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Recreational Music Exposure and Music-Induced Hearing Loss: A Systematic Literature Review

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RECREATIONAL MUSIC EXPOSURE AND MUSIC-INDUCED HEARING LOSS: A SYSTEMATIC LITERATURE REVIEW

by

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ABSTRACT

Recreational Music Exposure and Music-Induced Hearing Loss: A Systematic Literature Review

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Legislation regarding occupational noise exposure is the result of a long period of interest and research; more recently, the effects of recreational noise are receiving increasing attention. Various sources of recreational noise and music exposure have become more widespread amongst the general public, increasing research in this source of potential risk. The proliferation of personal music players that are easily available and accessible to children and adults has contributed to the spread of leisure music exposure. Leisure music exposure is also common in the attendance of concerts and clubs/discos, and bars/pubs. The present systematic literature review focused exclusively on recreational music sources, including personal music players, concerts, and clubs, and reviewed the current body of research available regarding recreational music exposure and its effect on hearing, as is evident through the measure of standard audiometric thresholds, extended high frequency audiometry, and otoacoustic emissions responses.

A systematic search was performed using the search engine One Search to identify the relevant peer-reviewed studies published in English. The following keywords were applied in various combinations*: music-induced hearing loss, recreational noise exposure*, *personal listening devices, hearing loss, noise induced hearing loss, music, clubs.* Throughout the search, the keywords of "music induced hearing loss" or "noise induced hearing loss" were always present. Eleven studies were identified for further investigation.

Results revealed that although a large body of evidence is available regarding the dangerously loud exposure of noise in a variety of recreational settings, there is still a lack of sufficient and consistent evidence that supports that hearing loss (as evidenced by pure tone audiometry) is apparent in this population. Although there have been multiple studies performed over the past few decades, the results of such studies that use similar methods are not in agreement. Long-term longitudinal studies are few and far between in this area. More studies of this nature may be necessary to display a hearing impairment in this population due to recreational music exposure over time. There is evidence that high frequency audiometry and otoacoustic emissions responses may serve as an early indicator of noise damage, but this claim has not yet been substantiated due to differences among study outcomes and requires future investigation.

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Introduction

Noise-induced hearing loss

Noise-induced hearing loss (NIHL), the most common preventable type of hearing loss, is a decrease in hearing acuity caused by an overexposure to loud noise. Noise may be defined as unwanted loud sounds in one's environment that may cause discomfort in the ears, interfere with verbal communication, , or cause decreased hearing sensitivity (Zhao, 2010). Noise-induced hearing loss is the second most common form of hearing loss, after presbycusis (age-related hearing loss) (Rabinowitz, 2000). The potential damage caused by noise exposure depends on the intensity, the duration, and the frequency of exposure. Additionally, there are differences among individuals in terms of susceptibility to noise damage (Carter, Carter, Williams, Black, & Bundy, 2014).

There has been much research regarding the mechanisms of damage that are caused by noise. Noise exposure has been shown to cause damage to the Organ of Corti, the inner organ of hearing, and thereby adversely affect hearing sensitivity. The damage from noise may happen in two ways (Zhao, 2010). The first way involves a noise trauma, which occurs from a short, transient exposure to a noise with an intensity greater than 140 dBHL. The cause of the trauma is the separation of the Organ of Corti from the basilar membrane, caused by the high-pressure level of the impact. The delicate tissue of the Organ of Corti then deteriorates and is replaced by scar tissue. The hearing loss that ensues from an acoustic trauma is permanent and immediate. Examples of causes of this category of damage are firecrackers or a rifle/gunshot that occur in near proximity to one's head (Clark & Bohne, 1999).

The second type of damage, often associated with noise exposure at work, is referred to as occupational noise-induced hearing loss, and stems from the exposure to noise that is relatively loud (85-90 dB and above) for extended periods of time. This kind of damage may also arise from repeated music exposure, which can damage the inner hair cells (IHC) upon the Organ of Corti, leading to irreversible hearing damage (Maltby, 2005). This is a gradual process that occurs over several years. In these occurrences, the excessive noise increases the shearing force on the hair cells and causes a metabolic overload within the hair cell (Rabinowitz, 2000). In addition, the level of glutamate that works as a neurotransmitter between the IHCs and the auditory nerve will increase when the IHCs are being over stimulated by high levels of noise. The glutamate can become ototoxic and cause IHC damage (Moore, 1998, as cited by Zhao, 2010).

The three-stage process that occurs during the acquisition of a noise-induced hearing loss is further described by Clark & Bohne (1999). In the first stage, the sensory cells deteriorate from overexposure, as described above, and are replaced by scar tissue. Following weeks to years of continued exposure, the hearing loss can be detected audiometrically, beginning in the high frequency range (3000 to 6000 Hz). During the second stage, an individual's speech discrimination ability is not yet affected, so it usually goes undetected. In the third stage, the hearing deficit spreads to the speech frequency range, and the individual affected will often seek medical attention at this point (Clark & Bohne, 1999).

Hearing symptoms resulting from noise exposure

In addition to a permanent sensorineural hearing loss, studies have shown that other auditory symptoms may result from excessive exposure to noise, such as a temporary threshold shift (TTS). TTS may occur following exposure to loud sounds for a length of time and can cause a transient decrease in hearing thresholds, which Clark & Bohne (1999) define as "indices of the ear's acclimatization to noise (p.1658)." TTS is a representation of temporary hair cell dysfunction, but with repeated exposure a permanent threshold shift may result (Rabinowitz, 2000). Although the mechanism of damage of TTS is unknown, some suggest that it is due to a change in blood flow in the cochlea, or perhaps due to synaptic fatigue. The repetitive overstimulation of hair cells may cause a permanent threshold shift (Zhao, 2010).

In addition to hearing loss, other effects from loud sounds have been reported. Transient and permanent tinnitus is one example. Balanay & Kearney (2015) surveyed more than 2000 college students regarding auditory symptoms and found that 18% of the subjects reported experiencing temporary tinnitus (defined as lasting less than 24 hours), and 5.7% reported permanent tinnitus after exposure. Beach, Williams, & Gilliver (2013) found that from the young adult group that they surveyed, the group that had a higher exposure (from clubs, concerts, gyms, and sporting events) was also more likely to report tinnitus. Tinnitus may be present with a clinically-measurable hearing loss, or it may be present in an individual with normal audiometric thresholds. Excessive exposure to noise may lead to other auditory symptoms as well, such asauditory symptoms of otalgia (ear pain), hyperacusis (sensitivity to sound), distortion, or abnormal pitch perception (Zhao, 2010).

Occupational noise exposure standards

As noted earlier, noise sources in occupational settings are a frequent cause of noise-induced hearing loss. Occupational noise exposure became more prevalent beginning from the time of the Industrial Revolution. With the proliferation of noisy workplace equipment, this condition was termed the “boilermakers’ disease” because it plagued many of those who made steam boilers. In our current day, noise-induced hearing loss does not merely pose a risk to boilermakers, but rather to many individuals in the workplace. It is estimated that 30 million Americans are exposed to occupational noise (Rabinowitz, 2000).

The International Organization for Standardization (ISO) first published data in 1975, reporting a statistically significant relationship between occupational noise exposure and a noise-induced permanent threshold shift. The ISO 1999 provided the “dose-response relationship” that is found between occupational noise exposure and hearing threshold shift. This relationship provides a measure of how much noise is considered a safe amount, based on the duration of exposure, before the individual is put at risk for hearing damage. The US Department of Labor set rules in the 1970s and 1980s to protect the hearing of the millions of Americans who worked in noisy workplace environments (Clark & Bohne, 1999).

The National Institute for Occupational Safety and Healthy (NIOSH) recommends that the recommended exposure limit (REL) for occupational noise workers is an 8-hour time-weighted average of 85 decibels, measured on an A-weighted scale. Exposure above the recommended limits may be hazardous and cause diminished health and functional capacity. Regulatory agencies, such as the Occupational Safety and Health Administration (OSHA) are responsible for the enforcement of these standards on the occupational community. OSHA obligates employers to put a hearing conservation program into practice if their employees are exposed to hazardous levels of noise (*www.cdc.gov/niosh; www.osha.gov).*

Recreational noise/music as a cause for concern

Legislation in regard to occupational noise exposure is the result of a long period of interest and research; more recently, various sources of recreational noise and music exposure have become more widespread amongst the general public, increasing research in this source of potential risk. Since the early 1980s, there has been a decrease in the prevalence of occupational noise exposure, while social noise exposure has tripled (Smith, 2000). The proliferation of personal music players that are easily available and accessible to children and adults has contributed to the spread of leisure music exposure. Leisure music exposure is also common in the attendance of concerts and clubs/discos, and bars/pubs. Common forms of non-music sources of recreational noise exposure include power tools (i.e. chain saws; drills), recreational vehicles (motorcycle; snowmobile), and firearms (Rabinowitz, 2000). In a survey of more than 2000 young adults, Balanay & Kearney (2015) found that the most common category of noise activity among the subjects were sporting events (59.7%), discos/dances (55.4%), and the attendance of rock concerts (42.7%). These three categories were followed by lawn mowing (38.3%) and the use of firearms (32.4%). Lass et al. (1990) similarly surveyed college-aged students and found that the most common leisure noise activities were dances (69.9%) and rock concerts (63.5%), and the most common types of equipment used were lawn mowers (47.0%) and firearms (11.3%).

SPL levels and recreational noise exposure

Multiple studies have measured the maximum intensity capabilities of personal music players, as well as the noise levels at concerts and clubs, to discover if these sources have the potential to cause a music-induced hearing loss. Beach, et al. (2013) gathered dosimeter readings from a database of recordings and reported that the average loudness level at nightclubs was 97 dBA and at concerts it was reported to be 92 dBA. There have been multiple measurements recorded from the 1970-80's that record that the maximum output levels of tape players range from 98-114 dBA (Portnuff, 2013). With regard to compact disc players, Fligor & Cox (2004), found that the maximum output levels range from 91-121 dBA. They noted that different headphones/earphones allow for different maximum output levels. Portnuff et al. (2011) detailed the output levels of current digital devices and reported that the maximum levels range from 97-107 dBA. For supra-aural-style headphones, the average maximum output level was 97 dBA, and for the earphone/earbud-style, the average maximum level was 101.5 dBA. Keppler et al. (2010) similarly reported that the maximum output levels for headphones was 97 dBA and for earbuds it was 102.5 dBA. Keith (2008) found that the maximum output levels of personal listening devices could reach 101 to 107 dBA, using standard earphones. With regard to sound level preferences, Levey, Levey, and Fligor (2011) measured the preferred sound level of personal listening devices of a group of 189 college students, ranging in age from 18-53 years old, and found that the average was 92.3 dBA.

Using occupational safety standards, Levey, et al. (2011) compared the intensity and self-reported duration of listening to the allowable noise dosage. The results showed that 58.2% of participants exceeded the recommended levels. In comparison to the annual occupational noise dosage, Beach, et al. (2013) found that 14.1% of their participants exceeded this dose. Thus, evidence exists that recreational music outlets have the capacity to reach hazardous listening levels. In comparison to occupational noise dosages, it appears that there is the possibility for individuals to place themselves at risk for a noise-induced hearing loss through exposure to recreational music sources.

There remains a lack of consensus of the impact of recreational music exposure on hearing and the auditory system. According to Carter et al. (1984), for example, the effects of recreational noise are slight. Others warn of an impending epidemic of noise-induced hearing loss. The present systematic literature review will focus exclusively on recreational music sources, including personal music players, concerts, and clubs. It will explore the noise damage risk from those recreational music exposure sources, and its effect on hearing, as is evident through the measure of audiometric thresholds, extended high frequency audiometry, and otoacoustic emissions responses.

Research Questions:

The following research questions will be addressed:

1: Does recreational music exposure, from personal music players and/or concerts/night clubs, negatively affect hearing health, as evident in the audiometric thresholds?

2: Does recreational music exposure have an effect on extended high frequency audiometric thresholds that is evident prior to a shift in conventional audiometric thresholds?

3: Can transient evoked and/or distortion product otoacoustic emissions responses be used for the early detection of a noise-induced hearing loss in those exposed to recreational music sources**?**

Methods:

A systematic search was performed using the search engine One Search to identify the relevant peer-reviewed studies published in English. One Search is a search engine that combs multiple databases according to the criteria that you specify. Examples of databases included are: MEDLINE/PubMed, OneFile, ProQuest Nursing & Allied Health Source. In addition, the reference lists of included articles were manually examined to locate relevant articles that did not appear in the direct search. The following keywords were applied in various combinations*: music-induced hearing loss, recreational noise exposure, personal listening devices, hearing loss, noise induced hearing loss, music, clubs.* Throughout the search, the keywords of "music induced hearing loss" or "noise induced hearing loss" were always present. Duplicate studies presented by the multiple searches were discarded. Relevant studies published from the year 1991 to 2016 were included. To determine whether the studies met the inclusion criteria, the titles and abstracts were studied throughout the search.

The following criteria were applied initially to exclude articles based on information obtained from the title or abstract, and subsequently to an in-depth review of the full article: articles relating to occupational noise exposure, articles pertaining to other forms of recreational noise sources (other than music, personal listening devices, and clubs/discos), no full-text version available, and articles exploring pharmaceutical research to prevent/treat noise-induced hearing loss. Most frequently, in reference to a systematic review, the level of evidence of each article is assessed and those which do not meet the criteria are eliminated from the study. Due to the nature of the present study and its reliance on voluntary noise exposure included in the participant's lifestyle, it is not possible to perform a randomized controlled study. Additionally, all the studies included a questionnaire/self-report detailing the duration and/or intensity of the exposure. Thus all the chosen articles in this review fall into the category of descriptive research.

Results:

One hundred and fifty relevant articles were identified using the keywords and databases described. Figure 1 is a flow chart that summarizes the search process for the identification of articles used in this study. Table 1 provides details about the eleven chosen studies in terms of the number of participants, age group of the participants, the evidence of the hearing loss, how the duration of exposure to recreational music exposure was detailed, how the intensity of exposure was detailed, and if the risk of noise exposure was calculated. An in-depth exploration of the eleven chosen articles follows Table 1.

Figure 1. Flow chart for the search and retrieval process for articles included in the systematic review.

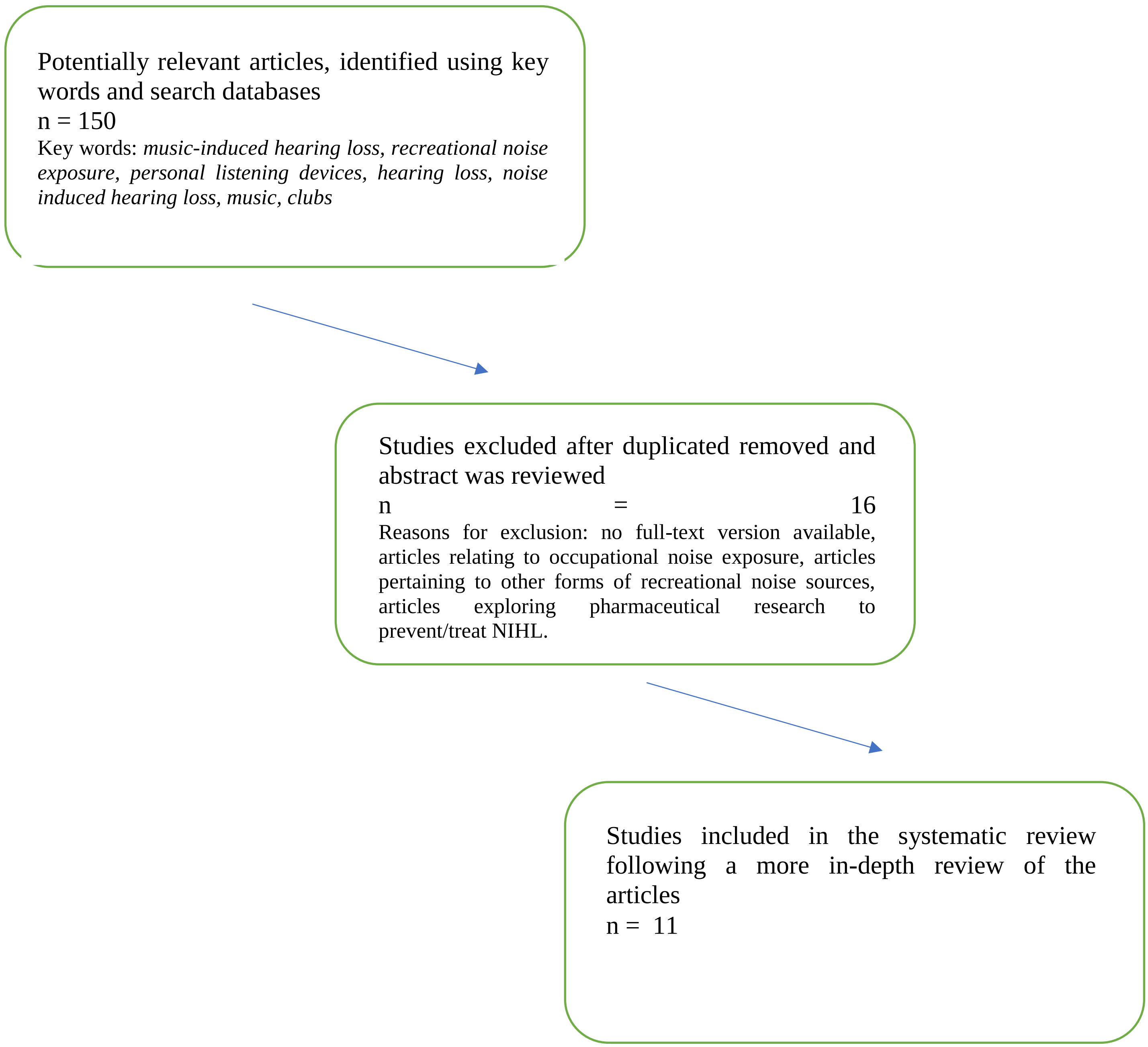

Table 1. Summary of studies retrieved from systematic review.

Study	**Sample size (n)**	**Population (Age)**	**Evidence of hearing loss provided?**	**Quantification of duration of exposure**	**Measure of intensity exposure**	**Risk calculation**	**Conclusion**
Meyer-Bisch (1996)	1364	Group 1: 14-18 years old Group 2: 17-25 years old (Remaining groups pertain to different forms of noise exposure)	Pure tone audiometry, with select extended high frequency testing (12k and 16k Hz)	For those who went to nightclubs: occasional; twice a month or less; more than twice a month. For users of PCP: occasional; 2-7 hrs/wk, and >8 hrs/wk For attendees of rock concerts: occasional; once a month or less; and more than once a month	X	X	Attendees of night clubs do not present with audiometric damage (on average); PCP listeners have a significantly higher hearing thresholds if listened more than 7 hours/week, compared to those who listen 2-7 hours/week and compared to the control group. Same in reference to attendees of rock concert – for those who attend at least twice a month.
Williams, Carter, & Seeto (2015)	1432	11-35 years old (Australian)	Pure tone audiometry; TEOAEs; DPOAEs	X	X	Yes - Calculated lifetime noise exposure (based on self-report)	No correlation found between cumulative lifetime noise exposure and audiometric PTA or OAE measures

Mostafapour, Lahargoue, & Gates (1998)	50	18-30 years old; college students	Pure tone thresholds; speech recognition thresholds; word recognition at 45 dBHL	One hour or more a day of personal stereo device use	Self report of sound level (low-medium-high)	Estimated lifetime exposure to noise	The presence/absence of a notch did not correlate with any kind of noise exposure; No difference between groups (divided by level of exposure) in pure tone thresholds or speech scores; Concluded that majority of youth were at *low risk* for substantive noise-induced HL
Serra, et al. (2005)	106	14-17 years old, boys - and girls	Hearing threshold levels- conventional audiometry (250-8k Hz) and extended high frequency audiometry (through 16k Hz). Subjects were re-tested over 4 year period.	Not specified, but students were given several inventories to complete regarding their noise attitudes and behaviors	In discos: wore noise dosimeter; PMP use: real ear level measurements on artificial head and torso	Calculated allowable noise dosage based on occupational standards	Disco intensity levels ranged from 104 dB to 112 dBA PMP listening ranged from 75 to 105 dBA. Higher mean HTL in boys than girls. HTL mean increased over the years (especially in the last two years of the study).

Keppler, Dhooge, and Vinck (2015)	163	18-30 years old	Pure tone audiometry; EHF; TEOAEs; DPOAEs	Hours/week or month; Years of usage	Self-estimated; Subjects divided into subgroups of: low, intermediate and high noise exposure (based on duration and intensity)	Yes, weekly and lifetime noise exposure calculated	No difference found between groups of low/intermediate/high. 86% reported temporary tinnitus following loud noise exposure. 1/3 exceeded weekly equivalent noise exposure of 75 dBA.
Le Prell, Spankovich, Lobarinas, & Griffiths (2013)	87	18-31 years old. College students. Subjects had hearing WNL (250-8k Hz)	Extended high frequency (10k-16k Hz)	Hrs/day Days/wk Years of use	Not measured Self-report for some – if they could hear someone speaking to them while listening and if they listened in a quiet or noisy background	X	No significance found between PLD users and hearing thresholds. Significant difference found amongst users of PLDs for > 5 years.
Biassoni et al. (2014)	172 (test); 59 (re-test)	Male only; tested at 14-15 years old; re-tested at 17-18 years old	Standard audiometry and extended high frequency audiometry; TEOAEs	Grouped into low, moderate, high, and very high exposure	Musical General Exposure (MGE): low, moderate, high, and very high exposure	X	Significant difference between test and retest in the HTL and overall amplitude of TEOAEs in group 1 (normal)

Feder, Marro, Keith, & Michaud (2013)	237	10-17 years old	Audiometry + EHF	Hours per week	Self-report + Portable DAP sound pressure level measurements (daily exposure levels calculated)	X	Thresholds were higher at 4k and 8k Hz when usage of PMP was more than 5 years, as compared to those who listened less than one year. Higher measured SPLs or PMP were associated with worse thresholds (500-4k Hz). Self-reported HL symptoms were reported by 33-50% of subjects.
Kim, et al. (2009)	490 subjects who used personal music players on a consistent basis	Adolescents aged 13-18 years old	Pure tone audiometry	Hours per day; Years of usage	X	X	94% of subjects used personal music players. Most of them have used PMPs for 1-3 hrs/day during 1-3 years. Significant increase in hearing thresholds noted in males, in adolescents who had used PMPs for >5 years. Conclude that PMPs can have a "deleterious effect on hearing threshold in adolescents."

Peng, Tao, & Huang (2007)	120 personal listening device users and 30 normal hearing young adults	19-23 years old	Conventional audiometry and extended high-frequency audiometry	Years of usage	Participants were asked to rate their listening level as low, medium, or high.	X	Hearing thresholds significantly increased for 3k-8k Hz in the personal listening device users. Conclude that long-term use of PLDs can impair hearing function. EHF is a sensitive method for early detection of NIHL.
Montoya, et al. (2008)	40 ears (232 ears in control group)	19-29 year old normal-hearing MP3 player users (control group: 18-32 year old not exposed to MP3 noise)	TEOAE and DPOAE incidence, amplitude, and spectral content	Hours per week; Year of usage	X	X	Several significant differences were found between experimental and control group. Conclude that cochlear impairment caused by MP3 usage may be detectable with TEOAE and DPOAE testing before the impairment becomes clinically noticeable.

The eleven chosen studies varied in a number of different variables. The number of participants included in the studies ranged from a small group of 40 ears to 1,432 participants. The population studied was either adolescents (no younger than 11 years old) or young adults (no older than 35 years old); several studies used a combination of both age groups. Some studies focused exclusively on personal music player (PMP) usage; while others looked at several recreational music sources, such as PMPs, concerts, and nightclubs/discos. The majority of the studies were published within the past eleven years (since 2005), with the exception of two (Meyer-Bisch, 1996 and Mostafapour, Lahargoue, & Gates, 1998). Regarding these two studies, it should be noted that the technology has advanced and recreational listening has become more prevalent since then, and while much of the information and research is still applicable, the earlier date should be kept in mind.

Regarding the evidence of hearing loss provided, the majority of studies conducted conventional pure tone audiometry. Six of the eleven studies additionally performed extended high frequency audiometry (Meyer-Bisch (1996); Serra et al. (2005); Le Prell, Spankovich, Lobarinas, & Griffiths (2013); Biassoni et al. (2014); Feder, Marro, Keith, & Michaud (2013); Peng, Tao, & Huang (2007)). Three studies measured Transient Evoked and/or Distortion Product Otoacoustic Emissions (Biassoni et al. (2014); Williams, et al. (2015); Keppler, Dhooge, & Vinck (2015)). Four of the studies made a risk calculation based on the allowable noise dosage, and predicted the risk of a noise-induced hearing loss (Williams et al. (2015); Keppler et al. (2015); Mostafapour et al. (1998); and Serra et al. (2005)).

It should be noted that several of the studies included a risk calculation based on measures reported from participant surveys or from actual dosimeter readings. Serra et al. (2005) fit a portion of the adolescents in their study group with a noise dosimeter prior to their attendance at a disco, in order to measure the sound pressure levels that they were exposed to there. An artificial head and torso was utilized to measure the level PMPs that some of the adolescents listened to. The highest sound level measured within the discos was 112.4 dBA, with peaks at 117.4 dBA and the lowest level (at a different disco) was 104.3 dBA. Nine discos were measured in total. This last measure greatly exceeded the allowable worker's standards for noise dosage, leading one to believe that the sound level in discos is potentially harmful to the subject's hearing. The sound pressure levels of the PMPs were calculated to be in the range of 75 dBA to 105 dBA. They concluded that the noise dosage from recreational music activities may negatively affect hearing thresholds.

Williams et al. (2015) calculated the allowable noise dosage based on OSHA occupational standards and reached a conclusion similar to Serra et al. (2005) above. The cumulative lifetime noise exposure for each participant was calculated based on the formula developed by the National Acoustic Laboratories (NAL) used for calculating the daily A-weighted sound exposure and extending it over a typical lifetime. The study delineates three vital factors that comprise the calculation of an individual's exposure to noise: The average loudness A-weighted equivalent level of the noise over the duration of the exposure; the length of time of the noise exposure; and the number of events of noise exposure over a lifetime. The last factor mentioned very much depends on the age of the individual. As the individual ages, from their teenage years to mid-adulthood, and into their elderly years, their exposure to recreational music changes as their lifestyle and preferences change.

It should be noted that the above calculations were based upon a survey – a self-reported response from each participant. While the Williams et al. study did not find any significant correlation between the lifetime noise exposure and decreased hearing thresholds or reduced otoacoustic emissions amplitude, they noted that many of the individual's cumulative exposure exceeded the occupational noise exposure standards, which may place them at risk for a permanent threshold shift (PTS) in hearing thresholds. They mentioned that each individual presents with a variation in susceptibility to noise induced hearing loss, which may account for the wide variation in hearing thresholds measured. Additionally, the study noted the expanding breadth of research supporting that central auditory processing slows down, is weakened, and is localized differently in the noise-exposed human brain. Therefore, there may be negative effects upon the auditory skills of an individual before a hearing loss is clinically measurable (such as the common complaint of having difficulty understanding conversation in the presence of background noise).

Similarly, Keppler et al. (2015) compared the self-reported measures from their participant questionnaire to the allowable noise dosage according to occupational standards. They reported that one third of their participant group exceeded the allowable noise dosage. They did caution that this must be interpreted cautiously due to the differences between occupational and recreational noise exposure sources, as will be discussed later.

Recreational Music and standard audiometric thresholds

The first research question related to whether recreational music exposure from PMPs and/or concerts/night clubs negatively affect hearing health, as evident in the audiometric thresholds. Meyer-Bisch (1996) looked at the frequency of exposure to various forms of recreational music listening opportunities (concerts, rock clubs/discos, personal cassette players), and its impact on audiometric thresholds and self-reported auditory symptoms, such as tinnitus and self-perceived decline of hearing. The subjects, a group of over one thousand adolescents and young adults, filled out a questionnaire that asked questions regarding occupational and recreational noise exposure. The questionnaire asked the subjects to approximate their total exposure to music, as well as any signs of ‘auditory suffering,’ such as tinnitus or a perceived decrease in hearing levels. The subjects were further divided into the type of recreational music venues that applied to them. Attendees of nightclubs were divided into subgroups; occasional attendees, those who frequented twice a month or less, and other who frequented night clubs more than twice a month. Those who listened to personal listening devices were divided into subgroups of: occasional listeners, those who reported to listen 2-7 hours a week, and those who listened for more than 8 hours a week. The results revealed no difference in audiometric thresholds in the group who only attended discos. In the personal cassette player (PCP) subgroup, there was no difference audiometrically between the control (non-exposed) group and the low exposure group (2-7 hours/week). There was a significant difference in hearing thresholds between the control group and the more exposed group (more than 7 hours a week) and between those who frequently attended rock concerts and the matched control group. The percentage of subjects who reported auditory suffering symptoms increased among the exposed group in comparison to the control group.

Mostafapour et al. (1998) sought to compare a group of 50 students, aged 18 to 30 years old, who each had a history of exposure to loud music (i.e. used a personal stereo device at least one hour or more per day), to established clinical norms of hearing thresholds and to the ISO 1999 Annex A standard of hearing thresholds of non-noise-exposure individuals. They measured pure tone hearing thresholds, speech reception thresholds, and word recognition (tested at 45 dBHL) for each subject. They recorded whether a "notch," defined as a 10dB threshold difference between two neighboring frequencies, was found within the audiometric findings of each subject. An "unequivocal notch" was defined as a difference of 15 dB or greater. The results of their study showed a notch was found in 11 subjects out of 50, and an unequivocal notch was found in 14 subjects. The presence or absence of either notch did not significantly correlate with any single or cumulative noise exposure source (within subjects). This finding may refute the claim made by a number of previous studies that a notch in the range of 3k-6k Hz can serve as an early indicator of noise induced hearing loss. Furthermore, the results of the study did not display any difference in pure tone threshold or speech testing scores between subjects when they were divided by noise exposure levels (low, medium, or high; self-reported). The study concluded that the risk of noise induced hearing loss from recreational noise exposure was low, but the risk remained and that noise exposure was an “additive process” over many years of continued exposure.

Feder et al. (2013) also focused exclusively on the pure tone audiometric thresholds of those who listened to MP3 players. They tested 103 male subjects and 142 female subjects who were aged 10 to 17 years old. Questionnaires were given to evaluate the listening behaviors and the hearing loss symptoms that the subject experienced. The participants were asked to share their listening duration and to rate their volume settings that they used when listening to portable digital audio player. Additionally, the participant was asked to play their favorite song at their usual listening volume and the maximum level they would listen to, and the sound pressure level was measured via a mannequin simulator. The results indicate that loud MP3 player sound levels may have negatively affected the hearing acuity in the sample group studied. It was found that the older the age of the subjects, the louder the measured sound pressure level was. For those who reported to listen for a longer amount of time (5 years or more), higher sound levels were measured and hearing acuity appeared to be poorer overall. This five-year mark was also noted in the study by Peng et al. (2007) and Kim et al. (2009). Furthermore, a quarter of the group reported to having experienced tinnitus, while one half to one third reported symptoms of a temporary threshold shift (TTS).

Kim et al. (2009) also studied the usage patterns of adolescents (age 13-18 years old) in regards to PMP, in relation to pure tone audiometric thresholds. Each subject filled out a questionnaire regarding their daily use of music players. The usage was quantified in both hours per day and in years of usage. The cumulative usage period for each subject was calculated by multiplying daily usage time by usage period. The results of the study revealed that male subjects had significantly higher hearing thresholds than their female counterparts. Thresholds were collectively higher in the 13-15 year old age group than the 17-18 year old group. The researchers hypothesized that this difference may be attributed to the new proliferation of personal listening devices available to adolescents. However, no relationship was found between hearing thresholds and daily use of PMPs. A significant increase in hearing thresholds was found in those who reported using PMPs for more than 5 years, compared to those who did not use them at all (as reported similarly in Feder et al. (2013) above). The majority of students in the study reported that they used their PMPs for 1-3 hours daily for the past 1-3 years. The authors caution strongly regarding the cumulative effect of loud music listening and they stress the importance of lowering the volume and decreasing the usage of PMPs.

Recreational music exposure and extended high frequency audiometric thresholds

The second research question addressed whether recreational music exposure has an effect on extended high frequency audiometric thresholds that is evident prior to a shift in conventional audiometric thresholds. Serra et al. (2005) utilized a longitudinal study approach to measure the hearing thresholds of adolescents in Argentina; the initial encounter was at age 14 and they were re-tested until age 17. The study group included 106 students; 63 were male and 43 were female. Both conventional audiometric measures were taken (250-8000 Hz), as well as the extended high frequency range (8000-16000 Hz), a region which may possibly aid in the early detection of noise-induced hearing loss. The results revealed a significant hearing threshold shift in several adolescents, particularly in the range of 14000-16000 Hz, and specifically within the third and fourth year of the study. A "small shift" was defined as 20 dB (or less) of a shift within the entire frequency range; 65% of the boys and 75% of the girls displayed a "small shift" in hearing thresholds. A larger shift was categorized as a shift of 20 dB or greater at one or more frequency; 35% of boys and 24% of the girls showed a large shift. As per the surveys that asked about recreational noise habits, disco attendance was the most popular form of recreational noise exposure for this adolescent group. The attendance greatly increased during the last two years of the study.

A retrospective analysis performed by Le Prell et al. (2013) also focused on extended high frequency (EHF) audiometry as an early indicator of NIHL. They gathered data from 87 young adults, aged 18-31 years of age. The participants were given a health and hearing-related survey to complete regarding the kinds of recreational music venues that they frequented. They were asked to specify whether they were exposed to music once a month or more frequently. The results revealed that PMPs were the most commonly reported source of recreational music exposure in this group, followed by night club/bar attendance. There was no significant relationship found between threshold (pure tone average or at a single frequency) and music player usage (yes/no to usage). There was no relationship when thresholds were evaluated in relation to hours of device use per day, days of use per week, and years of device use. The only statistically significant relationship found was between those who reported to using PMPs for longer than 5 years; threshold elevation of 3-6 dB were found among this group of users, mainly in the high frequency range of hearing. Of the participants, 6% reported having experienced a shift in hearing after exposure to a loud sound, and 56% reported experiencing tinnitus following a loud noise exposure. According to Le Prell et al. (2013), the usefulness of extended high frequency testing as an early indicator for noise damage is controversial. The study does seem to suggest that listening to a PMPs over an extended period of time (in years) and at a high volume can cause threshold shifts in EHF testing.

A study by Peng et al. (2007) also studied whether EHF testing was more sensitive to the early detection of noise damage than conventional audiometry. The experimental group included 120 young adults aged 19-23 years old who reportedly used personal listening devices (PLD) for at least one hour daily. The PLD group was further divided into subgroups based on their duration of PLD usage: 1 to 3 years; 3 to 5 years; and greater than 5 years. This group was given a questionnaire and were asked to detail the source of their noise exposure and to rate the sound level (low, medium, or high). The control group of the study included 30 adults aged 19-22 years old, who had normal hearing (500 through 8000 Hz) and no history of PLD usage. Conventional and extended high frequency audiometry (through 20000 Hz) were performed on each subject. The results of the study revealed significant differences between the three PLD groups and the control group for both conventional and EHF ranges. There were no significant differences between the three PLD groups. Overall, there was an incidence of hearing loss in 14.1% of ears after long-term use of PLDs. The PLD group that had normal hearing (500-8000 Hz) had significantly higher EHF hearing thresholds than the control group with normal hearing. The study concluded the EHF audiometry is more sensitive to hearing loss than conventional audiometry.

Otoacoustic emissions and music-induced hearing loss

The final research question addressed whether transient evoked and/or distortion product otoacoustic emissions responses can be used for the early detection of a noise-induced hearing loss in those exposed to recreational music sources**.** A recent study by Williams, et al. (2015) explored the question of whether an increase in recreational noise exposure has an adverse effect on the hearing of young Australians, as is evident by hearing thresholds and otoacoustic emission measures. The participant group from Australia included 1432 individuals ranging in age from 11 to 35 years old. A comprehensive survey was filled out by each participant and explored their hearing health attitudes and behaviors in regards to recreational noise exposure. The areas of recreational noise exposure included both music (personal stereo use, concerts, clubs) and non-music sources (firearm use, motor sports). The audiometric testing performed on each subject included air-conduction (500 through 8000 Hz) and bone-conduction audiometry, as well as distortion-product and transient-evoked otoacoustic emissions. The results of the study did not find any significant correlation between lifetime cumulative noise exposure and hearing thresholds or otoacoustic emissions amplitude.

A study by Keppler, et al. (2015) also tested pure tone audiometry and transient evoked and distortion product otoacoustic emissions, in addition to extended high frequency measures, to determine the effect of recreational noise exposure on these audiometric findings. Their subjects included 163 young adults, ranging in age from 18 to 30 years old. They completed a questionnaire regarding their attitudes and behaviors in regard to recreational noise exposure. The duration of exposure was questioned in regard to hours per week/month as well as time in years. The authors cautioned against previous studies that exclusively use an ‘hours per week’ measurement or exclusively a ‘years of use’ measurement. Both measures must be looked at together, otherwise the study may have an inaccurate measurement of the true listening time of the subject. The subjects in the present study were divided into three groups: low, intermediate, and high recreational noise exposure. There were no significant differences in hearing thresholds or in the amplitude of otoacoustic emissions between the groups. However, as part of the questionnaire, the subjects were questioned regarding hearing symptoms and 86% of the group reported experiencing temporary tinnitus following loud noise exposure. Additionally, one third of the group exceeded the allowable noise dosage, in comparison to occupational noise standards.

Montoya et al. (2008) also utilized Transient Evoked and Distortion Product OAEs to determine if these measures are good early indicators of noise induced hearing loss for MP3 player listeners. The MP3 user group included 40 ears of individuals between the ages of 19 and 29 who used MP3 players on a regular basis. The group included the same number of males and females; and the same number of right/left ears. A questionnaire gathered information regarding the nature of music exposure of the subject. The subject was asked to estimate how many hours per week they listened to their MP3 and how many years they had been using an MP3. The control group consisted of 116 participants in a similar age range as those in the MP3 player group, and had no exposure to MP3 noise. The results of the study revealed no statistically significant difference between the different MP3 subgroups (hours/week; years of usage). In comparison of the MP3 players group with the control group, the incidence of TEOAEs had a significantly lower incidence at 2000-5000 Hz. There was a significantly lower incidence of DPOAEs at the frequencies 700, 1000, 1500, and 2000 Hz, in comparison of the MP3 group to the control group. The amplitude of the DPOAEs was significantly reduced for the frequency range of 1500-6000 Hz and the DPOAE thresholds were significantly higher for all frequency bands in the MP3 group.

Biassoni et al. (2014) performed conventional audiometry, extended high frequency audiometry, and transient evoked otoacoustic emissions testing on 59 male adolescents at the age of 14/15 years and retested them at the age of 17/18 years old to discover the effect of recreational music habits on these audiometric measures. The initial hearing thresholds of the group determined their placement into one of three subgroups: Normal; slightly shifted (shift of up to 24 dB at one frequency); and significantly shifted (shift over 24 dB at least in one frequency). During both the test and retest, a questionnaire detailing the subject's recreational habits was completed. The subject's exposure to music was categorized into four groups, known as The Musical General Exposure (MGE): low, moderate, high, and very high exposure. Results of the study revealed an increase in hearing thresholds and a decrease in TEOAEs amplitude in the 'normal' hearing group. Additionally, the exposure to recreational music sources increased greatly from the time of the initial test to the re-test.

Discussion

The goal of the present systematic literature review was to examine the evidence regarding the effect of recreational music exposure on pure tone thresholds, high frequency thresholds, and otoacoustic emissions responses. More specifically, a systematic search yielded 11 studies which were chosen for inclusion in this review. These studies focused on recreational music exposure sources, such as personal music players, concerts, and clubs/discos. Several studies have recorded evidence that recreational music sources, specifically personal music players which have been increasing in popularity, are capable of producing a high enough volume to potentially cause hearing damage. The question being addressed within this review is whether the individual users display a recordable hearing loss that can measured with audiometric thresholds or otoacoustic emission testing.

The conclusions drawn from the 11 studies reviewed were mixed; some studies displayed a significant difference in pure tone thresholds between recreational music listeners and non-listeners or between levels of listening, while most did not. Meyer-Bisch (1996) found no difference between audiometric thresholds of nightclub attendees, but they did find differences between those who attended rock concerts at least twice a month compared to those who attended less or not at all. They also found a significant difference between those who listened to personal music player for more than 7 hours a week, in comparison to those who listened less than 7 hours weekly. Le Prell et al. (2013) also did not find any significant different between personal music player listeners and hearing thresholds, but they did find a difference among long-term listeners (more than 5 years). Feder et al. (2013) and Kim et al. (2009) also found a significant difference of hearing thresholds only among those who have listened for more than 5 years. Mostafapour et al. (1998) and Keppler et al. (2015) did not find any difference in pure tone thresholds between groups with different levels of exposure. It should be noted that Le Prell et al. (2013), Mostafapour et al. (1998), and Keppler et al. (2015) looked at a group of young adults, while Feder et al. (2013) and Kim et al. (2009) studied adolescents. The Meyer-Bisch (1996) study included a group of adolescents and a group of young adults. Taken together, it appears that use of personal music players over several years may potentially cause a shift in conventional and extended high frequency pure tone thresholds.

Several issues and possible confounding variables arise in consideration of the method of testing. As detailed by Carter et al. (2014), pure tone audiometry (PTA) appears to be the “gold standard” for measuring hearing sensitivity. However, this method is vulnerable to variations that arise from the test protocol used, test-retest reliability, the calibration of the equipment, the testing environment, and individual factors among participants, such as motivation. Some of these factors, such as the testing environment, obviously differed amongst the studies that measured pure tone averages. Other factors, such as the calibration and the motivation of the participants, remain unknown.

Another possible confounding factor that arose when comparing one study of this nature to another is that no specific criteria is agreed upon in terms of the cutoff for "normal hearing" vs. "hearing loss." In the clinical sense, a threshold above 20 dBHL or 25 dBHL is deemed "normal hearing." However, among researchers, a stricter criterion may be chosen. For example, in a study by Lees et al. (1985), a strict criterion of normal hearing was used; anything above 10 dBHL was considered a hearing impairment, which results in a much higher prevalence of hearing loss than other studies. Within the present group of studies, Peng et al. (2007) used the clinical criteria of a threshold greater than 25 dBHL to indicate hearing loss. Most of the remaining studies did not even delineate the cutoff criteria that were utilized. Williams et al. (2015) reported that the median measure of pure tone thresholds was a "normal range" according to clinical standards, but did not detail this range further.

Another issue noted is that not all studies had a baseline measure for pure tone thresholds. Due to the nature of the studies included, the group of participants that were gathered had already been exposed to recreational music, so a baseline measure was not possible. Most of the studies created a design where the "exposed" group was compared to a "non-exposed group." Some studies still utilized the term "permanent noise induced threshold shift," but it is inappropriate to use such a term when no baseline measure from that individual participant is available. It is highly possible that the participants did not begin at a threshold of 0 dBHL, and there are other risk factors that may result in elevated hearing thresholds (Carter et al., 2014). Biassoni et al. (2014) utilized a within-subject design and tested a group of adolescents at that age of 14-15 and then again at the age of 17-18. Although this study had a form of a “baseline” measure, many of the adolescents were already exposed to some degree of recreational music at the initial testing. Therefore, the initial testing was not a pure baseline measure prior to any music exposure, however at least a comparison from that point until the end of the study could be assessed for differences.

Regarding otoacoustic emissions, the studies similarly provided mixed results regarding its ability to provide evidence of hearing impairment. Williams et al. (2015) did not find any correlation between the calculated cumulative lifetime noise exposure and audiometric thresholds or otoacoustic emissions amplitude. Similary, Keppler et al. (2015) did not find any significant difference in otoacoustic emission amplitude. On the other hand, Montoya (2008) and Biassoni et al. (2014) did find some significant differences in the amplitude of otoacoustic emissions between groups in their studies.

There are several issues to consider regarding the studies using otoacoustic emissions testing as an early indicator of noise induced hearing loss. First, not all studies utilized a baseline measure for otoacoustic emissions, similar to the concern noted with pure tone thresholds. Results should be taken with caution when one group is being compared to another group; it cannot be assumed that all groups began at the same point. Additionally, as noted by Williams et al. (2015), there are no normative data regarding otoacoustic emissions responses. As Keppler et al. (2015) noted regarding their own study, the variability of otoacoustic emissions amplitude may have been too large, so that subtle cochlear damage between groups could not be detected. This problem could be avoided if a larger sample size is used.

A significant limitation of all the included studies is that the data rely heavily on self-reported measures. Due to the nature of this category of research, when noise exposure over a long length of time is being calculated, this limitation is unavoidable. A certain degree of trust is placed in the individual subject to accurately recall and report the amount, the duration, and sometimes even the intensity of exposure. Perhaps this variable can be partially avoided by implementing a longitudinal study design that follows the same subjects over time and can lend to more accurate reporting.

Although the studies that were included focus primarily on recreational music exposure sources, Keppler et al. (2015) noted that if a study did not determine if participants were exposed to a significant number of other sources of leisure noise (e.g., firearms, power tools, gardening equipment), this may present as a confounding variable. Most of the studies reported in this review did not consider if the participants were exposed to other sources of leisure-time exposure, in addition to recreational music exposure.

Regarding the hearing loss, there are several factors which may affect individual differences. Portnuff (2013) proposed that age may have an effect on listening levels; in their study, adolescents had a tendency to listen to their music at a louder volume than the graduate students tested. However, there is limited research on this topic and the reports are more anecdotal in nature. Some studies found a difference among gender in reference to recreational music habits, while others did not. Regarding ethnicity, one study that that African-Americans were more likely to exceed recommended listening levels; this area obviously requires more research (Portnuff, 2013). Carter et al. (2014) referred to a study conducted by Ferrite & Santana (2005) who propose that the use of tobacco amongst individuals may serve as a confounding factor among participants. The above individualized factors may cause a significant difference in individual susceptibility to noise damage.

Several studies that were reviewed, such as those of Serra et al. (2005) and Williams, Carter, & Seeto (2015), calculate the risk from noise damage based on occupational noise standards, however, there is a risk involved in this calculation. Whereas the allowable noise dosage for occupational standards is based on an 8-hour continuous daily exposure, recreational listening patterns are often less frequent and non-continuous. Jin et al. (2013) notes that the breaks that an individual takes between listening exposures may have a “protective effect” on the cochlea and prevent noise damage. Another issue arises when comparing the two kinds of noise - occupational and industrial noise versus music. The spectral qualities of the two differ; music has greater variability in spectral content and intensity, and a greater spread of energy over time, in comparison to industrial noise. Additionally, some studies calculated a lifetime noise exposure risk; the years that an individual is in a specific occupation is easier to speculate about than an individual’s recreational habits, which very much change over time.

Thus, although a conclusion regarding the risk of recreational music exposure has not been definitively proven, neither can it be ruled out. It appears prudent, therefore, to error on the side of caution regarding this issue. It is important, therefore, to consider the attitudes and behaviors of adolescents and young adults towards recreational music exposure and the use of hearing protection, so that they can be provided with the appropriate knowledge and awareness for the future. Zhao et al. (2011) provides research from a survey conducted by Lass et al. (1987) that assessed the awareness and knowledge of high school students about hearing health. Of the 101 respondents, 90.1% knew that noise exposure could lead to hearing damage, but 88.1% thought this was caused by damage to the eardrum and 38.6% thought that damage was solely related to the intensity of the exposure and unrelated to the duration of exposure. Of great concern, 48.5% were under the impression that noise damage was treatable and corrected by medical treatment.

In a large online study, conducted by Chung et al. (2005) the hearing health care attitudes of 9,693 subjects were assessed. The mean age of participants was 19 years old, so this was a survey that targeted the adolescent/young adult group. In comparison to general health concerns of drug and alcohol use (47%), depression (44%), smoking (45%), nutrition and weight issues (31%), and acne (18%), hearing health was of the least concern (8%). Just 16% of the participants reported having heard, read, or seen anything publicly regarding hearing loss, and only 9% reported receiving education regarding hearing health at school. Only 14% of respondents reported that they had used hearing protection, and 20% reported the intention to do so at future concerts or clubs. However, many more (66%) would be motivated to wear ear protection if they were made aware of the permanent nature of noise-induced hearing loss, or if recommended by a medical professional (59%). This is important information in considering the education of youth about hearing damage and protection. However, research suggests that merely providing education and raising awareness of the consequences is not enough in and of itself to lead to a change in behavior (Zhao et al., 2011).

Since the consequences of music/noise exposure are most frequently not immediately experienced, it is simple for adolescents to deny that any risk is involved. It is challenging for youth to understand how serious the problem may possible be in years to come. Although the damage caused by noise is usually not immediately apparent, hearing symptoms sometimes do immediately accompany noise exposure. Portnuff (2013) found that those who personally experienced a hearing symptom tend to have more negative attitudes towards noise (anti-noise attitudes). Similarly, Balanay & Kearney (2015) similarly found that college-age students who experiences severe hearing symptoms, such as ear pain or permanent tinnitus, are more likely to adopt attitudes against noise.

The Health Belief Model explains that a trigger, such as a negative health outcome, like a hearing symptom, can cause an individual to begin additional "health-oriented behaviors," such as the use of hearing protection. Balanay & Kearney (2015) reported that students who experienced at least one hearing symptom were more likely to report the use of hearing protection. Students who reported more severe hearing symptoms (i.e. tinnitus, ear pain, hearing loss) were more likely to adopt hearing protection, in comparison to those who reported a less severe hearing symptom, such as noise sensitivity.

The Theory of Planned Behavior posits that an individual's plan to perform a certain behavior depends on their attitude towards the behavior, their perception of the social norms regarding the behavior, and their perceived control over their own behavior. Balanay & Kearney (2015) provide proof that a person's attitude toward noise affects their adoption of hearing protection. Those who reported use of hearing protection during rock concerts, disco, or sporting event attendance had clear anti-noise attitudes. Those who did not report hearing protection use during the above activities had neutral attitudes towards noise. Additionally, Balanay & Kearney, 2015) found that hearing protection was more likely adopted during activities such as use of firearms, power tools, and other noisy equipment (such as lawnmowers). Even those who had a neutral attitude toward noise were more likely to utilize hearing protection during these activities. This may likely be linked to the youth's perception of what is socially acceptable. Portnuff et al. (2013) points out that youth may accept socially acceptable behavior without questioning it. The use of hearing protection is often perceived as common and acceptable regarding the use of power tools and lawnmowers. Furthermore, the noise during these activities is often viewed as unwanted and bothersome (Balanay & Kearney, 2015).

The knowledge of the potential risk of noisy behaviors and the use of hearing protection is important to convey to the youth and young adult population to protect their long-term hearing health. Hearing impairment is known to negatively affect an individual's quality of life and may also have psychological effects on the subject. These consequences include depression, emotional disturbances, and difficulty concentrating (Erlandsson & Hallberg, 2003, as quoted by Balanay & Kearney, 2015). Williams et al. (2015) indicate that there is increasing evidence that noise-exposed individuals experience slower and weaker auditory processing skills. The effect on central auditory processing may precede clinically recordable hearing loss. Additionally, Xiong, Yang, Lai & Wange (2014) suggest that impulse noise experienced in young adulthood may later accelerate the onset of presbycusis. Even when immediate hearing damage is not present, or if a temporary threshold shift is present but is followed by recovery, the individual may be causing damage to his auditory system that may only be present years in the future.

Conclusions

Clinical Implications & Future Research Needs

- A large body of evidence is available regarding the dangerously loud exposure of noise in a variety of recreational settings. However, there is still a lack of sufficient and consistent evidence that supports that hearing loss, as evidenced by standard pure tone audiometry, is apparent in this population.
- Although there have been multiple studies performed over the past few decades, the results of such studies that use similar methods are not in agreement.

- Long-term longitudinal studies are few and far between in this area. More studies of this nature may be necessary to display a hearing impairment in this population due to recreational music exposure over time.
- With the above in mind, there is evidence that some degree of risk potentially exists in the population regarding recreational music exposure. Therefore, there is a need to further investigate the most effective way to educate the adolescent and young adult group regarding the importance of hearing health and noise damage prevention.
- High frequency audiometry and otoacoustic emissions responses may serve as an early indicator of noise damage, but this claim has not yet been substantiated due to differences among study outcomes and requires future evidence.
- Other topics to be considered for future research need:
    - Are there other aspects of auditory perception that may be adversely affected by recreational music exposure, other than audiometric thresholds and otoacoustic emissions measures?
    - What is the risk of central auditory processing damage prior to auditory decline?

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