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Entertainment-Related Excessive Sound Exposure (ERESE): Associated Audiometric-Threshold Patterns

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ABSTRACT

Previous studies have reported that exposure to hazardous sounds can result in a mild to profound degree of temporary and permanent hearing loss. Typically, individuals exposed to loud industrial noise develop a notch or dip at or near the pure-tone test frequency of 4,000 Hz. Exposure to hazardous recreational and work-place sound has been associated with noise-induced hearing loss (NIHL) and tinnitus has been associated with exposure to high-intensity concert sound as well. The purpose of this project was to report whether audiometric patterns have been reported in the literature that may be associated with entertainment-related excessive sound exposure (ERESE). Over 30 articles were read and a total of 14 articles were analyzed for this literature review. We determined that extended ERESE primarily affects hearing thresholds in the high-frequency range. This result is consistent with the audiometric configuration of occupational NIHL. To prevent NIHL and ERESE, hearing protection should be worn properly and for the entire duration of exposure. Altogether, limited research was discovered that identified audiometric configurations associated with ERESE, so more research is needed to gather clinical evidence about audiometric outcomes and best practices for hearing loss prevention.

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CHAPTER 1

Introduction

Noise-induced hearing loss (NIHL) has been considered the most preventable type of hearing impairment. Although exposure to noise can cause temporary hearing shift, continuous noise exposure may be cumulative, which results in permanent hearing loss (Yassi, Pollock, Tran, & Cheang, 1993). Hazardous noise may be defined as a sound that is equivalent to, or exceeds, 80 decibels (dB) with exposure of at least 40 hours per week (Le Clercq, Van Ingen, Ruytjens, & Van Der Schroeff, 2016). Noise-induced hearing loss is generally characterized by a threshold notch on the audiogram involving the pure-tone frequencies 3,000, 4,000, or 6,000 Hz, with hearing-threshold recovery at 8000 Hz. This impairment type is usually cochlear, diagnosed as sensorineural and typically bilateral (Kirchner, Evenson, Dobie, Rabinowitz, Crawford, Kopke, & Hudson, 2012), and results from trauma to the blood supply and hair cells within the cochlea structures (Le Clerq et al., 2016) due to the nature of the injury. Exposure to hazardous noise results in hearing loss and produces symptoms such as tinnitus, hypersensitivity, or perceived temporary hearing loss (Bohlin & Erlandsson, 2007). Noise exposure alone typically does not produce a hearing loss that is greater than 75 dBHL in the high frequencies and 40 dBHL in the low frequencies (Le Clercq, Van Ingen, Ruytjens, & Van Der Schroeff, 2016). Presbycusis can produce a high-frequency hearing loss that is similar to NIHL and develops from aging. With presbycusis, hearing threshold does not typically recover at 8000 Hz, whereas, it does for NIHL. Noise exposure, when accompanied by presbycusis, can lead to greater severity of hearing loss (Kirchner et al., 2012).

Exposure to high-intensity noise can result in temporary threshold shift (TTS). A TTS may be defined as a temporary hearing impairment that typically happens after exposure to high-intensity sound with elevation to the quietest sound that can be perceived (Yassi et al., 1993). A TTS may serve as an early indicator that permanent NIHL will eventually occur if high levels of noise exposure continue (Kirchner et al., 2012). In other words, continuous exposure to noise and repeated TTS may eventually lead to a permanent threshold shift (PTS). A PTS is a permanent reduction in hearing (Hutchinson & Schulz, 2014) and it is vital to prevent that from occurring.

High-intensity sound exposure may be produced by occupational noise and recreational activities. In the United States, work-related noise exposure is regulated by the Occupational Safety and Health Administration (OSHA, 1983). Presently, OSHA defines the amount of noise a worker can withstand in a given day, in order to avoid injury (Opperman, Reifman, Schlauch, & Levine, 2006). It is important to monitor daily noise exposure levels, commonly represented by safety professionals as noise dose, which is the percentage of allowable noise exposure a worker has experienced (Hutchinson & Schulz, 2014). It incorporates the permissible exposure limit (PEL) and the exchange rate. According to the Occupational Safety and Health Administration (OSHA, 1983), the PEL is one hundred percent of a noise level acceptable for an 8-hour day when the sound level is 90 dBA. Sound levels are typically measured using the A-Weighting scale because it is most predictive of the effect of noise on human hearing and may be used to predict sensitivity and auditory responsiveness to noise. The exchange rate reflects the association between allowable exposure times and specific noise levels. OSHA uses a 5-dB exchange rate, which indicates that an increase of 5 dBA is equivalent to doubling of the dose. Per OSHA (1983), exposure to 90 dBA is permissible for 8 hours; whereas, exposure to 95 dBA is allowable for 4 hours. Table 1 depicts this relationship, which is OSHA's standard for noise exposure (Opperman et al., 2006). At the time this report was completed, no U.S. regulation for recreational noise exposure existed.

Sources of high-intensity sound, such as gunshots, nightclubs, loud motors, power tools, and music concerts, create hazardous exposure levels even though they are leisure activities. At the time this report was written, there were no sound exposure standards for concertgoers. A study by Opperman et al. (2006) reported that mean sound levels were 99.8 dBA with a peak intensity of 125.6 dB for three different concerts across three music genres. In a different study (Bogoch, House, & Kudla, 2005) reported that noise exposure at concert venues can result in sound pressure levels varying from 90 dBA to over 100 dBA when measured using personal dosimetry and stationary area-monitoring sound level meters. When comparing these reported sound measurements to the OSHA (1983) standard, it is evident that use of appropriate hearing protection should be required for concertgoers. According the OSHA (1983) guidelines, a two-hour music concert with an average sound exposure level of 100 dBA would reach 100% dose, and continuous exposure from the concert could be harmful. Many concerts last longer than two hours and most concert attendees do not use hearing protection. Taken together, concertgoers are over-exposed to high intensity sound that may result in a TTS and, eventually, PTS.

The purpose of this literature review is to identify if hearing threshold loss and any audiometric patterns might be associated with concert attendance and other forms of high-intensity entertainment. Our assumption is that hearing thresholds for avid concertgoers will approximate threshold patterns typically seen with occupational NIHL.

CHAPTER 2

Methodology

Search Procedure

Two databases, ComDisDom and PubMed, were used to obtain publications for the literature review. In all searches, an advanced inquiry method was performed using terms such as “*Concert noise* AND *hearing threshold*” as well as “*Concert noise* AND *hearing*”. Additional resources were provided by my capstone advisor to support this review.

For the selection process, articles about audiometric threshold changes following exposure to loud entertainment sound were included. Book chapters were excluded. Selected publications were all written in English and there were no age or gender-specific requirements for articles retained for final review. In addition, six articles were recommended by my capstone advisor to promote further research for this study. Overall, 14 articles were used to complete this literature review. Figure 1 illustrates how the two research databases performed for the article search and selection.

ComDisDom generated eight articles that were retained for review (see the first panel on Figure 1). Only three of those publications were accepted after finer analysis, so ComDisDome had a hit rate of 37.5%. An additional article was retained from this database that provided information on noise-induced tinnitus resulting from concert attendance; however, this article did not report any associated audiometric configurations.

An additional search was conducted using PubMed, which produced 10 articles that were held for further review (see Figure 1). Only five articles were retained after full analysis of these publications, so PubMed had a hit rate of 50%. My Lab Project Advisor contributed 6 relevant articles for the review or 42.8% of the final set of reviewed reports. Consequently, (3/14) 21.4% of the final article set were discovered through ComDisDome and (5/14) 35.7% from PubMed.

Search term combinations were entered into the databases. Table 2 lists search terms that were used and the number of articles provided by the ComDisDom and the PubMed databases. ComDisDome initially generated 49 articles using the search terms listed in the Table (2). PubMed initially yielded 114 articles using the search terms listed. Of 49 articles from ComDisDome, 18.3% (9/49) were selected for full review in the intermediate stage. From PubMed, 8.7% (10/114) were selected for intermediate full review. The search terms that generated the greatest number of retained articles were *Hearing* AND *Loud Music Exposure,* which produced three related publications through PubMed. Furthermore, PubMed generated the most articles in the initial, intermediate, and final phases of the literature search.

All 14 articles described specific audiometric configurations resulting from concert attendance, which ranged in the date of publication from 1991 to 2016. Acceptable publications were obtained from the following journals: The Journal of the Acoustical Society of America, Canadian Family Physician, Audiology: Official Organization of the International Society of Audiology, Archives of Acoustics, Otology and Neurotology, Noise and Health, International Journal of Audiology, Journal of the Royal Society of Medicine, Brazilian Journal of Otorhinolaryngology, and Otolaryngology - Head and Neck Surgery. Although multiple search terms were used, few publications were discovered. Notably, the term *Audiometric Patterns* did not return any relevant references; however, terms that included *Hearing* or *Hearing Threshold* produced references that were relevant to the topic of interest.

CHAPTER 3

Results

Using the paradigm described in the previous section, 14 articles were discovered that described audiometric patterns associated with exposure to high-intensity entertainment noise. Opperman et al. (2006) studied the use of hearing protection and the incidence of hearing threshold shifts following modern concerts. Their data revealed that 9 out of 14 participants that were not wearing hearing protection incurred a significant threshold shift (STS), which was calculated using one of the following protocols:

(1) OSHA STS criterion

(2) American Speech-Language and Hearing Association (ASHA) definition

(3) Multinomial statistical procedure

Each of these methods identified a threshold shift using the test frequencies 2,000 Hz, 3,000 Hz, and 4,000 Hz and their pure-tone average (PTA), a conventional occupational calculation. For a work-place environment, identification of a STS would, with a best practice approach, require retest, counseling and education, and hearing protection re-fit training, in a effort to mitigate the possibility of persistent threshold shift.

Research has been conducted with musicians exposed to high-intensity sound during various live-concert conditions. A study by Royster, Royster, & Killion (1991) analyzed the hearing thresholds of symphony orchestra musicians. Their audiometric data revealed that 52.5% of musicians had a notched audiogram, which is a clinical marker for NIHL and entertainment-related excessive sound exposure (ERESE).

The effects of loud music and noise, as it pertains to professional pop, rock, and jazz musicians, has been the subject of scientific investigation. According to Halevi-Katz, Yaakobi, & Putter-Katz (2015), increased hearing thresholds between 3,000-6,000 Hz were prevalent in their research subjects. Musicians with increased ERESE demonstrated higher hearing thresholds.

Santoni & Fiorini (2010) researched hearing thresholds as well as satisfaction with the use of hearing protection for 23 male pop-rock musicians. Hearing protection was given to musicians to be worn for three months. The greatest mean pure-tone hearing-thresholds were measured at 3,000, 4,000, and 6,000 Hz. In a study reported by Drake-Lee (1992), temporary auditory threshold shifts for rock musicians were analyzed after a concert, which indicated that musicians revealed a notch in their audiogram at 6,000 Hz, prior to the concert. Following the concert, audiometric results demonstrated higher measured thresholds at all frequencies (Drake-Lee, 1992).

Biassoni et al. (2014) analyzed the effects of loud music on hearing in a group of adolescent listeners. Loud music exposure was defined as recreational activity such as nightclubs, personal music players, and rock concerts. A group of adolescents age 14-15 years were tested, and then retested at age 17-18 years. Hearing thresholds from the baseline test were compared to the retest, which revealed statistically-significant differences at all frequencies. The authors reported that the extended high frequency range (e.g., 8,000-16,000 Hz) was sensitive to ERESE and might be used clinically as an early-warning indicator of vulnerability of the auditory system.

Research has been published on recreational noise exposure and its effects on adolescent hearing sensitivity, specifically in the extended frequency range (Serra et al., 2005). This group analyzed children age 14-17 years over a four-year period. Subjects were exposed to loud recreational activities such as discotheques, personal music player use, live concerts, and playing of musical instruments. An increase of hearing threshold levels was reported for both sexes, especially at 14,000 Hz and 16,000 Hz. The authors identified that hearing thresholds were higher in males, possibly because they are more often exposed to higher sound levels than females. Higher sound levels have been related to noisy sports, tools, guns, and firecrackers, but not music. Further research on these data included an analysis of baseline test thresholds of study participants (Biassoni et al., 2005). In this report, the most significant difference in hearing threshold levels for males was found at 3,000 Hz in the right ear and 6,000 Hz in the left ear. For females, the largest difference in hearing threshold level was 3,000 Hz bilaterally.

Keppler, Dhooge, & Vinck (2015) conducted research that examined attitudes and beliefs about noise, hearing loss, and the use of hearing protection in a population of young adults. This study analyzed NIHL in young adults exposed to high intensity levels of leisure noise. Their results identified a significant difference in hearing threshold levels at 6,000 Hz based on scores from the Youth Attitude to Noise Scale (YANS). In the group with a positive attitude about noise, hearing thresholds increased at 6,000 Hz, but subjects who had a negative attitude did not show such an increase. A positive attitude towards noise represented a belief that a loss of hearing was viewed as unproblematic. A significant increase in hearing threshold was found at 4,000 Hz when analyzing the intent to influence sound environment on the YANS. A higher hearing threshold level was found at 4,000 Hz for those who had a negative or neutral attitude on the intent to influence sound environment compared to those who had a positive attitude. The conventional audiometric-test frequencies (250 – 8,000 Hz) showed a significant difference, but the extended high frequencies (specifically, 10,000, 12,500, and 16,000 Hz) did not. These results were in disagreement with Biassoni et al. (2005) who reported that ERESE affected the extended high frequency responses of listeners.

High frequency hearing loss was not present following ERESE in all scientific investigations, and a notched audiometric configuration was reported in 8.3% to 46% of observed cases. A systematic literature review conducted by Le Clerq et al. (2016) focused on music-induced hearing loss (MIHL) in children, adolescents, and young adults. This study primarily exposed the effects of personal music players versus live-concert attendance. Audiometric notchiness increased as sound exposure increased for the older subjects. Some articles analyzed by Le Clerq et al. (2016) found increased thresholds at 12,500 and 16,000 Hz in the extended high frequency range. The low-frequency PTA for 500, 1,000, and 2,000 Hz was 5.50 dBHL and the high frequency PTA (e.g., 3,000, 4,000, and 6,000 Hz) was 10.43 dBHL. This systematic review included an analysis of otoacoustic emissions. A decrease in the amplitude of distortion product otoacoustic emissions was discovered, including 4,000 Hz and 6,000 Hz for subjects with increased rates of ERESE (i.e., music). Transient evoked otoacoustic emissions had a decrease in amplitude between 2,000 and 4,000 Hz. A self-report assessment revealed that 69% of the participants reported a hearing-related symptom. The most commonly reported symptom was tinnitus; however, reports of otalgia or aural pressure and perceived hearing difficulties were commonly reported as well. Although ERESE can damage the extended-frequency hearing sensitivity in humans, it can also produce significant auditory symptoms and physical damage.

Yassi et al. (1993) investigated auditory risks after ERESE, specifically, rock concert attendance. The effects of noise and TTS were analyzed following rock-concert exposure. A TTS of 10 dB, or greater, was identified in 81% of the participants 5 to 25 minutes after the concert. Furthermore, 76% of these individuals continued to show a TTS at 4,000 Hz, 40 to 60 minutes after the exposure. A significant TTS was defined as a shift of 10 dB or greater from the pre-concert audiometric baseline. This study supports the assertion that ERESE (i.e., rock concerts) should be approached as a risk factor for auditory injury.

A study by Ristovska, Jachova, & Atanasova (2015) analyzed the frequency of audiometric notches following excessive noise exposure. They included subjects who were exposed to occupational and recreational noise. They did not include concert attendance as a recreational setting, although they did list loud music listening as one of the recreational activities. These authors determined that 74% of individuals with excessive noise exposure demonstrated poorest hearing at 4,000 Hz and this test frequency was determined to be most affected compared to other tested pure tones.

An earlier report by Meyer-Bisch (1996) reported that amplified music, such as personal cassette players, discotheques, and rock concerts was hazardous to hearing. The author compared two groups of individuals who went to rock concerts at least twice monthly, compared to controls that would attend a concert once per month. A significant hearing threshold difference was found between the groups. Those individuals who attended a rock concert at least twice a month had a statistically significant difference in hearing thresholds at 4,000 and 6,000 Hz. This study reinforced that frequent ERESE is hazardous to high-frequency hearing in humans.

A Swedish study by Holgers & Petterson (2005) analyzed noise exposure among children. Exposure consisted of leisure noise, which was mainly attendance at concerts. Results did not include audiometric data; but, the risk for noise-induced tinnitus was approximately four times higher in the group that attended concerts 6-12 times a year versus those who did not attend concerts. Since no audiometric data were found in this study, it could not be used to estimate the audiometric thresholds that might result from ERESE.

Ramakers et al. (2016) researched the effectiveness of earplugs in preventing recreational noise-induced hearing loss following music exposure. They analyzed individuals who attended an outdoor music festival in Amsterdam and reported that threshold shifts primarily affected 3,000 and 4,000 Hz. Furthermore, they concluded that the use of hearing protection is an effective method to prevent temporary hearing loss after ERESE, specifically, loud music.

CHAPTER 4

Discussion

Subsequent to a review of the relevant research, it is evident that ERESE is capable of inflicting damage on the human auditory system. Although there are conflicting results about specific frequencies affected, much of the literature has concluded that repeated exposure to high-intensity sound caused hearing shift and loss. Table 3 is a summary of key indicators that emerged from the relevant articles in the foregoing review.

Two studies reported that the poorest mean audiometric thresholds were found 3,000, 4,000, and 6,000 Hz (Halevi- Katz et al., 2015; Santoni & Fiorini, 2010) and another determined that threshold shifts from live concerts affected 2,000, 3,000, and 4,000 Hz (Opperman et al., 2006). In a systematic review by Le Clercq et al. (2016), the high frequencies, 3,000, 4,000, and 6,000 Hz were almost two times poorer than the low frequencies, namely, 500, 1,000, and 2,000 Hz.

Historic research suggests that 53% of individuals with notched audiograms have a NIHL, although no specific frequency data were provided (Royster et al., 1991). This research was about symphony orchestra musicians and not concert attendees. Keppler et al. (2015) identified a significant increase at 4,000 and at 6,000 Hz from research about the attitudes and beliefs of adult listeners. Meyer-Bisch (1996) found audiometric threshold differences at 4,000 and 6,000 Hz for individuals who attending rock concerts.

Drake-Lee (1992) reported that subjects had a noise notch at 6,000 Hz prior to a live concert, but afterwards, all measured pure-tone responses exhibited increased thresholds. Differently, Ramakers et al. (2016) found that the audiometric thresholds at 3,000 and 4,000 Hz were worse following ERESE. Research suggests that adolescent males demonstrated threshold differences at 3,000 Hz in the right ear and at 6,000 Hz in the left ear, while adolescent females showed threshold decrements at 3,000 Hz in both ears after ERESE such as live-concert attendance (Biassoni et al., 2005).

Investigations have indicated that 4,000 Hz may be the test frequency where the audiometric threshold is most-significantly impacted by ERESE. One study did not specify if the ERESE was live-concert attendance but described the exposure as excessive noise (Ristoska et al., 2015). It is unclear, but a portion of the exposure may have included attendance at a concert. Nevertheless, sound exposure at rock concerts has been associated with TTS at 4,000 Hz (Yassi et al., 1993).

Research has shown that the extended high frequencies may be damaged by loud music exposure (Biassoni et al., 2014; Serra et al., 2005). These studies demonstrated worsening of audiometric thresholds at 14,000 and 16,000 Hz following ERESE. Le Clercq et al. (2016), reported that increased thresholds were observed at two frequencies, 12,500 and 16,000 Hz. By contrast, Keppler et al. (2015) found no differences in the extended high-frequency range following ERESE.

It may be inferred that, after ERESE, 4,000 Hz is most affected pure-tone test frequency. In 10 of the 14 (71%) articles we identified from the literature search, ERESE produced poorer high-frequency hearing thresholds. Hence, decreased high-frequency hearing acuity should be anticipated when patients report frequent ERESE (Opperman et al., 2006; Royster et al., 1991; Halevi-Katz et al., 2015; Santoni & Fiorini, 2010; Keppler et al., 2015; Ristovska et al., 2015; Meyer-Bisch, 1996; Yassi et al., 1993; Ramakers et al., 2016).

An occupational NIHL is characterized by a high-frequency hearing impairment and notch on the audiogram at 3,000 through 6,000 Hz, with improved hearing at 8000 Hz (Kirchner et al., 2012). A review of the literature provides evidence that 4,000 Hz is most likely to be impaired after ERESE, so clinicians should not expect differences in audiometric pattern when comparing patients with ERESE and those with significant unprotected history of industrial noise.

Merely two publications from the literature review reported audiometric thresholds for a complete audiogram in ERESE subjects. The first, Ramakers et al. (2016), investigated the effectiveness of earplugs in preventing temporary hearing loss following ERESE. Their report provided specific threshold changes observed when hearing protection has not been used. Table 4 shows the audiometric threshold differences for the right and left ear when no hearing protection has been worn (from Ramakers et al., 2016). Changes in threshold mainly affect 2,000-4,000 Hz in the right ear and 3,000-6,000 Hz in the left ear. The largest threshold change in the right ear was at 3,000 Hz, with that mean pure-tone response decreasing by 9 dB following ERESE. The largest threshold change in the left ear was at 4,000 Hz, with the threshold decreasing by 7 dB following ERESE. There was a larger audiometric change observed for thresholds in the right ear when compared the left ear. Remarkably, these differences do not exceed accepted audiometric-threshold variability for human subjects (i.e., 10 dB).

Opperman et al. (2006) analyzed the effect of hearing protection during a concert. Observed changes from baseline pre-exposure threshold were reported. Table 5 shows the mean audiometric thresholds with, and without, hearing protection from Opperman et al., 2006). These results demonstrate that thresholds decline when a person experiences ERESE without adequate hearing protection when compared to those that do. The largest threshold decrement was associated with 6,000 Hz, where a difference of the means of nearly 10 dB observed between hearing protection users and non-users after ERESE. Notably, the reported differences did not exceed clinical audiometric-threshold variability (i.e., 10 dB), but when viewed independently, hearing threshold changed by 11.6 dB at 4,000 Hz for the group that did not protect themselves from ERESE.

Anecdotally, it has been said that the youth of today have poorer hearing than previous generations. This belief stems from the increased use and popularity of large-storage, electronic, portable music devices and smartphones. According to epidemiologic research (Hoffman, Dobie, Ko, Themann, and Murphy, 2010), this does not appear to be straightforward. In fact, audiometric thresholds were analyzed at specific ages across two birth cohorts. Results indicated that high frequency audiometric thresholds were poorer in the 1994-2004 cohort when compared to 1959-1962. Hearing impairment was found to be more prevalent in past generations than current ones. This suggests that the increase in popularity of personal loud music listening may not be affecting younger populations as some may assume. Said differently, younger individuals may actually be doing a better job with hearing preservation than their older counterparts. Further, young people may not be experiencing as much ERESE as their elders.

ERESE Intensity Factors

There are several factors that may be attributed to the degree of hearing shift or shift that have been associated with ERESE. One point to consider is the location and proximity to the sound source. In addition to speaker sound level and location, the acoustical conditions of ERESE events are equally important (Yassi et al., 1993). For instance, an individual who is seated in front or in close to a speaker array will generally be exposed to a higher sound intensity level compared to one seated at a further distance from the speakers. The strength of a speaker should be considered as some speakers produce more hazardous sound levels than others. Higher intensity exposures are more injurious to the auditory system. It is critical to acknowledge that when ERESE occurs indoors, room acoustics dictate higher levels of exposure risk, including the impact of sound reverberation. By comparison, outdoor events have unique acoustical characteristics that may also increase exposure levels; however, generally, risk should be lower for outdoor environments.

Some crowds produce more noise compared to others. Opperman et al. (2006) concluded that younger audiences at pop concerts shout and whistle at higher levels when entertainers begin the concert or return from intermission. The risk was not the same at a heavy metal or rock concerts. Crowd yelling and screaming was lower at heavy metal concerts compared to pop or rock concerts because the fans were distracted by activities such as mosh pits, which lowered their noise contribution. It is important to consider the music genre as well as the subject's age.

Progressively raising sound intensity over the course of a concert is a common technique used by production staff to sustain the initial perceived sound level within the audience (Yassi et al., 1993). This is a practice that will likely harm hearing. Therefore, it is important to identify as many mediating factors as possible to define how incidents of ERESE might affect a person's peripheral auditory system. Clearly, use of acceptable protection should be encouraged for people who participate in repeated ERESE events.

CHAPTER 5

Conclusion

The search terms used in this study did not produce an ample amount of publications for this literature review. The two databases used for this project were ComDisDome and PubMed. Approximately half of the articles (8) used to execute this review were found through those two search mechanisms. Finding information about audiometric thresholds and threshold-patterns resulting from ERESE, using relevant search terms, was restricted. Therefore, further research about the short and long-term effects of ERESE is needed in order to improve our understanding of this issue and the clinical markers that may be used by audiologists when they encounter these patients.

It is important to consider the unique elements of each of the reviewed articles. Some articles described the effects of ERESE for symphony musicians, while others pertained to rock concerts. The type of ERESE varied between the articles but music genre should not affect the level of sound output (Opperman et al., 2006). Seating location and sound environment (indoor versus outdoor) is a distinguishing variable. Other issues to consider are age of the exposed individual and their ERESE history. For this literature review, the age of study populations varied between articles. Each of these differences raise concerns that make it difficult to draw direct conclusions about the study outcomes. For hearing loss prevention purposes, use of hearing protection is recommended when exposed to ERESE. Precautionary measures that may reduce hearing shift and loss include: (1) reduction of exposure duration, (2) maintaining a safe distance from the source of ERESE (Ramakers et al., 2016), and (3) use hearing protection.

Audiologists should play a more active role in educating patients about ERESE and hearing loss prevention. Patients should be instructed about proper use of hearing protection.

Audiologists should provide audiometric monitoring for patients who work in ERESE environments. Part of this monitoring should include a test that is more sensitive to the sub-clinical effects of ERESE, such as otoacoustic emission (OAE) testing (Musiek, Baran, Shinn, & Jones, 2012). The OAE are an electroacoustic phenomenon that may be more effective for early identification of NIHL. An audiological test battery could also include a threshold test of the extended high frequencies (Biassoni et al., 2014; Serra et al., 2005), this may be sensitive to the deleterious effects of ERESE as well.

From the discovered literature, it is evident that ERESE primarily distresses 4,000 Hz on the audiogram. Audiologists should be aware that the ERESE audiometric configuration appears to be similar to the outcome pattern that results from industrial noise. A patient's age, previous history of ERESE, including exposure to industrial-occupational noise must be uncovered during a case history. Audiologists should serve a more prominent role in informing patients about the dangers of ERESE, understanding that some patients may be less alert to the hazards of ERESE than others.

Future Research

Education for children and young adults about the risks associated with ERESE and the importance of hearing loss prevention should be administered in the schools. A school program might include hearing-loss simulation activities, auditory anatomy, provision and use of hearing protection, and sound measurement demonstration (Johnson & Seaton, 2012). Working adults should be educated about the risks of ERESE as well. At this time, controlled scientific investigations that directly report the audiometric-configuration outcomes from ERESE are limited. Therefore, funded research on the effects of ERESE is warranted.

TABLES AND FIGURES

Table 1. Occupational Safety and Health Administration's (OSHA) Standard for noise exposure using a 5-dB exchange rate.

Sound Pressure Level dBA	**Duration (Hours)**
80	32
85	16
90	8
95	4
100	2
105	1
110	.5 (30 minutes)
115	.25 (15 minutes)
120	.125 (8 minutes)
125	.062 (4 minutes)

Table 2. ComDisDome and PubMed search terms and resulting articles found.

Search Terms	**Total Articles from Initial Search**	**Articles Retained for Review**	**Final Articles Retained**
ComDisDome			
Concert AND hearing thresholds	15	3	1
Concert noise AND hearing	19	5	1
Hearing thresholds AND concerts	15	1	1
PubMed			
Concert noise AND hearing threshold	5	4	1
Concert noise AND hearing	28	1	1
Hearing AND loud music exposure	81	5	3

Table 3. Summary of research findings for each article, specifically for comparison of sample size, standard or temporary threshold shift, and incidence of hearing loss and audiometric notch.

Author	Sample size	STS/TTS	Hearing Loss	Notch
Opperman et al. (2006)	29 volunteers	64 % (9/14) participants who did not use earplugs showed an STS		
Royster et al. (1991)	Chicago Symphony Orchestra			52.5% of individual musicians
Halevi-Katz et al. (2015)	42 pop/rock/ jazz musicians		Higher hearing thresholds from 3,000 to 6,000 Hz	
Santoni & Fiorini (2010)	23 male pop-rock musicians		Highest mean audiometric threshold values occurred at 3,000, 4,000, and 6,000 Hz	
Drake-Lee (1992)	4 members of a heavy metal band			6,000 Hz
Biassoni et al. (2014)	59 adolescents aged 14-15 years at initial test and 17-18 years at retest		All hearing thresholds (250-16,000 Hz)	
Serra et al. (2005)	Boys and girls aged 14-17 years		Increased hearing threshold, especially at 14,000 and 16,000 Hz	
Biassoni et al. (2005)	Adolescents		3,000 Hz and 6,000 Hz affected for the boy group and 3,000 Hz affected for the girl group	
Keppler et al. (2015)	163 subjects		Significant difference at 6,000 Hz and 4,000 Hz; no effect on the extended high frequencies	

Author	**Sample size**	**STS/TTS**	**Hearing Loss**	**Notch**
Le Clerq et al. (2016)	Literature review on music exposure in children		Increase in hearing levels at high frequencies (3, 4, 6k Hz) was found in 9.3%	
Ristovska et al. (2015)	257 patients		74% of patients with excessive noise exposure had greatest hearing loss at 4,000 Hz	
Meyer-Bisch (1996)	211 subjects		Concertgoers had significant difference at 4,000 Hz and 6,000 Hz	
Yassi et al. (1993)	22 volunteers	81% showed a TTS 2-25 minutes following a rock concert;76% showed a TTS 40-60 minutes after a rock concert		
Ramakers et al. (2016)	51 volunteers	TTS primarily found at 3,000 and 4,000 Hz in 42% of the unprotected group		

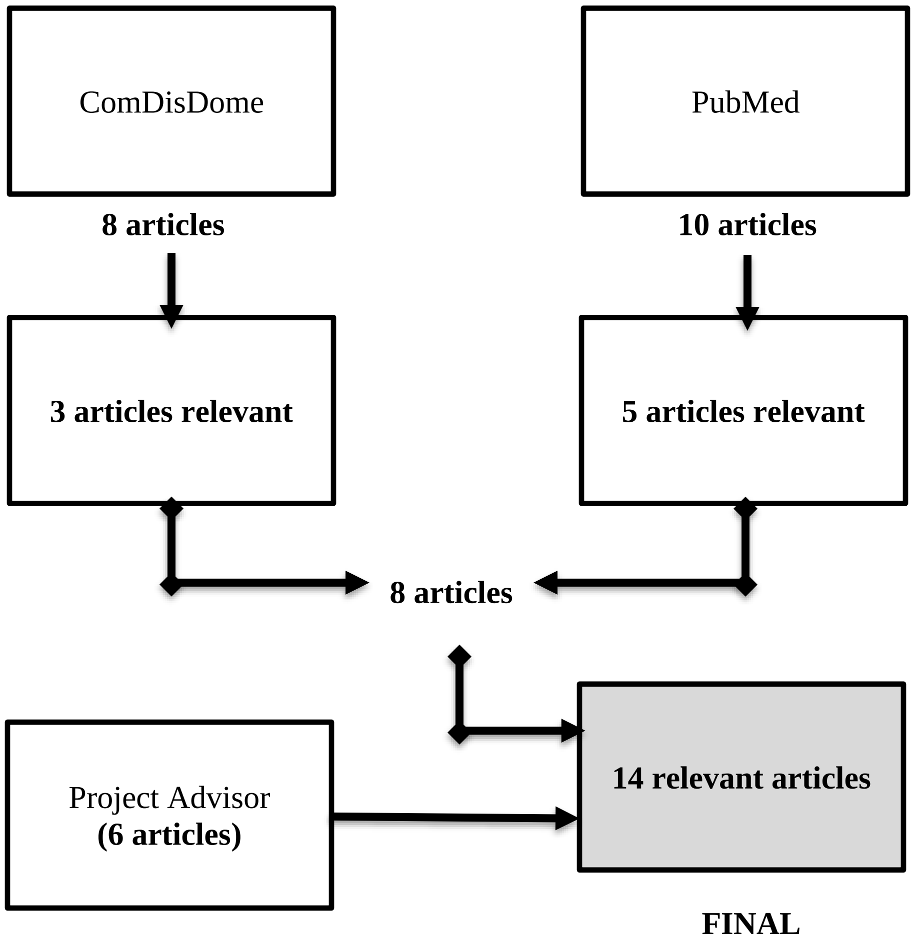
Table 4: Mean audiometric threshold differences reported by Ramakers et al. (2016), comparing the right and left ears with and without hearing protection for ERESE conditions.

Frequency (Hz)	**500**	**1,000**	**2,000**	**3,000**	**4,000**	**6,000**	**8000**
Right Ear without protection (dB)	3.9	3.5	5.2	8.8	7.9	3.3	1.7
Left Ear with protection (dB)	3.7	4.2	4.0	6.5	7.1	5.4	1.2

Table 5: Mean audiometric threshold differences reported by Opperman et al. (2016), comparing with and without hearing protection for ERESE conditions.

Frequency (Hz)	500	1,000	2,000	3,000	4,000	6,000	8000
With Hearing Protection (dB)	-0.17	0.83	1.5	2.67	3.33	-1.00	0.33
Without Hearing Protection (dB)	2.86	3.04	5.36	10.18	11.61	8.46	3.57

Figure 1. Topic-specific article discovery diagram.



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