heller, L. M. (2001). Distortion-product otoacoustic emissions as a screening tool for noise-induced hearing loss. *Noise and Health*, *3*(12), 43.

Neitzel, R., Seixas, N. S., Camp, J., & Yost, M. (1999). An assessment of occupational noise exposures in four construction trades. *American Industrial Hygiene Association Journal*, *60*(6), 807-817.

Neitzel, R., Gershon, R. M., Zeltser, M., Canton, A., & Akram, M. (2009). Noise Levels Associated With New York City's Mass Transit Systems. *American Journal Of Public Health*, *99*(8), 1393-1399.

NOISE AND HEARING LOSS PREVENTION. (2017, January 13). Retrieved January 25, 2017, from https://www.cdc.gov/niosh/topics/noise/

O'Brien, I., Wilson, W., & Bradley, A. (2008). Nature of orchestral noise. *The Journal of the Acoustical Society of America*, *124*(2), 926-939.

Rodrigues, M., Freitas, M., Neves, M., & Silva, M. (2014). Evaluation of the noise exposure of symphonic orchestra musicians. *Noise and Health, 16*, 40.

Root, K. S., Schwennker, C., Autenrieth, D., Sandfort, D. R., Lipsey, T., & Brazile, W. J. (2013). Firefighter Noise Exposure During Training Activities and General Equipment Use. *Journal Of Occupational & Environmental Hygiene*, *10*(3), 116-121. doi:10.1080/15459624.2012.753023

Santos, L., Morata, T. C., Jacob, L. C., Albizu, E., Marques, J. M., & Paini, M. (2007). Music exposure and audiological findings in brazilian disc jockeys (DJs). *International Journal of Audiology, 46*(5), 223-231. doi:10.1080/14992020601188575

Seixas, N. S., Kujawa, S. G., Norton, S., Sheppard, L., Neitzel, R., & Slee, A. (2004). Predictors of hearing threshold levels and distortion product otoacoustic emissions among noise exposed young adults. *Occupational and environmental medicine*, *61*(11), 899-907.

Suter, A. (2002). Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis. *AIHA Journal,* 768-789.

Zhao, F., Manchaiah, V. K., French, D., & Price, S. M. (2010). Music exposure and hearing disorders: An overview. *International Journal of Audiology, 49*(1), 54-64.

Zytoon, M. (2013). Occupational noise exposure of fishermen aboard small and medium-scale fishing vessels. *International Journal of Industrial Ergonomics,43*(6), 487-494.

Zhang, Y., Zhang, X., Zhu, W., Zheng, X., & Deng, X. (2004). Distortion product of otoacoustic emissions as a sensitive indicator of hearing loss in pilots. *Aviation, space, and environmental medicine*, *75*(1), 46-48.