Current Practices in the Assessment of Recreational Noise-induced Hearing Loss: a review

This document presents a review of current practices in the assessment of hearing loss caused by exposure to loud sounds in recreational settings. The review will be used to stimulate discussion and consider the points raised in the accompanying discussion paper regarding the need for a universal research protocol. This review has been undertaken by Dr. Kamakshi Gopal, in collaboration with the World Health Organization.

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**PURPOSE OF THE REPORT**

Hearing loss, temporary or permanent, from exposure to recreational noise is a worsening public health problem, particularly in children, adolescents, and young adults. This is attributable to the fact that young people utilize their leisure and relaxation time in activities that expose them to high levels of music or noise at concerts, bars, sports arenas and clubs, or listen to unsafe levels of music on their personal audio systems. Despite this emerging widespread trend, there are currently no universal standards set to limit exposure to recreational noise. Currently the World Health Organization, along with academic experts and other stakeholders, has taken the initiative to set global standards for exposure limits, apply health communication strategies for safe listening, and create safe listening software programs. It is imperative that, for a critical evaluation of the effectiveness of these strategies, we must use a uniform assessment protocol. Hence, the purpose of this report is to provide an overview of existing literature in the area of recreational noise-induced hearing loss, and to highlight the need for creating a universal protocol for assessment.

**GOALS OF THE REPORT**

The goals are (1) to summarize existing peer-reviewed literature in the area of recreational noise-induced hearing loss, and (2) to lay the foundation for creating a universal research protocol to provide guidance to future researchers who plan to evaluate the effects of recreational noise exposure on hearing and the effectiveness of safe listening initiatives. Implementation of uniform protocols would facilitate comparison of results across the globe more effectively.

**METHODS**

A literature search was conducted for scientific articles in the area of recreational noise exposure and hearing loss. Databases were searched for peer-reviewed articles on recreational noise-induced hearing loss and their assessment techniques. Key words such as “recreational noise- induced hearing loss”, “music and hearing loss”, “recreational noise”, “noise-induced hearing loss”, “noise exposure”, “temporary threshold shift”, “permanent threshold shift”, “adolescents and noise”, and “personal audio systems” were used in the search. The selection criteria included exposure to music in educational and professional activities, recreational noise, and other loud personal leisure activities resulting in varying degrees of shift in hearing thresholds, temporary or permanent. Cross-sectional, as well as longitudinal studies, were included. Studies that used control groups (non-exposed participants), or those that compared pre- versus post-exposure data from the same set of subjects were included. Studies that were in languages other than English, and studies that were performed on animals, were excluded from this review. All articles that resulted from the literature searches were assessed against the inclusion criteria for possible importance to the topic of assessment of noise-induced hearing loss. The articles of relevance were read in full, evaluated and summarized below.
**EXECUTIVE SUMMARY**

There are several challenges to assessing the harmful effects of recreational noise on hearing sensitivity. They include, but are not limited to: absence of pre-noise exposure hearing sensitivity data, lack of definitive evidence that temporary threshold shifts (used as risk indicators) lead to permanent threshold shifts, and teasing out the effects of co-existing factors such as exposure to occupational and leisure noise in people exposed to both types of noise. As WHO and the stakeholders move forward with instituting safe listening initiatives, establishing a universal research protocol for adoption in future investigations, especially longitudinal studies, can address some of the aforementioned challenges. This review provides a snapshot of the current research protocols and findings published in the area, upon which the new research protocol can be designed. This report is not intended to include an exhaustive literature review of recreational noise-induced hearing loss, but rather summarize the methods adopted and results obtained by various investigators to highlight the variability and commonalities among the studies.

The publications summarized in this report were grouped under the following three subsections:

1. Studies categorized under noise exposure from concerts/discotheques/bars
2. Studies categorized under noise exposure via personal audio systems (PAS, also referred to as personal music players, personal stereo players, and personal cassette players)
3. Studies categorized under noise exposure from sporting arenas

As seen from the summaries, the sampling technique varied depending on the goals of each study. Some studies used a targeted approach where subjects were selected based on their recreational noise exposure history, while others used a non-targeted approach in which volunteers served as subjects. Likewise, the number of subjects, inclusion criteria, subject age ranges, exposure venues, audio gadget usage, quantification of exposure, testing environment, tools and test procedures used in hearing assessment, pre- and post-exposure evaluation conditions, criteria for change in hearing status, questionnaire items, and standards for daily dose assessments were also widely variable. However, some commonalities between these studies were also observed. Most studies reported using teenagers and young adult subjects in their investigation. Most clinically-based studies used case history information and tympanometry to rule out middle ear disorders prior to enrolling them in their study. Shift in pure tone thresholds between 0.5 – 8 kHz was most often investigated, although some included extended high frequencies and otoacoustic emission testing. Tinnitus was reported in the majority of studies on recreational noise. A lot of these studies evaluated temporary threshold shifts (TTS) from experimentally induced noise or from exposure to loud noise in real-life situations (e.g., concerts), but a few looked at permanent threshold differences in recreational noise-exposed subjects in comparison to their age-matched controls. Although TTS assessment was based on observable threshold shift, the criterion used in the assessment of TTS was not always similar, as some used a minimum shift of 10 dB HL as the acceptable level, and others
used any shift that was recordable and further examined if that shift was statistically acceptable. Thus, comparison of results across research studies has been a challenge because of varied samples, methods and protocols used by the investigators. However, it must be acknowledged that, even with varied methods and protocols, the data obtained thus far supports the presence of risk posed by recreational noise on the human auditory system. Most studies point to the fact that excessive exposure to loud recreational noise does impact human hearing capacity and can lead to other auditory-related symptoms, such as tinnitus, difficulty understanding speech, and hyperacusis.

Understanding these current practices and methodological variations is the first step in developing a standardized research protocol that can be applied for uniformity in data collection.
Hanson and Fearn (1975) completed a study including 79 participants (mainly students) of ages ranging from 18 to 25 years, with the average age of 19.7 years. Participants completed a questionnaire, underwent an otoscopic examination, and completed pure tone audiometry following three days of without exposure to loud noise. The control group was made up of 29 students who claimed that they did not attend pop-music functions, and the remaining 50 students made up the test group claiming they had attended pop-music functions at least once a month. Results showed that there was a decrease in the average hearing thresholds of students who attend pop-music functions regularly as compared to those who do not. At 2 kHz, 6 kHz, and 8 kHz, the levels were not significantly different, but at 500 Hz, 1 kHz, and 4 kHz, the hearing loss was found to be significant ($P < 0.01$) and at 3 kHz, the hearing loss was found to be highly significant ($P < 0.001$).

Lindgren and Axelsson (1983) completed a study using ten teenagers (average, 16.2 years old) who volunteered to participate in an assessment comparing Temporary Threshold Shift (TTS) in music versus noise exposure. Each participant indicated normal hearing limits, according to pure tone audiometry, tympanometry, and contralateral reflexes. All ten listeners were subjected to five rounds of pop music at ten minute increments, followed by five other instances of nonmusical noise. In each nonmusical listening scenario, level, frequency, and time characteristics were measured in octave-band equivalence to the pop music. Results indicate TTS sensitivity from 4000 to 6000 Hz, with a greater impact after exposure to the nonmusical noise stimulus. This evaluation implicates sound factors contributing to differing degrees of TTS.

Clark and Bohne (1986) assessed noise exposure to determine TTS in six rock concert attendees. Audiometric evaluations before the concert revealed normal hearing sensitivity in five of the six volunteer test subjects, ages 16-44 years old. During the concert, noise exposure levels were attained using dosimeters worn by two of the concert attendees at different locations within the venue. These measurements indicated an average exposure level of 100 – 100.6 dBA over a period of 4.5 hours. Following the concert, participants underwent two re-evaluations: the first, 30 minutes after and the second, sixteen hours after the concert. According to audiometric evaluations taken 30 minutes after the concert, five participants revealed significant threshold shifts, particularly in the 4 kHz region. Audiometric measurements taken after sixteen hours revealed that normal hearing returned to all test subjects. Results indicating a TTS 30 minutes after noise exposure suggest that participants may have sustained some sensory cell loss due to excessive exposure levels over a sustained period.

Yassi et al. (1993) performed a study using 11 men and 11 women (22 participants) with an average age of 25 years, to determine the nature, degree, and duration of temporary threshold shifts due to the noise exposure from the attendance at modern rock concerts. Pure tone audiograms were obtained for each participant prior to the concert. The frequencies that were tested included 500, 1000, 2000, 4000, and 6000 Hz. After baseline audiograms were completed, the participants were split up into three groups and assigned a different area of the arena to watch the concert depending on the availability of group seating. One member of each
group wore a dosimeter for the duration of the concert. After the concert, a new audiogram was obtained and compared to each participant’s baseline audiogram to determine if there were any TTS. A temporary threshold shift was defined as a shift in threshold of 10 dB or more from the baseline audiogram. Participants who presented with significant threshold shifts were retested 40-60 minutes later. Those who still presented with a significant threshold shift were tested again 24 hours later. After attending the concert, all participants completed a questionnaire that assessed each participant’s impressions, symptoms, and any possible confounding factors that could impact the results of this study. The results showed that data from the dosimeters indicated that every participant was exposed to more than double the daily dose of acceptable noise exposure in one day, with peak levels of noise reaching 139.5 dBA. Some even received more than four times the acceptable daily dose of acceptable noise exposure. TTS of 10 dB or more was seen at 4 kHz in 81% of the participants tested within the first 25 min, and 76% continued to show TTS at 40-60 min testing. Results of the questionnaire demonstrated that 60% of the participants described the noise level of the concert as “intolerable” or “too loud” and 10 out of 17 participants who presented with TTS did not notice their temporary threshold shift at all. This demonstrates that noise-induced hearing loss can be insidious to the general population.

5. Meyer-Bisch (1996) completed a study in 211 people attending discotheques, 136 people attending rock/variety concerts and 195 subjects that use personal cassette players (PCP) to assess the repercussions from exposure to loud music. Each group was compared to a control group, and each group also had three subgroups based on the frequency of music exposure. Questionnaires were administered to all participants included in this study, which included questions on auditory suffering (AS), i.e., tinnitus and/or auditory fatigue. The participants were separated into groups based on their answers from the questionnaires. Audiometric tests were completed in sound-proof booths on each participant, and their audiograms were assessed and compared to their type and frequency of recreational noise exposure. Results indicated a significant increase of average hearing threshold in people using a PCP for more than seven hours/week compared to the control group and people using PCPs less than seven hours/week. Similarly, a significant increase in average hearing thresholds was found in subjects who attend rock concerts at least twice a month compared to their matched controls. However, no significant difference was found in hearing thresholds for the discotheque subjects compared to their control group. The authors recommended reduction of sound levels, education of music and entertainment professionals as well as PCP users. A significant difference in the rate of AS was found between the discotheque, PCP and rock concert attendees compared to their respective control groups.

6. Tin et al. (2000) examine attitudes and perception toward amplified music, and the effect of discotheque music on hearing threshold. A group of 48 participants with normal audiometric thresholds attended a single discotheque session for four hours, at one of two popular discotheques, A and B. Hearing thresholds were obtained one week before, thirty minutes after, and two days after the discotheque session. Two volunteers wore noise dosimeters to assess the mean time-weighted average noise exposure of participants over a four-hour period. A-weighted sound levels for discotheque A and B were 101 dBA and 108 dBA respectively. More
participants who attended discotheque B reportedly perceived the music as too loud, compared to those in discotheque A who found the volume just right for them. In discotheque B, 63.6% of participants experienced tinnitus. Most discotheque attendees perceived their hearing to be worse and had significant threshold shifts in their audiograms. All participants’ hearing thresholds and tinnitus recovered two days after discotheque exposure. Equivalent weekly exposure levels were 91 dBA and 98 dBA for groups A and B, and equivalent monthly levels were at 85 dBA and 92 dBA respectively, putting patrons who visit discotheques more than once a month at a possible risk for noise induced hearing loss. Researchers indicate the importance of educating individuals on the risks of noisy discotheques and the benefit of reducing frequency of attendance.

7. Dalton et al. (2001) performed a study to assess the association of leisure-time noise exposure and age-related hearing loss. This study included 1,540 men and 2,031 women, ages 48 – 92. Baseline data was established for Epidemiology of Hearing Loss Study (EHLS), based on age-related hearing loss. Participants were given a hearing-related medical history and noise exposure questionnaire, followed by pure tone air- and bone-conduction audiometry. Leisure-time noise included exposure to woodworking, metalworking, recreational vehicle use, yard work with power tools, chain saws, musical instruments, noisy kitchen appliances, vacuum cleaners, and hair dryers. Using logistic regression to account for individual activities such as age, gender, noisy occupation, cardiovascular disease, smoking, and the use of recreational firearms, a dose-response relationship summary was created. Participants engaged in leisure activities with average sound levels greater than 90 dBA were found to be significantly more likely to have a hearing loss compared to those that did not engage in loud leisure activities. Furthermore, individuals who were engaged in woodwork were more likely to have a hearing loss than individuals that were not engaged in woodwork. They concluded that health care should counsel their patients the risk involved with noise leisure activities.

8. Krishnamurti and Grandjean (2003) investigated the acute effects of simultaneous exercise and exposure to loud music on auditory function. Their study included nine normal hearing women with a mean age of 22±5 years who regularly worked out while listening to music. Hearing acuity was measured before and after three different conditions: listening to music via earphones at 90 to 95 dB SPL for 20 minutes, exercise at 60% of their VO2 max for 20 minutes, and a combination of the two simultaneously for 20 minutes. Pure tone thresholds at 2 - 8 kHz, and distortion product otoacoustic emissions were used to measure hearing. Results showed unaltered hearing acuity and auditory function after exposure to each of the three conditions (p > 0.05). The authors concluded that loud music during moderate-intensity exercise is not risky for young physically fit adults with normal hearing.

9. Bogoch et al. (2005) used questionnaires to examine the perceptions of risk of NIHL and use of hearing protection among rock concert attendees. They chose four different rock genre concerts in hopes of getting a good variety of participants for their sample. They distributed 272 questionnaires across four concerts and 204 were returned for a 75% response rate. Participants were 14-65 years old with a mean of 20.6 years and median of 19 years. The questionnaires asked about demographics, hearing protection use or willingness to use, if any
concerns about noise levels at the concerts, and hearing concerns following concerts. Results indicated 34.3% thought it was somewhat likely and 39.8% thought it was very likely that music concerts were loud enough to damage their hearing. About 80% reported not using hearing protection at concerts, and 84.7% reported tinnitus while 37.8% reported some form of hearing disturbance following concerts. Attendees experiencing hearing disturbances and concerns about developing a future hearing loss were significantly associated with concert attendees' use of hearing protection. They also found that 40% of respondents reported their willingness to wear hearing protection if it were provided for free at the concert hall. Willingness to use hearing protection was significantly associated with previous use of hearing protection, a higher score on the readiness scale for behavioral changes and a lack of cosmetic concerns for ear plugs. Authors recommended reduction of music sound levels as well as access to ear plugs and public education at the venue.

10. Chung et al. (2005) examined adolescent and young adult’s exposure to loud music, awareness of the relationship between loud music and hearing loss, and the feasibility of an online survey to collect health information. The survey was randomly presented to visitors at the MTV web site and addressed general health issues, including hearing loss, socioeconomic status, and factors that might increase use of hearing preservation, and personal exposure to recreational noise. 9693 surveys were completed, with 8% of respondents considering hearing loss as “a very big problem,” based on a Likert scale. Among the respondents, 61% had experienced tinnitus and 43% had experienced hearing impairment attending concerts and clubs. Only 14% of respondents had used earplugs, while 66% reported motivation to try ear protection based on awareness of the potential for permanent hearing loss. Survey results indicate hearing loss as a low concern in relation to other health issues, such as alcohol and drug use, sexually transmitted diseases, and depression, as the detrimental effects may not manifest for years or are not life-threatening consequences. This study supports the necessity for hearing-conservation-educational programs to communicate the impact of loud music and the importance of ear protection in reducing noise-induced hearing loss.

11. Serra and Biassoni et al. (2005) published a series of studies investigating the relationship between recreational noise exposures and hearing loss, as they wanted to address the high incidence of hearing loss in young Argentina people at the beginning for their working life without a valid medical history. The first study summarized below was focused on describing the development of the study and its outstanding results. This was basically a longitudinal study of high school students aged 14-17 years who were exposed to loud levels of recreational noise and used personal listening devices (PLD). At the end of four years, there were 63 boys and 43 girls who completed the study. Every year, otoscopy was performed, each student underwent pure tone testing for both the conventional (250-8000 Hz) and high-frequency ranges (8000-16000 Hz), and the ‘Auditory State Questionnaire’ was administered. Measurements using a noise dosimeter and a chain of miniature measuring instruments were collected at the discos that were frequently attended by many of the participants. Real ear level measurements were made using an artificial head and torso equipped with two ear simulators. A small group of subjects set their personal music players to the level they normal listen to, which was then fed
to the ear simulators, and the electric signals were analyzed. Results were broken up into three groups (A, B and C), based on their thresholds. Only results of Group A were discussed in the paper since all subjects in that group had normal thresholds to begin with from 250 Hz to 2000 Hz, as well as between 3000 Hz to 16 kHz. To compare the thresholds across the four years of the study, the range of frequencies tested were divided into three categories, and one representative frequency from each category was selected. Frequency of 1000 Hz was used for the low frequencies, and it was determined that there was no difference in hearing thresholds. Frequencies of 4000 and 6000 Hz were used for the middle frequencies due to their importance for speech understanding. It was found that for boys there was an increase in the mean threshold for both frequencies in both ears. For girls, there was no difference at 4000 Hz; however, there was a trend towards an increase in threshold at 6000 Hz. Frequencies of 14000 and 16000 Hz were used for the high frequencies as they are considered early predictors of noise-induced hearing loss. Results showed that there was an average increase in threshold at both frequencies for boys and girls. Comparison between the genders showed that the mean hearing threshold levels were higher for boys compared to girls. Sound pressure levels were between 104.3 and 112.4 dBA at discos frequented by participants, and between 75 and 105 dBA for the personal music players that the students listened to. Boys, in general, were found to have higher sound level exposures than girls. These results shed light on the effects of leisure activity on hearing in young people.

12. In continuation of their previous study, Biassoni and Serra et al. (2005) reported significant threshold shifts among adolescents in their long-term study, highlighting the relationship between noise exposures during leisure activities and hearing impairment. Due to the varying levels of hearing thresholds found, participants had been grouped into three groups, and only data from group A was reported in both parts of the study. Group A presented normal hearing and Groups B and C had hearing problems. Group A indicated a significant hearing threshold shift, more than 30 dB during third year evaluations and was further divided into subgroups. Subgroup 1 (39 boys and 32 girls) had a small HTL shift with a history of participation in recreational activities and Subgroup 2 (21 boys and 10 girls) had larger HTL shifts and higher participation in musical recreational activities than Subgroup 1. Subgroup 1 indicated HTL averages for boys increased with age, while the HTL for the girls did not. Subgroup 1 represented the “tough ear” theory, implying that some ears do not experience significant threshold changes despite exposure levels. Subgroup 2 showed an increase of the mean HTL, representative of easily damaged “tender ears.” Results show that hearing thresholds associated with recreational noise exposure are dependent upon individual hearing sensitivity. However, there is great susceptibility for noise-induced hearing loss in adolescents with exposure to excessive recreational noise levels.

13. Jokitulppo et al. (2005) examined hearing thresholds and noise exposure history in 1,054 young men (19-27 years) in the military (conscripts) at the beginning of their military service, with most of them not exposed to occupational noise. All participants filled out a voluntary questionnaire about ear history, noise exposure, hearing loss, and tinnitus. Weekly noise exposure levels according to the noise energy principle for all of their leisure-time activities were calculated. All participants underwent pure tone audiometry from 500-8000 Hz and were
classified according to their hearing thresholds. Results indicated that 27% of the conscripts were exposed weekly to noise levels above 85 dBA risk limit. Tinnitus was reported by 67% of the conscripts. The prevalence of hearing loss was found to be about 20% among these young men. The occurrence of hearing symptoms correlated with increased noise exposure.

14. Kramer et al. (2006) performed a study to identify if the antioxidant N-acetylcysteine can reduce temporary changes in auditory function from exposure to loud music. They evaluated changes in auditory thresholds because of exposure to noise in a nightclub. Out of total of 31 subjects, 15 were used as experimental subjects and received the antioxidant. The remaining 16 were used as control subjects and received placebo. Participants were required to have hearing thresholds of 25 dB or less and DPOAEs with amplitudes greater than 20 dB SPL and 6 dB above the noise floor for four different frequencies. Pure tone thresholds and DPOAEs were obtained in a hearing conservation test van before and within 15 minutes after a two-hour exposure to live music in a nightclub. A member from each group wore a dosimeter to record the average level of noise exposure that the participants experienced during the 2 hours in the nightclub. Breathalyzer tests were administered pre- and post-participation to ensure that alcohol would not be a factor in the outcome of the study. Results from this study showed that the average noise exposure ranged from 92.5 to 102.8 dBA, with a mean of 98.1 dBA. No statistically significant differences were found between the groups for pure tone threshold or DPOAE shifts between pre- and post-exposure. Data collapsed across all subjects showed that the mean pure tone threshold shift across all frequencies was 7.6 dB HL, and the greatest shift was at 4000 Hz. Post exposure DPOAE amplitudes for collapsed data showed a decrease of 5 dB following music exposure and the reductions occurred most often at 3 kHz.

15. Opperman et al. (2006) completed a study on TTS after 3 concerts, in a variety of genres (pop, heavy metal, and rockabilly music). This study consisted of 29 participants who completed a noise exposure and medical history questionnaire. Each participant had an audiogram that was completed in a mobile audiometric booth before entering the venue. The participants were split up into groups of two and strategically dispersed throughout the venue. One person in each group wore earplugs for the duration of the concert while the other did not. The earplugs used in this study had a noise reduction rating of 21. Upon leaving the venue after the concert, all participants had another audiogram in the same mobile audiometric booth. Results showed that the average dBA of the pop, heavy metal, and rockabilly concerts were 98.92 dBA, 99.04 dBA, and 101.70 dBA, respectively. Maximum dBA recorded was 125.6 dBA for the pop concert, 124.3 dBA for the heavy metal concert and 118.3 dBA for the rockabilly concert. It was determined that, per OSHA thresholds shift standards, when using earplugs, only 4 temporary threshold shifts were observed (three participants experienced a TTS in one or both ears). In contrary, there were 14 temporary threshold shifts among participants who did not wear earplugs (nine participants experienced a TTS in one or both ears). This study shows some people’s misconception that they don’t need hearing protection for certain genres of music, because they are not as detrimental to hearing. Although this misconception may expose people to lower levels of noise, these levels of exposure can still damage hearing if people do not wear appropriate hearing protection further causing hearing loss over a longer period. Any genre of music, when listened to loud enough, can cause thresholds shifts in peoples’ hearing.
16. Schmuziger et al. (2007) studied 16 non-professional pop/rock musicians, including instrumentalists (guitar [N=4], bass [N=5], percussion [N=4], keyboard [N=2]) and one vocalist (N=1). The average age of participants was 35.5 years (SD = 6.8) and included two females and 14 males. Participants were required to have been part of a band for at least 5 years and participate in a minimum of a 2-hour rehearsal weekly. None of the participants wore hearing protection during rehearsals. Participants were tested in a sound-treated booth before rehearsals and after rehearsals, following a 15-20 minute drive to the testing site. Otoscopy and immittance measures were normal for all participants prior to initial pure tone audiometry. Participants were tested using standard and extended high-frequency (EHF) audiometry. With the focus being on the EHF range related to TTS, participants were tested in the following order of frequencies: 9, 10, 11.2, 12.5, 14, 0.5, 1, 2, 3, 4, 6, and 8 kHz, and researchers made sure to test right and left ears in a counterbalanced manner to avoid order effect. During rehearsals, the sound-level meter recorded a maximal and equalized (1 hour = 1-Leq) sound level of 111.4 dBA (range 106.2 to 115.1 dBA) and 102.9 dBA 1.5-Leq (range 100.1 to 104.8 dBA 1.5-Leq), respectively. Significant TTS in pure tone thresholds were found at 0.5, 1, 2, 3, 4, 6, and 8 kHz (p < 0.001), and 1.5 kHz (p = 0.004), but absent in all EHF conditions (p > 0.05). No PTS was found in participants. Consistent with other researcher’s findings, these researchers found the percussionists had slightly higher sound level exposures, likely due to the impulse noise they are exposed to.

17. Goggin et al. (2008) evaluated sound levels among various nightly entertainment venues, and associated risk factors of noise-induced hearing loss (NIHL) caused by overexposure to loud music. 303 voluntary participants attended or worked at one of twelve popular nightspots in a metropolitan area of Perth, Western Australia. First, using calibrated Rion integrating sound level meters, recordings were obtained from four to six positions within each venue. Then, patrons and staff of the entertainment venues were randomly selected to participate in a questionnaire regarding demographic information, frequency and duration of attendance, adverse auditory consequences of noise exposure, perception of noise and use of hearing protection, attitudes towards hearing protection provided by the venue, and knowledge of public campaigns on the effects of loud noise on hearing. Duration of noise exposure based on sound level meter measurements indicated an average exposure time per session of 4 hours and 39 minutes. Noise exposure levels averaged 95 dBA, with minimum levels of 70 dBA, and maximum levels of 115 dBA. Most participants (69%) were between 19 and 25 years old, with no significant effect of age on mean exposure time. Majority of questionnaire respondents (64%) indicated suffering an adverse auditory or systemic consequence of excessive noise exposure, most commonly, non-pulsatile tinnitus. 16% of respondent’s experienced temporary hearing loss and 49% considered entertainment venue noise levels dangerous or excessive. With average exposure levels of 95 dBA for over 4 hours, participants are at risk for NIHL. Few respondents (7%) were willing to use earplugs provided at no cost by the venue. Due to social perception and image concern, hearing protection usage was found to be minimal among females and those under the age of 26. The authors concluded that informing venue management of the risk, and regulating noise levels in venues may be the most effective strategies for prevention of recreational NIHL.
18. Holland (2008) completed a study on 9 collegiate student musicians in a concert band and the conductor of the band, resulting in 10 participants. Sound pressure levels were measured via a noise dosimeter throughout six different musical works performed by the band during six concert band rehearsals. Measurements were taken at 11 locations (one at each student musician’s position and one at each of the conductor’s ears). Pre- and post- audiometric exams were administered to each participant. Results demonstrated that OSHA and NIOSH permissible noise exposure limits were not exceeded during the band’s rehearsals; however, temporary threshold shifts of 10 dBA or greater were identified among all of the participants. A total of 139 threshold shifts were noted that were greater than 10 dBA when test frequencies of 500 Hz through 8000 Hz were tested for each participant after each rehearsal. These results were concerning because of the high incidence of temporary threshold shifts, which can lead to permanent threshold shifts and noise-induced hearing loss when temporary threshold shifts are repeated frequently.

19. Quintanilla-Dieck et al. (2009) completed a study through MTV.com by having 2500 viewers of MTV complete a 73-item questionnaire, derived from an earlier survey from 2002, about their music noise exposure. Respondents were 9 to 31 years old with an average age was 21.7 years. Questions elicited information about hearing loss awareness, earplug use, MP3 players, personal health measures, and potential changes in attitude about using earplugs. Results showed that hearing loss was considered a problem by only 32% of the respondents compared to 62% of respondents who considered other health issues such as drug and alcohol use, cigarette smoking, sexually transmitted diseases, weight loss/nutrition, depression and acne as a problem. More than two-thirds of people who responded reported that they had been made aware of music-induced hearing loss, and nearly half of respondents experienced some form of ear problem, such as tinnitus, difficulty hearing, or pain, when exposed to loud sounds. Only 15% of respondents had used earplugs at a concert or club. Most respondents revealed that with educational awareness, they were willing to adopt protective behavior, especially if informed by health care professionals, but ironically the least likely source of awareness of music-induced hearing loss came from health care providers. The authors recommend that health care professionals must actively educate and campaign for hearing preservation.

20. Martinez-Wbaldo et al. (2009) completed a study on 214 high school students in Mexico to identify the frequency of hearing loss in students exposed to recreational noise, and determine associated risk factors. The mean age of the students was 16.3 ± 1.07 years, with 73% males and 27% females. All participants completed a questionnaire to assess each student’s medical history, audiological history, and their typical exposure to noise. Following this, audiological testing was performed using otoscopy, pure tone audiometry, and tympanometry in a mobile bus containing audiological equipment and sound-proof rooms. Hearing loss was found in 21% of the participants, with 39 subjects showing a mild noise-related sensorineural hearing loss and five showing moderate noise-related hearing loss. Recreational music exposure included use of personal stereos and attendance at discotheques and music concerts. About 32% of students in the research sample had exposure to at least one type of recreational noise at a
high intensity level, and 21% reported combined exposures. Exposure to loud music levels was found to be significantly related with hearing loss (P < 0.05). The authors concluded that sensorineural hearing loss in teenagers was significantly related noise exposure from recreational activities, including combinations of concert attendance, concerts and discotheques, earphones, and school workshops (all were found to have significance risk; P < 0.05). Hence, specific education in hearing conservation, limits on loudness levels for personal stereos and music concerts, and use of ear plugs for hearing protection were recommended.

21. Epstein et al. (2010) investigated iPod output volumes in a variety of environments to estimate the actual listening levels of 64 iPod users. Earbud output levels were measured using a real ear reference to estimate volume levels in the presence of a variety of different background noises. The authors used an Audioscan Verifit real-ear analyzer to determine sound output levels (SPLs) at 25%, 50%, 75%, and 100% of the iPod volume using stock earbuds. Then, iPod users were approached in different settings, including a heavily trafficked street in downtown Boston, on the Boston Massachussets Bay subway, in a university library, and in a university student center. Participants were asked not to adjust the volume on their iPods and a digital recorder analyzed the listener’s stimuli at the same volume settings directly from the iPod. Then they answered questions regarding iPod usage and levels of exposure. Thirteen listeners’ average listening levels were greater than 80 dB SPL near the tympanic membrane (dBTM), of those, eight exceeded 85 dBTM, 29 recording were greater than 90 dBTM, 18 were greater than 95 dB dBTM, and 13 exceeded 100 dBTM. Of five free-field equivalent A-weighted samples, none exceed 85 dBA. Eight samples had peak levels greater than 90 dBA, six greater than 95 dBA, but none exceeded 100 dBA. Based on permissible noise exposure criteria set by the Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH), participant listening levels were within recommended dosage standards. Results do not indicate a substantial risk for hearing loss based on these sound pressure levels, but iPod users should still limit their duration and listening levels.

22. Muhr and Rosenhall (2010) recruited to 839 young healthy men (19-22 years) who were reporting for primary military service in Sweden. They distributed a self-developed questionnaire following and performed audiometry. Questionnaires involved questions of participants estimated prevalence of auditory symptoms, estimated prevalence values of self-assessed noise exposure and factors for impairment, analyses of relations between noise exposure and other factors, analyses of relations of noise and other noise related factors to presence of symptoms and hearing impairment, and analyses of relations between symptoms and measured hearing impairment. Audiometric results from the participants in the range of 500 Hz to 8 kHz were examined. Results showed that 51% of the young men reported one or more auditory symptoms. The conscripts had a history of exposure to excessive noise levels, most often leisure time music. Tinnitus after the noise exposure was reported to be a common occurrence. The prevalence of hearing impairment expressed as hearing thresholds above 20 dB HL in one or both ears at one or more frequencies was 14.5%. The prevalence of tinnitus and sensitivity to noise was 23.2% and 15.5% respectively. The final recommendation of the study was more education directed to youth about temporary threshold shift and tinnitus as symptoms of NIHL.
23. Derebery et al. (2012) used pre-and post-concert assessment to examine the effect of exposure to a single pop/rock concert on pure tone hearing thresholds and outer hair cell function. Twenty-nine participants, 10 males and 19 females, were recruited into the study. Participants ranged in age between 13 and 20 years, with a mean age of 17.7 years. Almost all participants had normal pure tone thresholds bilaterally (less than 25 dB HL) except for one individual who had one threshold at 30 dB HL. Participants filled out a preconcert questionnaire about tinnitus, PLD use, loud noise exposure, and ear history. Before the concert, participants had their hearing testing in the mobile hearing conservation test vehicle with the automated pure tone threshold program. Pure tone thresholds were obtained at 500-8000 Hz for both ears, and then DPOAEs were tested in one ear. Before the participants attended the concert, foam earplugs were offered for hearing protection and proper use was demonstrated. The concert occurred in a large sport/concert arena with the participants positioned straight in front of the stage between 15 and 18 rows from the front so that they could all receive similar sound level exposure. After the concert, all participants underwent post-concert assessment with pure tone audiometry, DPOAE testing for one ear, and a follow-up questionnaire about noise-induced stress, ear discomfort, tinnitus, and whether they used the hearing protection provided. Sound pressure readings obtained using a calibrated sound level meter from a standing position among the subjects indicated an average sound level of 98.5±3.8 dBA with a range of 82 to 110 dBA. For the pre- and post-concert analysis, data from only 25 participants was used due to technical problems. The study indicated that the pure tone average of 2, 3, and 4 kHz thresholds showed an increase of 6.3 and 6.5 dB for the right and left ears respectively following the concert. A 10 dB or greater post-concert shift in pure tone average was obtained in 33.3% of the subjects in at least one ear. Of the participants, 59.3% had thresholds that worsened in three or more frequencies with only one participant showing no changes of 10 dB or greater. The average change in DPOAE results was 1.4 dB, and was found to be statistically significant (p ≤ 0.004). 25% of participants experienced tinnitus post-concert and only 10.7% chose to wear the provided hearing protection throughout all or part of the concert. The research indicated that 72% of the participants experienced either a threshold shift and/or a reduction in DPOAE amplitude post-concert attendance.

24. Gilles et al. (2012) assessed questionnaires that were given during a lecture. Participants were 145 university students (44 male and 101 female) whose average age was 20.77 years with an age range from 19 to 26 years. The questionnaire looked at the occurrence and loudness of temporary tinnitus, presence of permanent tinnitus, concerns about temporary hearing loss and about the possibility of permanent tinnitus following loud music, discotheque attendance frequency, and attitudes toward loud music. The results showed that 89.5% of respondents reported temporary tinnitus with 92.9% being female and 81.8% male, with females reporting louder tinnitus than males. Two-thirds of the respondents reported having the feeling of decreased hearing ability following loud music, use of hearing protection was reported by only 11% of the respondents, 14.8% reported having permanent tinnitus in one or both ears, yet few respondents were worried. Most respondents had a neutral or positive attitude toward loud music, and were not fully aware of the risks of excessive noise exposure. However, the possibility of permanent tinnitus was a motivating factor for use of hearing protection. The
25. Gilles et al. (2013) conducted an epidemiological study aimed at obtaining prevalence data of temporary and permanent noise-induced tinnitus, as well as attitudes and beliefs towards noise and hearing protection. They distributed a validated Dutch version of The Youth Attitudes to Noise Scale (YANS) questionnaire, and a validated version of the “Beliefs about Hearing Protection and Hearing Loss” (BAHPHL) questionnaire to students of 15 randomly selected high schools and obtained had responses from 3991 students (83% response rate). The mean age of the subjects was 16.64 ±1.29 years, with a range of 14-18 years old. Respondents were asked about the presence, intensity, and duration of tinnitus, exposure to noise, including playing an instrument solo or in a band, listening to PLD, attendance at discotheque, attitudes about noise, and beliefs about hearing protection and hearing loss. PLD’s were assessed by the volume setting percentage, and discotheques were assessed using five options from ‘too quiet’ to ‘too loud.’ The tinnitus rating assessed loudness of the tinnitus and duration. Results indicated 74.9% of students reported temporary tinnitus and 18.3% reported permanent tinnitus, with an increase in prevalence of temporary tinnitus with increase in age. Tinnitus was most often reported to be bilateral for temporary and permanent tinnitus conditions. In 63.2% of subjects, initiation of tinnitus or worsening of the existing tinnitus worsened after noise exposure up to two hours, but 94.8% of them did not fear permanent tinnitus. Regarding experiencing subjective noise-induced hearing loss, 39% reported experiencing it sometimes, and 11.4% reported experiencing it often. The study found that most students had a neutral attitude towards loud music, and the use of hearing protection was minimal (4.7%). However, students with a negative attitude towards noise, as identified from their questionnaire scores, used hearing protection significantly more than those with neutral or positive attitude. The researchers concluded that strategies and campaigns about noise exposure should include younger children, and should emphasize that tinnitus is a warning signal of noise-induced damage, and that temporary symptoms can result in permanent damage.

26. Gopal et al. (2013) examined noise exposure and the underlying risk of auditory impairment in 14 Music College students engaged in jazz music activity in comparison to 11 non-music students in regular classrooms. The goal was to determine if routine exposure to music among college students enrolled in the jazz band-based instructional activity exceeded the daily permissible limits set by NIOSH, and if those individuals exposed to such activity were at risk for hearing loss. Participants completed a case history form detailing hearing health and music exposure information, and underwent audiological evaluations prior to a 50-minute class period which consisted of instructional band practice for the music students and regular classroom activities for non-music students. During the class period, the subjects wore a noise dosimeter that continuously measured the noise level in the classroom. Following cessation of the class period, subjects were retested within 10 minutes. Noise dosimeters registered an average Leq level of 99.5 ± 2.5 dBA, a level that exceeded NIOSH standards, in the class engaged in jazz music activity, but only an average of 49.9 ±10.6 dBA in the regular classroom. Pre- and post-exposure audiological results showed a significant temporary threshold shift at 4000 Hz (P < 0.05), and a significant decrease in TEOAE amplitude (P < 0.05) for the music group.
compared to the non-music group. The post-exposure auditory test results paired with excessive music exposure levels indicated that those music students were at a higher risk for hearing loss.

27. Tung and Chao (2013) performed a study in which 1787 participants (average age of 18.9 years) completed a study that included information on how many times in a year each participant used earphones to listen to music or attended recreational noise activities. The researchers evaluated the average duration of these situations and the volume levels the participants were exposed. A screening was completed for each of the participants. If a participant did not pass the screening at any frequency (the passing criteria was 25 dB HL) then the participant underwent a full audiological evaluation in an audiometric booth. Results revealed that 80.9% of participants attended at least one loud noise recreational activity within the past year and 90.9% of participants regularly used earphones. 11.9% of participants had a hearing threshold of greater than 25 dB HL in at least one ear and in at least one frequency. The authors recommend that continued education regarding risks from recreational noise should be compulsory, especially for teenage students as they are more likely to participate noisy activities.

28. Biassoni and Serra et al. (2014) performed a longitudinal study over three years to assess the hearing of adolescents who were exposed to high intensity music. This study started with 172 males aged 13-14 years old, but reduced to 59 during the three year follow up. A baseline audiogram was performed after the participants had 10 to 12 hours of auditory rest in a utilitarian vehicle that served as the audiometric booth. Testing included a questionnaire to inquire about each participant’s medical history, otoscopy, tympanometry, conventional and high frequency pure tone audiometry and TEOAEs. Participants were then grouped into categories based on their amount of noise exposure (low, moderate, and high exposure). A three-year retest protocol revealed that most adolescents increased their music exposure levels as they grew older. Results indicate a significant shift in hearing thresholds for pure tones (P < 0.001) and significant worsening of TEOAE results in accordance with increased levels of music exposure (P < 0.001). The study recommends educational programs to promote hearing health among young people.

29. In a consecutive article, Serra and Biassoni et al. (2014) examined the relationship between NIHL and musical recreational listening habits among adolescents, and assessed sound emission levels in nightclubs and personal music players (PMPs). The participants were 172 adolescents aged 14-15 years who underwent audiological evaluations and completed a questionnaire regarding exposure to music-related recreational activities. Participants were categorized based on their hearing threshold levels (HTLs); those in the normal range (Group 1), slightly shifted (Group 2), and significantly shifted (Group 3). Based on their musical general exposure (MGE), the participants were categorized into low, moderate and high exposure groups. Results indicate significant differences (P < 0.01) in audiometric profiles between Group 1 and 2 at all frequencies tested, Group 2 and 3 in extended high frequencies (P < 0.05), and Group 1 and 3 at all frequencies (P <0.01). TEOAEs showed decreased amplitude and reproducibility between Group 1 and 2 as well as between Group 1 and 3 (P < 0.05). No significant associations were
identified between the HTL groups and MGE, however, there was a tendency toward a higher mean HTL in the group with high music exposure. PMP sound levels ranged from 82.9 to 104.6 dBA and sound level averages from nightclubs ranged from 107.8-112.2 dBA. Both recreational activities presented risky levels of sound exposure, demonstrating the need for preventative hearing health education and promotion.

30. Degeest et al. (2014) assessed the characteristics and prevalence of tinnitus after leisure noise exposure in students. Additionally, otoacoustic emissions were assessed in participants that had chronic tinnitus. All participants, found via online applications, completed a 44-item questionnaire, addressing ear history, leisure noise exposure, time wearing ear protection during noise exposure, presence of tinnitus after exposure, and whether tinnitus is transient (disappearing within 72 hrs.) or chronic. Those with chronic tinnitus were evaluated and compared to a control group. Questionnaire responses were received from 151 individuals, 51 males and 100 females, with an age range of 18-27 years. Transient tinnitus was reported by 111 (73.5%) of the respondents, while 10 (6.6%) respondents reported chronic tinnitus. Tinnitus was most often bilateral and described as continuous pure tone with a high pitch. Questionnaire analysis found no statistically significant relationship between the occurrence of tinnitus and the frequency of attending music events, but it was observed more often in those who spent longer amount of time at the event. Seven respondents (3 males, 4 females) who indicated they had chronic tinnitus underwent an in-depth audiological assessment, which included otoscopy, admittance testing, pure tone audiometry, otoacoustic emissions (DPOAEs and TEOAEs), and tinnitus analysis. A comparison was performed between the chronic tinnitus group (TG) and the control group (CG) matched per age and gender. Respondents with chronic tinnitus that were further evaluated showed a significant difference in hearing threshold at 1000 Hz (P < 0.05). Mean amplitudes in the TG were lower compared to the CG for DPOAEs and TEOAEs, with the most significant difference occurring at 1 k Hz and 4 k Hz for TEOAEs (P < 0.05) and 1.5 k Hz for DPOAEs (P < 0.01).

31. Spankovich et al. (2014) used impulse noise that may be heard in a video game, simulated as a 12-gauge shotgun blast, to see if TTS resulted under different conditions. Subjects were 66 volunteer participants (27 male and 39 female) who were all university students between the ages of 18 to 29 years (mean age = 21.1 ± 2.7 years). Repeated exposure to impulse noise was used at a rate of ~1 shot/second and increased in duration of shots (min = ~50; max = ~3200) and intensity of stimulus (min. = 88 dB peak SPL; max. = 117 dB peak SPL) that combined, accounted for 52 different stimulus conditions and exposure completed in a lab setting. Participants completed screening questionnaires and had otoscopy, tympanometry, and pure tone audiometry completed to apply exclusion criteria that resulted in the 66 participants. After exposure participants had DPOAE measures taken at 2- and 15-minute intervals and pure tone audiometry to test for TTS. When DPOAE measures showed TTS at both 2- and 15-minute intervals, participants were tracked for a longer period of time until TTS was no longer seen. Some participants showed TTS >5 dB HL. Following testing, 16 participants reported tinnitus, but this was not consistently linked to specific stimulus conditions. The scale of the tinnitus ranged from 1 (barely noticeable/not bothersome) to 10 (almost unbearably loud/unbearable) with average loudness = 2.1 ± 1.3 (range = 1 – 6), and the average objectionable/bothersome
score was 1.3 ± 0.9 (range = 0 – 4). All tinnitus fully resolved during each session. TTS did not reach or exceed 5 dB under most stimulus conditions. Three stimulus conditions had TTS results, the most prevalent being at 114 dB x 3200 shots, which showed TTS of >5 dB in some participants; however, no TTS was seen in the overall group data.

32. Helleman et al. (2014) assessed the effectiveness of listening breaks in reducing temporary threshold shift after exposure to discotheque music. They found that the left ear had worse temporary threshold shift and recovery time than the right ear. Between the test and control group, taking a break from discotheque music exposure had minimal influence on temporary threshold shift. Although minimal differences, using “chill-out zones” reduces the overall duration of noise dosage over an extended period. Discotheque should implement sound level limits and quiet areas with safe noise levels.

33. Balanay and Kearney (2015) completed a survey research study that used 44 questions, including 19 from the Youth Attitudes to Noise Scale (YANS), to look at attitudes towards noise, current negative hearing symptoms, exposure to noise, and hearing protection use. Researchers tested 2151 adult participants in a college setting. Noise exposure questions focused on shooting/use of firearms, playing in a band, sporting events, lawn mowing, attending rock concerts, discos/dances, and using noisy tools. Significant findings included 13.2% (284 participants) reported temporary tinnitus and 4.2% (91 participants) reported permanent tinnitus. While some results indicated temporary threshold shift (TTS), no results were reported. Additional significant findings revealed 22.5% (485 participants) reported ear pain after noise exposure, 20.8% (448 participants) reported noise sensitivity, and 8% (173 participants) self-reported hearing loss. Researchers concluded that reports of hearing protection were higher when participants had at least one identified hearing symptom than with no identified hearing symptoms. Participants attending discos/dances, rock concerts, or sporting events had lower incidence of reported hearing protection use as compared to participants exposed to firearms, noisy tools, and lawn mowing equipment. Due to the high prevalence of RNIHL among college students, future suggestions to help minimize the impact of RNIHL included implementing a hearing health and awareness section into required health course during collegiate education to reach a large amount of college students.

34. Tronstad et al. (2016) investigated average sound level exposure of two Norwegian music festivals, Hove and Øya, over sequential days of exposure. Of eight university students attending the festivals, four went to Hove and four attended Øya, for seven and five days respectively. Using personal noise dosimeters, researchers determined that Hove attendees exceeded recommended sound dosage by seven times, two participants exceeded yearly sound dosage levels over the seven-day musical festival. Øya participants did not exceed recommended sound dosage levels. The average daily dose for all participants corresponds with a 4-h equivalent level of 97.5 dB. Although participant affects such as position relative to the stage, speakers, and dosimeter placement produced variability, this data provides support for the importance of sound exposure guidelines and regulations for music festivals and concert supporters.
35. Gan et al. (2016) investigated the relationship between leisure- and occupational noise exposure, high-frequency hearing loss and coronary heart disease (CHD). Some studies indicate a relationship between chronic exposure to loud noise in the workplace and CHD, prompting a study on correlations between exposure, CHD, and hearing loss. Using a questionnaire, researchers gained information regarding occupational and leisure noise exposure and risk factors of cardiovascular disease (CVD) in 5223 respondents. 34% of participants had unilateral or bilateral hearing loss. Participants with bilateral high-frequency hearing loss were 1.91 times more likely to have CHD, than their normal hearing counterparts. Additionally, high-frequency hearing loss was associated with leisure noise exposure. Researchers call for a longitudinal study, including participants without hearing loss or CHD, to measure how these effects influence each other over an extended amount of time.

36. Henning et al. (2016) compare audiometric measures and cochlear function of college music majors and nonmusic majors using distortion product otoacoustic emissions (DPOAE) as an early indicator of cochlear damage. Using twenty-eight music majors and a control group of thirty-five nonmusic majors, researchers evaluated self-reported recreational noise using a questionnaire, audiometric testing, and DPOAEs. Bilateral pure tone air-conduction thresholds were normal for all participants in both groups, with no significant difference between group thresholds. For six music majors, DPOAEs were absent for at least one frequency in one ear and one music major had absent DPOAEs for at least one frequency in both ears. All the nonmusic majors had present DPOAEs at every frequency in both ears. Although normal sex effect and chance could have an impact on these results, variances in DPOAE data could prove that music majors are at a greater risk for future hearing loss due to early stages of cochlear damage. Researchers encourage the need for longitudinal studies to further understand early indications of cochlear damage and the importance of hearing protection in the prevention of more damage.

37. Throughout two-days of testing, Washnik et al. (2016) analyzed exposure levels of 57 collegiate level music students relative to the National Institute for Occupational Safety and Health (NIOSH) recommended noise dosage standard. Using personal dosimeters, researchers measured the sound level exposure of music students playing a variety of primary instruments, in different practice settings. Results indicate that 49% (28/57) of music students exceed 100% of NIOSH recommended daily noise dose at least one day, and 19% (11/57) exceed 100% of NIOSH noise dosage standards on both days. Students who play the trumpet, trombone, horn, saxophone, or drum are at a greater risk of exceeding NIOSH standards throughout the day. During large ensemble practice, 25% of students exceed NIOSH dosage standards, while only 16% exceed the daily standards during individual practice sessions throughout the entire day. This study provides evidence of excessive levels of sound exposure during a student musician’s day, and supports the necessity for hearing conservation programs and education on the risks of loud sound exposure and noise-induced hearing loss.

38. Degeest et al. (2017) examined risk factors associated with noise induced hearing loss (NIHL) based on leisure noise exposure and attitudes and beliefs towards noise in teenagers and young adults. A total of 517 participants responded to a questionnaire regarding sociodemographic
variables, subjective hearing status, leisure noise exposure and use of hearing protection devices (HPDs), the ‘Youth Attitude to Noise Scale’ (YANS), characteristics of tinnitus after leisure noise exposure. The audiological evaluation included pure tone audiometry, distortion product- and transient evoked-otoacoustic emissions (DPOAE and TEOAE). Subject groups were determined based on hearing status, including normal hearing, sub-clinical hearing loss, and clinical hearing loss. Based on these classifications, 84.3% associated with normal hearing status, 15.7% with sub-clinical hearing loss, and none represented clinical hearing loss. The highest amount leisure noise exposure among participants was found for watching movies or plays (95.6%), followed by nightclubs or music venues (92.5%), and attending music concerts or festivals (85.5%). Gender did not have a significant effect on hearing status, but age was associated with sub-clinical hearing loss. Although hearing loss was not found among participants, many engaged in multiple noisy leisure activities, meaning greater exposure over time. These effects on hearing ability might be seen over time, therefore a longitudinal study is necessary to better understand attitude towards HPDs and noise exposure throughout a lifetime.
**Personal Audio Systems (PAS) Studies**

39. Fligor and Cox (2004) intended to create safety guidelines on noise dosage by measuring sound levels generated by the headphones of commercially available portable compact disc players, and provide safety guidelines. Measurement procedures took place in the Boston University Hearing Research Center Sound Field Laboratory. Using a Knowles Electronics Manikin for Acoustical Research (KEMAR) and a personal computer, headphone output levels were measured and compared to output levels from eight different musical genres. Four headphones were assessed to determine influence on output level. Six types of CD players/PLDs were used to survey output levels across manufacturers. Results indicated that the output levels varied across manufacturers and headphone types, with smaller headphones exhibiting higher sound level output for a given volume setting and headphones placed closer to ear canal entrance produced significantly higher output levels. Free-field equivalent sound pressure levels at maximum volume control setting ranged from 91 dBA to 121 dBA. Results indicated possibility of cochlear damage due to portable CD player usage exceeding 100% noise dose, depending on ambient noise levels, characteristics of headphone attenuation of the ambient background noise, and a listener’s preferred signal-to-noise ratio. The authors recommended usage of supra-aural headphones and limiting the one hour or less per day at a volume setting of 60% maximum.

40. Williams (2005) conducted a study to identify the risk of noise injury from personal stereo players (PSP). The researcher measured the output from PSPs in 55 participants 15-48 years, whose daily activity included listening to their PSPs. While the measurements were being made, the participants responded to a questionnaire which collected information on their PSP usage such as: hours per day of use, years of use, incidence of tinnitus, self-reported/ family expressed hearing loss, conversational difficulty in background noise, and occupation. The mean measured A-weighted, eight-hour equivalent, continuous noise level was found to be 79.8 ± 9 dB, with most of them falling within the acceptable risk level of 85 dB. The study also found a significant difference in the measured noise levels between females (average of 75.3 dB) and males (average of 80.6 dB). No correlation was found between self-reported hearing loss or tinnitus and PSP levels. The study concluded that there was no significant increase in the risk to potential noise injury from PSP use alone.

41. Trask et al. (2006) assessed the potential for long-term hearing damage through excessive, prolonged noise exposure linked to their PLDs. 95 university students completed a seven-question survey detailing their listening habits and awareness of noise-induced hearing loss. Using a portable sound pressure meter linked to a silicone ear, ten-second fast dBA-weighted samples were taken of the songs at the level that subjects typically listened to. PLD listening levels ranged from 65 to 111.33 dB, with an average of 89.32 dB. Additionally, total average usage time was found to be 2.2 hours/day. According to these results, more than 16% of participants were exposed to average decibel levels greater than 100 dB. Based on NIOSH standards, 43% of individuals were at risk for long-term hearing loss. According to OSHA, 17% of subjects were considered at risk. About 95% of their subjects were aware of the risk of hearing loss from loud noise, but only 28% believed that their PLD use qualified as a risk factor. Hence,
more targeted education to prevent hearing loss was recommended.

42. Peng et al. (2007) investigated the effects of the use of PLDs on hearing in young adults. The study assessed 150 participants (students at Wuhan University that responded to an advertisement for volunteers), 120 PLD users and 30 normal-hearing young adults. The PLD users consisted of 64 males and 56 females with an age range of 19-23 years, and a mean age of 20.6 years. The control group of 30 normal hearing listeners with no history of PLD use consisted of males and females with an age range of 19-22 years, and a mean age of 20.5 years. The PLD group was further divided into three subgroups based on duration of use of the devices, 1-3 years, 3-5 years, and >5 years. The participants were assessed using the following tests after 24 hours without PLD use, otoscopy, screening tympanometry, pure tone audiometry from 500-8000 Hz, and high-frequency audiometry at 10, 12.5, 16, and 20 kHz. Results indicated that hearing thresholds between 3 to 8 kHz were significantly increased in all three PLD groups compared to the control group (P < .01). Furthermore, the frequency range of increased thresholds became wider as the duration of PLD usage got longer. Significant differences were also found between the three PLD subgroups and the control group in the hearing thresholds at the extended high-frequencies (P < .01). No significant difference was noted between the PLD subgroups in the extended high-frequencies (P > .05). This study found that hearing loss occurred in 14.1% of ears (34 of 240) following long-term use of PLDs. Extended high-frequency audiometric testing was shown to be more sensitive than the conventional audiometric testing of 500-8000 Hz.

43. Vogel et al. (2007) provided a summary of the literature on sociodemographic, psychosocial and other correlates of risk and protective behaviors for hearing loss in young people between the ages of 12-25 years. The protection motivation theory (PMT) was used as the theoretical framework for categorizing the psychosocial correlates. Based on their search, 33 articles were selected for identifying the correlates. The researchers identified several sociodemographic and psychosocial correlates to hearing loss including age, gender, smoking habits, education level, music preference, physical activity social influence, ethnicity, country and free supply of hearing protection, intrinsic and extrinsic rewards of maladaptive response regarding the relationship between young people’s attitude towards music and the likelihood of wearing hearing protection. Vogel’s article concludes that specific evidence- and theory-based longitudinal studies are necessary to prompt hearing protection in youth and PLD users.

44. Bhagat and Davis (2008) examined cochlear function in response to predetermined exposure level and duration of MP3 player music. Audiometric measures, distortion-product otoacoustic emissions (DPOAEs), synchronized spontaneous otoacoustic emissions (SSOAE), and hearing thresholds were evaluated for 20 adult participants who all indicated normal parameters. They were then exposed to MP3 listening sessions while a probe microphone monitored the 85 dBC presentation level for 30 minutes. DPOAE reassessed two minutes after music exposure, followed by SSOAE and hearing threshold re-evaluation. Pre-exposure and post-exposure measurements did not reveal significant differences in hearing threshold. Significant reduction in DPOAE and SSOAE levels indicate possibility of hair cell damage resulting in the later development of music-induced hearing threshold shifts or possible cochlear damage.
45. Montoya et al. (2008) evaluated the use of transient evoked otoacoustic emissions (TEOAEs) and DPOAEs as a method to identify cochlear function alteration in young adults exposed to MP3 players. All participants filled out a questionnaire about their MP3 player use. The participants were divided into an MP3 player user group and a control group. The MP3 player group consisted of 20 participants between 19 and 29 years, 50% males and 50% females, with normal hearing. This group was further classified by years of use, less than 5 years, between 5 and 10 years, and more than 10 years. The control group consisted of 116 participants between 18 and 32 years old, 50% males and 50% females. Participants were assessed by otoscopy, tympanometry, acoustic reflexes, pure tone audiometry, TEOAEs and DPOAEs. Results indicated that participants with had used MP3 players showed a reduction in TEOAE and DPOAE incidence and amplitudes, and an increase in DPOAE thresholds compared to participants in the control group. For TEOAEs, a significant difference was found (P < .05) between non-MP3 users and the MP3 users, where the MP3 users had a poorer incidence of frequencies at 2000, 3000, 4000, and 5000 Hz. A significant difference (P < .05) was also found with MP3 users showing a poorer incidence at 700, 1000, 1500, and 2000 Hz for DPOAEs compared to non-MP3 users. For the MP3 user group, the amplitudes were significantly lower for TEOAEs and DPOAEs in the ranges of 2000-4000 Hz and 1500-6000 Hz respectively. The study concluded that exposure to MP3 player noise can cause impaired cochlear function which can be detected with TEOAEs and DPOAEs before the dysfunction is clinically apparent.

46. Torre (2008) used a two-part research model to assess PLD noise volume and listening patterns of young adults. San Diego State University students were chosen for the study after indicated PLD use. In the first part of the study, 1016 participants completed an 11 closed-set questionnaire regarding the their PLD use, type of earphones, most common listening environment, length of time per day, and the average music volume. In the second part of the study, probe microphone measurements were conducted for 32 voluntary participants, including twenty-one women (average age 23.1 years) and 11 men (average age 26.2 years). The participants selected volume levels from four subjective categories, including: comfortable or medium (71.6 dB SPL), loud (87.7 dB SPL), very loud (97.8 dB SPL), and low (62 dB SPL). Results indicate over 50% of participants used PLDs between 1 and 3 hours per day, while almost 90% reported listening at medium (53%) or loud (35%) volume.

47. Vogel et al. (2008) conducted focus group interviews in 73 adolescents aged 12-18 years from pre-vocational and pre-university schools to investigate their perception of loud music and associated risk of exposure from MP3-players. Framed within the PMT, researchers identified six themes from the discussions with the adolescents which included, possession and use of MP3 players, preferred listening levels, perceived consequence of exposure to loud music, possible problems caused by hearing loss, action towards hearing conservation, and parental influence. Using those six themes, descriptive reports were obtained from the adolescents. The researchers found that more male MP3-player users, especially from pre-vocational schools, listened to MP3 players at maximum volume than females. The adolescents acknowledged awareness of the risk of listening to excessive limits of music, but underestimated their personal vulnerability to music-induced hearing loss, and did not have intentions of changing
their listening habits now, but would consider a change if it was officially established that loud music causes hearing loss. Parental warnings, if any, were reported to be infrequent. In conclusion, the researchers recommend longitudinal research studies, hearing education and legal volume standards for PLDs for adolescents who are at risk for noise induced hearing loss.

48. Bulbul et al. (2009) used a self-developed 41 question questionnaires to examine the presence and duration of Walkman usage and the presence of intra-familial physical trauma in 428 students in both primary and high school settings. The students were also given the Tinnitus Patients Survey, a questionnaire adopted from the American Tinnitus Association to help determine the loudness level of tinnitus that was present. The students were divided into three age groups based on age, group 1 (11-13 yrs.), group 2 (13-15) and group 3 (16-18). Each group was questioned regarding hearing loss, hearing loss in family, listening to loud and noisy music, presence of tinnitus, presence of tinnitus after loud music, exposure to explosion, and concentration difficulty in the classroom. The results indicated that 81.8% of participants listened to loud noisy music in group 1, 95.4% in group 2 and 87% in group 3. Furthermore, 32.1% reported hearing loss and 33.5% reported tinnitus in group 1, 19% reported hearing loss and 36.8% reported tinnitus in group 2, and 28% reported hearing loss and 3.5% reported tinnitus in group 3. The study concluded that there should be more education for adolescents, their families, teachers and the whole community at large, and that these issues should be taken included in public health policy.

49. Danhauer et al. (2009) developed the Personal Listening Device and Hearing Questionnaire (PLDHQ), a comprehensive 83-item questionnaire used to assess college students’ knowledge about, experiences with, attitudes toward, and practices/preferences for hearing health and PLD use. They used two identical versions of the questionnaire, one that was completed using paper and pencil and the other that was completed online. The paper version was distributed at University of California, Santa Barbara (UCSB) in classrooms outside the Department of Speech and Hearing Sciences during the spring 2006 semester and the response rate was 89.6% for completed questionnaires. The online version of the PLDHQ was advertised during a three-day block at UCSB and during a one-day block at 39 other universities throughout the United States. All responses were pooled from the paper-and-pencil version and the online version for a total of 609 responses (223 male, 334 female, 52 N/A response) with an age range from 17 to 30+ years (86.4% between 18-21 years). Responses throughout the survey varied, but generally indicated some knowledge of safe listening habits and hearing health as well as most respondents indicated using safe listening levels and durations. Some responses indicate that a smaller group of college students may listen to PLDs at unsafe levels or durations.

50. Hodgetts et al. (2009) completed a study using 24 participants (12 male, 12 female) who were all young adults (mean age = 23.4 years; range = 18-30 years) and looked at subjective versus objective measures of listening level in various testing conditions. Each participant initially passed a 20 dB HL pure tone screening at 0.5, 1, 2, 4, and 6 kHz. They then took a 40-item questionnaire to help understand participant listening habits. Following this, participants were put through three test conditions in random order that included resting in quiet, resting in noise, and exercising (determined by a heart-rate monitor measuring 60-80% max heart-rate) in
noise. Participants were fit with a real-ear analyzer and then once they were comfortable in each listening condition, they were given a PLD and asked to set the volume with the screen covered. Once the volume was set, the real-ear measures were taken to get the actual dB SPL that the participants were experiencing. Subjective questionnaire measures were lower in both rest and exercise setting than the objective real-ear measures analyzed. Participants reported listening at 48% of the maximum volume while at rest, but real-ear data showed averages of 70% and 86% for rest-in-quiet and rest-in-noise conditions respectively. Participants reported average listening of 66% of maximum volume while exercising, but real-ear measures averaged 89% of max volume for all participants in the exercise-in-noise condition.

51. Fontana Zocoli et al. (2009) examined the behaviors and attitudes of Brazilian teenagers towards noise and their audiological characteristics. Participants consisted of 245 teenagers between the ages of 14-18 years, with 49% male subjects and 51% female subjects. Participants completed questionnaires that consisted of demographic questions, a hearing health survey, and a Portuguese version of the Youth Attitude to Noise Scale (YANS). A subgroup of 24 randomly selected participants with no history of occupational noise exposure was assessed with audiometric testing consisting of otoscopy, pure tone audiometry at 500-8000 Hz, and immittance testing. The results of the study indicated that listening to music through their personal media players was the most common type of noise exposure. Daily or weekly usage of the media players was reported by 71% of participants, while 21% reported periodic usage. Temporary tinnitus was reported more often by females, but a total of 69% of all subjects complained of tinnitus after attending discos, music concerts and exposure to media players. Only 1.6% of the participants reported using hearing protection. When analyzing the audiometric data from the subsample, one participant had middle ear issues, two female participants had bilateral noise notches and reported listening to devices for 6-10 hours daily, and the remaining participants had normal audiometric results. The YANS scores indicated a significant difference between male and female responses to the question “it is easy for me to ignore traffic noise”, showing females had a more negative attitude towards noise. YANS scores reported were slightly lower than the scores obtained in Sweden and the US, indicating more negative attitude towards noise in this population. No significant relationship was noted between hearing thresholds and YANS scores. The authors concluded that gender and country/region are variables that can perhaps influence exposure to music and hearing outcomes, and thus recommended comparative studies between countries for initiating effective global hearing conservation programs.

52. Kumar et al. (2009) completed a study using an experimental group of PLD users and a control group who were age-matched non-PLD users. There were 70 experimental participants (35 male, 35 female) with an average at of 20.5 years (range = 17-24 years) and the age-matched control group had 30 participants. Participants had normal otoscopic findings (i.e., no occluding wax, etc.) and normal tympanometry findings. PLD users were tested with real-ear measures after setting their PLD to preferable levels in two settings: quiet and with 65 dB SPL bus noise. Real-ear measures were also taken at maximum volume output level. PLD users listened to music at an average of 73 dBA for mobile phones (range = 40-93 dBA), 76 dBA for iPods (range = 56-86 dBA), and 79 dBA for MP3 players (70-84 dBA). No significant differences were shown
between the settings of quiet versus noise (p > 0.05). $L_{eq8h}$ for maximum volume was significantly different from the other two listening conditions (p < 0.01). No significant differences were found between PLD users (divided into $L_{eq8h}$ groups of <80 dBA and >80 dBA) and PLD nonusers. Results of this study showed some correlations between hearing threshold and music exposure levels at 6 kHz in both ears (right ear at p < 0.01 and left ear at p < 0.05), between DPOAE amplitude and music exposure levels at 2 frequencies and 1 frequency in the right and left ears, respectively (p < 0.05). A third correlation was found between DPOAE SNRs and music exposure levels at 3 frequencies in the right ear and 1 frequency in the left ear (p < 0.05). This study reported participants did not have any symptoms of tinnitus or TTS following PLD use.

53. Kim et al. (2009) investigated the relationship between the use of personal music players and hearing threshold. Middle and high school students were randomly recruited and selected from hospitals as participants after being cleared of exclusion criteria, which included serous otitis media, perforation, hearing loss due to disease or otologic disorders, tinnitus, and exposure to loud toys, guns, or loud concerts. Participants consisted of 167 males and 323 females, ranging from 13 years to 18 years. Each participant filled out a questionnaire regarding daily use of PLDs, listening method, and cumulative usage. A pure tone audiometric evaluation was then completed at 500, 1000, 2000, and 4000 Hz. Among the 490 participants, daily use of personal music players ranged from 0-5 hours daily, with a cumulative usage that ranged from 0 to greater than 5 years. Insert earphones were used by 399 participants, 53 used headphones (supra-aural type), and 10 used speakers. Results indicated that male students had significantly higher hearing thresholds in both ears compared to female students. A significant difference in hearing threshold, especially at 4 kHz, shows a change in cumulative threshold in participants who used PLDs for more than 5 years, while no relationship was noted between daily use of PLDs and hearing threshold. The study also found that participants who listened to music using speakers had significantly lower thresholds than those using headphones followed by those using earphones.

54. Hoover and Krishnamurti (2010) distributed a link for their survey via Facebook to target students at 35 randomly selected universities throughout the U.S. and 1,000 emails sent to randomly selected students at Auburn University, which resulted in 428 respondents. This survey was aimed at identifying listening habits and attitudes of typical college students that use MP3 players, and investigate safety issues related to MP3 player listening. The students that listened frequently to their MP3 players filed out a 30-item online survey. Results indicated that most the subjects wore their players for less than two hours per day at safe volume levels. More than 90% of the respondents reported turning the volume louder than the background noise sometimes, frequently or always. About one third of the respondents reported trouble hearing while wearing the MP3 player in public places. More than one third experienced soreness in the ears after listening sessions, and more than one third reported distraction while listening to their player. About 37% of the respondents reported listening at full volume in at times. More than half of the subjects reported that they were concerned about hearing loss. About half the subjects were also willing to reduce the volume levels, decrease listening duration and buy specialized earphones that are not too loud to conserve their hearing. The
authors recommend a more organized public education on safety issues associated with MP3 players.

55. McNeill et al. (2010) evaluated the potential risk to hearing from portable digital audio players. They distributed a 49-item questionnaire to 28 volunteer undergraduate students of the University of Ottawa ranging from 17 to 23 years old with an average age of 19 years old. The questionnaire was to assess participant listening habits, the relationship between exposure to loud noise and the measures of hearing health, which included symptoms such as difficulty understanding conversations in noise, mumbled speech, tinnitus, and the typical and worst-case listening levels for participants. Sound level measurements from the devices at typical and worst-case volume levels were made using a head-and-torso simulator and soft silicone rubber pinna. Student volunteers answered the questionnaires, and listened to their favorite song through their listening device coupled through to a head and torso simulator to measure their listening levels at both typical and worst-case volume. The median frequency of player usage was 2 hrs./day for 6.5 days a week. The median sound levels measured on the simulator for typical and worst case volume settings were 71 dBA and 79 dBA respectively, which did not surpass the daily listening limits/standards. Males were found to typically listen at a higher median volume level of 74 dBA compared to females who listened to 67 dBA. Among the respondents, 19 students reported experiencing at least one auditory symptom of possible noise-induced hearing loss. Ten participants reported having ‘non-problematic’ tinnitus in general, with seven of them experiencing it following exposure to digital audio players. Most the subjects said that they had been adequately warned about potential risks of loud music listening habits, took responsibility for protecting themselves from potential hearing health problems, and were slightly, moderately or very concerned about their devices impacting their hearing health.

56. Shargorodsky et al. (2010) examined the change in the prevalence of hearing loss in US adolescents by analyzing the demographic and audiometric data from 1988 to 1994 in the Third National Health and Nutrition Examination Survey (NHANES III) and NHANES 2005 to 2006. They examined results from 2928 participants from 1988-1994, and 1771 participants from 2005-2006, who ranged in age from 12 to 19 years. Audiometric testing was completed bilaterally at 500-8000 Hz across a -10 to 120 dB intensity range. The low-frequency average (LPTA) was obtained from thresholds at 0.5, 1 and 2 kHz, and high-frequency average (HPTA) was obtained from 3, 4, 6 and 8 kHz. A low-frequency hearing loss was defined as a LPTA greater than 15 dB and a high-frequency hearing loss defined as an HPTA greater than 15 dB in either ear. Results indicated that overall prevalence of hearing loss among US adolescents was higher in 2005-2006, especially involving the high frequencies in males, with 1 in 5 adolescents demonstrating some degree of hearing loss, thus accounting for a one-third increase in prevalence. The authors commented that this significant increase in high-frequency hearing loss between 1988-1994 and 2005-2006 may perhaps be attributed to the increase in loud noise exposure of greater than 5 hrs./week among the adolescents.

57. Vogel et al. (2010) used data from 1512 questionnaires collected from students’ ages 12 to 19 years (mean = 14.7 ± 1.21 years), who were from 68 classrooms at 15 Dutch secondary schools.
The respondents were equally 50% male and female and 49.7% who were attending prevocational classes. The questionnaires were about demographic information, usage of MP3 players or nonportable music players (both per day and per week usage), frequency of attendance at discotheques and pop concerts and duration of each, and if participants experienced any hearing-related symptoms following any of the music-related experiences. Based on previous outside research, music experiences were assigned specific dBA weighting (5.5 dBA added to the outputs when earbud-style earphones were used, 2.75 dBA added when the participants used both earbud-style and supra-aural headphones, 100 dBA assigned to discotheques, and 105 dBA assigned to pop concerts). Participant results were then categorized into groups of either being exposed to potentially hazardous music levels or not. Participants were also categorized based on severity of risk relating to exposure to each kind of music source and by all music sources combined. Researchers used the European occupational safety standard of potentially damaging noise occurring at 80 dBA for 40 hours per week or 89 dBA for 1 hour per day for 7 days a week and used this 7 day equivalent to say potentially damaging noise potentially occurs at 80 dBA for up to 56 hours in a week (the added 16 hours accounting for non-school/work periods of time). Analysis revealed that all music sources combined showed 54.4% of participants exceeded the revised safety threshold, 32.2% for users of only MP3 players alone, an estimated 9.0% of participants exceeded the threshold using earphones on nonportable music players, and 40.1% exceeded the threshold while attending discotheques or pop concerts. Analysis also showed participants who may be above 100 dBA include 6.0% for all music sources combined, 5.5% for MP3 player users, 0.5% for users with earphones on nonportable music players, and none exceeded 100 dBA while attending discotheques or pop concerts. Finally, research analysis showed hearing-related symptoms were more prevalent in those exposed to at least 90 dBA or more in the last month after listening to an MP3 player (odds ratio (OR) = 2.42; 95% confidence interval (CI) = 1.79, 3.29) or in the last year after going to a discotheque (OR = 3.30; 95% CI = 1.66, 6.56).

58. Figueiredo et al. (2011) assessed the incidence of tinnitus in users and non-users of MP3 players. 100 participants, that were students and faculty from secondary schools, were involved in the study. Of the 100 participants, 54 were regular MP3 users (group 1 with an average age of 17.5 years ± 2.2 years) and 46 were non-users (group 2 with an average age of 21.3 years ± 4.7 years), with an age range of 15 to 30 years. All participants filled out a medical history form consisting of information about profession, listening to music, ear history, medication use, dietary intake, and tinnitus qualities. The study used the Tinnitus Handicap Inventory (THI) for those with tinnitus, high frequency audiometry, and TEOAE in their test battery. Results indicated similar THI scores in both groups. A statistically significant higher incidence of tinnitus in participants who were regular MP3 users (group 1) was found, although the incidence was shown not to be related to the duration of use. This study did not assess volume as a variable. Further analysis of group 1 subjects with and without tinnitus revealed that thresholds at 8 kHz were significantly higher in tinnitus individuals. TEOAEs were found to be lower at 2 kHz in group 1 compared to group 2, which could reflect the beginning of cochlear alterations that precede threshold changes.
59. Henderson et al. (2011) investigated trends in low-frequency hearing loss (LFHL), high-frequency hearing loss (HFHL), and noise-induced threshold shifts (NITS) using data from 1988-1994 and 2005-2006 National Health and Nutrition Examination Survey (NHANES). This is the same data from NHANES used by Shargorodsky et al. (2010), but Henderson et al. used a different criterion for identifying high frequency average. Participants in the Henderson et al. study consisted of 4305 adolescents ranging from 12 to 19 years old. Data for this study was collected through interviews and audiological examination. Participants were assessed with questionnaires, tympanometry and pure tone audiometry for each ear at 500-8000 Hz. Low pure tone averages were calculated by averaging thresholds at 500, 1000, 2000 Hz and the high pure tone averages were calculated by averaging thresholds at 3000, 4000, and 6000 Hz. Results of the investigation revealed there were no significant increases in rates of NITSs, LFHL, and HFHL between 1988-1994 and 2005-2006 among the participants. Overall, the prevalence of loud noise exposure or listening to music through headphones increased from 19.8% to 34.8% between the two-time periods. A greater increase in the rate of noise induced threshold shifts was observed among female adolescents. The authors recommended greater health education among all teenagers, especially females.

60. Le Prell et al. (2011) investigated the hearing status among 56 college students who had self-reported normal hearing during an initial telephone screening. 28.6% of participants reported both the use of a personal music player (PMP) and accidental, unprotected impulse noise exposure, while 17.9% reported experiencing neither. Using pure tone thresholds, researchers found that 7% and 12% of participants had thresholds greater than 25 and 20 dB, at one or more frequencies, respectively. Using high-frequency pure tone audiometry, hearing loss was identified among 7.1% of listeners. For males, a high correlation was found between personal music player usages and decreased hearing status. None of the audiograms revealed an audiometric noise notch, associated with noise exposure. This study maintains the importance of educating college students on the risk factors associated with early symptoms of hearing loss and the need for larger-scale studies to better understand the effects of different sound sources on hearing thresholds.

61. Levey et al. (2011) completed a study of 189 college students ages 18-53 years (mean = 22.2 years) that assessed the use of their PLDs. Students were from the City University of New York campus and included those walking, biking, and exiting a subway station near the campus. The questions the researchers wanted to answer were if some PLD users were at risk for exposure to noise-induced hearing loss (NIHL), if PLD users on the subway listen at higher levels, and if there are gender differences in the level of exposure to PLDs. Participants were given a questionnaire and asked to put their music into a mannequin, which was built by the researchers and calibrated to mimic typical in ear measures of sound. The mannequin was limited to ear buds and over-the-ear headphones and was unable to accommodate in-the-canal earphones due to the size of the artificial ear. The questionnaire asked about demographic info, whether they had just exited the subway, if they changed volume since leaving the subway, type of PLD and earphones, and duration and frequency of PLD use. Research demonstrated that average free-field corrected listening level was 92.6 dBA ± 10.7 dB and an average reported listening time of 18.4 hours per week ± 17.1 hours. No significant correlation
was found between the listening levels and reported duration of PLD use (p = .36). Results showed the average listening level for participants using the subway as 93.1 dBA ± 10.91 dB and participants traveling by other methods (foot, bus, or car) as 92.3 dBA ± 10.68 dB, which also showed no significant difference. There was no significant difference between those who changed the volume after leaving the subway and those who didn’t with the average dBA for each group being 91.5 ± 9.67 dB and 94.5 ± 11.69 dB, respectively. There was no significant difference found between males and females in regards to the measured listening level, hours PLD use per day, or hours PLD use per week (p > .05).

62. Portnuff et al. (2011) examined the listening behavior and attitudes of 29 teenagers as it pertains to PLDs and an increased risk for music-induced hearing loss (MIHL). The participants were recruited from the Denver and Boulder, Colorado areas and consisted of 12 males and 17 females, ages 13-17 years. Using a four-part approach, researchers analyzed volume control settings in relation to PLD output levels, listening behavior in relation to background noise, self-reported listening levels relative to laboratory-measured listening levels, and the validity of the Listening Habits Questionnaire in the evaluation of attitudes related to PLD use behavior. With a two-sided research design, output levels of PLDs were determined using an acoustic mannequin. Additionally, self-reported information was gathered about PLD output levels and listening behavior and attitudes of teenage PLD users. Results of this experiment indicate that 14% of the teenage participants exceeded the NIOSH 50% noise dose. Researchers suggest this 50% noise dose may be a more acceptable level for allowable noise recommendations due to teenagers being exposed to noise levels outside of PLDs. The Listening Habits Questionnaire proved a useful tool in the relational analysis between attitudes and listening behavior.

63. Vogel et al. (2011) used a hierarchical multiple regression analyses to examine correlates of adolescent PLD behavior and the PMT, which explains how people apply proven health information in their own lives. They offered questionnaires to 1687 adolescents between the ages of 12-19 years, and collected information regarding MP3-player usage, sociodemographic characteristics, and psychosocial determinants of listening (consideration of future consequences, protection motivation, and habit strength). Among the participants, 90% reported using earphones on MP3 players and 28.6% of users were deemed at risk for hearing loss with estimated exposure levels of 89 dBA for greater or equal to one hour per day. Listeners at risk were more likely to not live with both parents, to experience rewards from listening to high levels, to report a high habit strength to risky listening, and less likely to be motivated to protect their hearing. Habit strength had the highest correlation for risky listening behavior, suggesting benefits of a multiple strategy approach for prevention of MP3-induced hearing loss. Vogel recommends educational strategies, regulations, and PLD facilities that promote protection motivation and safeguard adolescents from excessive noise exposure levels and further prevent noise induced loss.

64. Danhauer et al. (2012) distributed an 83-item questionnaire to high school students with approved parental and student consents, and obtained responses from 131 students. The age range of the participants was 13 to 17 years. The study focused on assessing the students’ perception about their iPod use as it relates to risk of hearing loss or injury, students’
knowledge of hearing health, and openness to further education around hearing health. The questionnaire was updated from a previous study and questions regarding risk-taking behavior were added. Results indicated a large percentage (79.4%) of the participants reported ‘rarely’ or ‘sometimes’ having ringing in the ears. A small percentage (5.6%) of participants reported having ringing in the ear ‘frequently’ or ‘always’. The study also indicated that most participants did not have concerns with temporary threshold shift (TTS) and no specific results of this were reported, although some information indicated a small percentage of TTS may be present. Approximately 32% of participants did not recognize ringing in the ears to be a warning sign of over exposure to potentially hazardous sounds. Further, the study revealed that many of the respondents could be at risk for injury to themselves or others when they were unaware of their surroundings while listening to their iPods. Most students were not knowledgeable about hearing health and were open to education about safe hearing levels despite negative sentiment toward some previous education and media coverage about safe hearing levels.

65. Le Prell et al. (2012) completed a study using 33 adult college students (13 male, 20 female; mean age = 20.9 years; range = 18 – 27 years), assigning them to three different groups and exposing each group to different levels of music to look at pre- versus post-music pure tone and DPOAE thresholds. Volunteers completed a screening consisting of a questionnaire, otoscopy, tympanometry, and both air and bone conduction pure tone threshold testing at standard frequencies (0.25, 0.5, 1, 2, 3, and 4 kHz for both air and bone, and additionally, 6 and 8 kHz for air). Following screening of volunteers, participants were selected and completed a brief tinnitus questionnaire, pure tone audiometry using air conduction at standard and extended high-frequency (EHF) tones (0.25 to 8 kHz and 10, 12.5, 14, and 16 kHz), and DPOAEs. Participants could then choose between ‘pop’ and ‘rock’ music to listen to pre-determined lists for four hours. Groups were assigned as DAP1, DAP2, and DAP3, and were exposed to in-ear/in-coupler dBA weighted music at ~94 dBA, ~98 dBA, and ~100 dBA, respectively. Following music exposure, participants were tested at 15 minutes, 2 hour 15 minute, and 3 hour 15 minute post-music times using brief tinnitus/hearing loss symptoms questions, pure tone audiometry (standard and EHF), and DPOAEs. DAP1 had one participant report tinnitus and DAP2 had one participant report hearing loss, fullness, and other symptoms. Both participants’ symptoms resolved within one hour post-music. DAP3 had three participants report tinnitus, two participant sensations resolved within one hour and the third resolved within 24 hours. TTS was found at 15 minute post-music tests in the DAP3 group. There was no consistency, but data shows a larger shift at 4 kHz and higher values of TTS in those who started with better (lower) thresholds at 4 kHz pre-music. The authors suggested that this laboratory study showed small but consistent lab-induced TTS (mean=6.3±3.9 dB; range=0–13 dB) that recovered within the first three hours. It was proposed that a controlled model such as this could help in TTS studies that use drug agents to preventatively reduce TTS.

66. Muchnik et al. (2012) completed a two-part study using questionnaires and real-ear measurements in both quiet and background noise settings. A total of 289 teenage participants (149 females, 140 males) with an average age of 14 years (SD = 0.5, range = 13-16) completed questionnaires that addressed awareness and knowledge of hearing health, listening habits, and hearing symptoms related to PLD use. Questionnaires were completed by participants
during school with researchers overseeing the administration. Questionnaire results showed that the majority of participants (79%) had some knowledge of the relationship between loud music and hearing loss. Few participants (13%) found hearing loss to be one of their major concerns in contrast to things such as drug use (75%) and terrorist acts (71%). Many participants (80%) reported using PLDs on a regular basis. 41% reported listening to PLDs daily and 19% reported listening one to two times per day. 39% reporting listening to music at a ‘moderate’ level compared with a combined 31% listening at ‘very high’ or ‘high’ levels or a combined 30% at ‘soft’ or ‘very soft’ levels. Most participants (83%) reported listening to PLDs during travel in a vehicle such as a bus or a car. 49% reported having some kind of hearing symptom, including 21% who reported a change in hearing and 11% who reported some degree of tinnitus. Following questionnaires, researchers completed two, smaller real-ear measurement experiments using settings in quiet and with background noise. A subgroup of 11 females, ages 14-17 (mean = 15, SD = 1) years participated in the real-ear measurements in quiet. Average diffuse field listening levels were 82 (SD = 9, range = 71-99) dBA and out of the 11 participants in this experiment only one had eight hour equivalent levels above 85 dBA for both the upper and lower limits of the eight hour equivalent levels. A subgroup of 74 participants (26 males, 48 females) ages 14-16 years (mean = 15, SD = 0.4), participated in the real-ear measurements in background noise. The average diffuse field level was 89 dBA (SD = 9, range = 74-103), and 26% and 28% of participants were above of 85 dBA for the lower and upper limits of the eight hour equivalent levels. The relationship between PLD use and the occurrence of tinnitus was significant (p = 0.003) and participants who reported regular PLD use reported more symptoms than non-regular PLD users.

67. Oghu et al. (2012) conducted a cross sectional study of students of the College of Medicine, at the University of Lagos, Nigeria. They distributed self-administered questionnaires to 388 students. The participant average age was 21.7 years old ±2.6 years with an age range of 16-35 years. The questionnaires were looking at the prevalence of the use of personal stereo player (PSP) coupled to earphones, and the presence of subjective tinnitus. Results indicated that 95.6% of the total participant population reported listening to PSPs through earphones, and 20.6% reported having tinnitus. More than 90% who reported use of PSPs had used it for 3-6 years. Of those with tinnitus, 93.8% used earphones with their PSPs.

68. Feder et al. (2013) examined the relationship between portable digital audio player (DAP) listening behaviors, sound pressure levels, audiometric measures, and self-reported hearing loss symptoms in children and adolescents. 237 students, between ten and seventeen years old, were randomly recruited from local private and public schools. Participants completed a listening habit questionnaire, took home a parent questionnaire, played a self-selected song at preferred listening levels while sound pressure levels (SPLs) were measured, and underwent audiometric testing. The DAP listening habit child questionnaire included: self-reported hearing problems, recreational noise exposure factors, hearing loss symptoms, earphone fit, self-reported listening measures, hearing protection use, and hearing loss prevention knowledge. The parental questionnaire addressed socio-economic status and case history. Portable DAP SPL measurements were averaged for listener’s typical and maximum self-identified settings. Participants who reported using a portable DAP for more than five years were associated with
higher sound levels at maximum condition. Additionally, students who reported using their
device for five or more years had significantly higher hearing thresholds compared to those
who reported using their device for less than a year. Participants who reported tinnitus or
difficulty following a conversation when there was background noise had higher thresholds at 4
kHz. Mean SPLs were 69 and 76 dBA at typical and maximum volume settings respectively. Age,
years of PAD use, and user listening habits contributed to DAP exposure levels. Of participants
who used firearms and engaged in carpentry, 36% and 31% reported the use of hearing
protection. 75% of students had never worn hearing protection despite 17.3% worried they
may be losing their hearing or going deaf, and 13.9% feeling at risk of losing their hearing.

69. Le Prell et al. (2013) analyzed the applicability of extended high-frequency thresholds (EHF) as
an early indicator of the effects of recreational noise on the inner ear. Using 87 young adult
college students with normal hearing thresholds at conventional frequencies (0.25-8 kHz),
researchers collected noise history data regarding recreational noise exposure. In a survey,
participants reported the type of leisure sounds they were exposed to, including personal music
player use, loud music in a vehicle, hunting/shooting range, and sporting events. 15 to 18% of
respondents reported a history of tinnitus, while over half of those participants reported
experiencing tinnitus after noise exposure. Five participants reported experiencing hearing loss,
only after loud sound exposure. Between the sources of loud sound exposures, listening to
personal music players was the most widely reported activity. EHF results indicate that
participants who reported using music players for more than five years, or at higher listening
levels, had worse thresholds by 3-4 dB at 10 and 12.5 kHz and 6-7 dB at 14 and 16 kHz. This
data supports the use of EHF as an early indicator for hearing loss, with previously established
baseline data and the implementation of hearing conservation educational programs.

70. Portnuff et al. (2013) distributed questionnaires to 52 participants ages 18 to 29 years (mean =
25 years; 31 females and 21 males) to determine the usage patterns of PLD listeners through
both self-reporting of habits, direct monitoring of behavior over time, and the relationship
between self-reported PLD exposure and actual PLD exposure measured over time. For all 52
participants, pure tone thresholds were found to be normal (<20 dB HL) from 250-8000. The
questionnaires obtained information on their typical volume setting, total duration of listening
and duration of listening at different volume settings. Specific dB weights were assigned to each
setting based on previously collected PLD output levels. A smaller group of 24 participants
(mean = 24.4 years, range = 19-29 years; 14 females and 10 males) was chosen at random from
the initial 52 participants to participate in a dosimetry experiment to measure their actual PLD
exposure. This group used preselected and measured earbuds with their own PLDs, and the
output was connected to an Etymotic Research ER-200D dosimeter, which recorded an A-
weighted measure of the input for up to seven days. The self-report data showed average
listening of user at 14.3 hours per week ±10.6 hours (range = 4-50 hours) and the usual volume
control level at 6.8 out of 10 ± 1.6 (range = 3-10). Analysis of the duration between volume
settings 10% to 100%, the ‘usual’ average was found at 82.1 dBA ± 10.4 dB. When measured
against the NIOSH damage risk criterion (DRC), 14.3% of participants were at ≥100% dose from
the reported ‘usual’ listening level, 25% of participants were at ≥100% dose for the ‘usual’
volume setting. The dosimetry data analysis demonstrated PLD users averaging 71.7 dBA ± 14.9
dB (range = 45.9-103.1 dBA) and listening for an average of 12.1 hours per week ± 8 hours (range = 3.2-32.5 hours). The dosimetry group data was compared against the DRCs for both NIOSH and OSHA standards. One participant was an outlier with a 31,754% dose according to the DRC of NIOSH. Analysis showed 16.7% of participants were exposed to >100% dose per NIOSH standards, and 8.3% were >100% dose per OSHA standards. The analyses demonstrated a strong correlation between the usual and measured doses ($r = .813, P < .01$); however, no significant differences were found between the self-reported and actual times, showing than participants reported their listening times with reasonable accuracy in the questionnaires.

71. Fligor et al. (2014) assessed PLD exposure and influential behavior factors across a range of ethnicities, education levels, music genres, and type of PLDs to examine correlations between urban environmental noise levels and noise induced hearing loss. Researchers measured the average listening level in 88 women and 72 men, a total of 160 New York adults with mixed ethnicity and a mean age of 25 yrs. The study took place in two locations; a college campus and Union Square, a high traffic area for many people. Participants completed a questionnaire regarding demographic information such as gender, ethnic identity, education level, type of PLD and earphone used, and duration and frequency of usage per day. Ambient environmental sound levels measured using a sound-level meter registered a mean level of 60.6 dBA in the college campus and 82.3 dBA in the Union Square. Researchers used a KEMAR mannequin and sound-level meter to measure each PLD user’s noise output starting at the point where the participant paused their music when approaching the testing area. Estimates of 8-hr equivalent continuous A-weighted sound levels and 40-hr equivalent continuous A-weighted sound levels were made based on the levels measured from the subjects’ headphone. Levels obtained from the subjects were compared to the recommended exposure limit of 85 dBA. Results indicated that the average listening level was 94.1 dBA, with 99 of 160 (61.9%) and 92 of 159 (57.5%) exceeding daily and weekly recommended exposure limits respectively. The most significant indication for higher exposure were ethnic background and age. African Americans participants listened to PLDs at the highest levels averaging 99.8 dBA, and participants 24 or younger listening at an average of 95.5 dBA compared to 91.1 dBA for the over-24 age group. Thus ethnicity and age were significant for listening level, whereas gender, education, awareness of PLD risks and music genre were not. Results indicate PLD users in an urban environment exceed daily and weekly sound level limits and were at risk for noise induced hearing loss. The study recommended broader education on the effects of noise on hearing.

72. Marron et al. (2014) assessed PLD exposure for in 180 college students. Using the participants PLD, headphone, and listening level of choice, researchers obtained free-field equivalent measures to determine the intensity level of exposure. Per the questionnaire, 77% of students reported PLD use for 10-12 years, with 24.4% reporting frequent noise exposure of more than 7.5 hours per week. About half of the participants reported recreational noise exposure at bars or concerts, and 7% during athletic events or listening to car speakers. Based on preferred listening level, 96% participants did not exceed the SCENIR daily and weekly noise exposure recommendation. In self-reported listening levels estimates, participants accurately described their preferred exposure levels in accordance with real-ear measurements, supporting 87% of
participants who reported not listening to their PLD at harmful levels. The study supports the management of PLD exposure and education about the benefits of using hearing protection.

73. Sulaiman et al. (2014) evaluated hearing status in 35 PLD users using otoacoustic emissions (TEOAEs and DPOAEs), conventional audiometry, and extended high-frequency audiometry, then compared results to a matched control group (same sex and age ±3 years). Participants were students or staff recruited from a university between the ages of 18-30 years (PLD user group average age 22.8 ±2.3 years and control group 23.3 ±2.2 years), with no prior history of exposure to loud occupational noise. PLD users had to have been using PLDs for at least a year on more than 50% volume, while the control group was age- and sex-matched with the PLD user group, and had to have never or rarely used PLDs. PLD users were interviewed about usage and symptoms following use such as ear pain, tinnitus, and headaches. Listening levels of PLD users were estimated by asking them to listen to 40 seconds of a preselected song while blinded from the volume, and to set the volume to their usual listening level. The sound output levels set by the PLD users were measured using a KEMAR ear-and-cheek simulator and sound level meter. These levels were used to compute the overall free-field A-weighted sound levels in dBA and levels were compared to noise exposure limits in occupational setting. Results indicated that of the 35 PLD users, six exceeded the safety exposure level of 85dBA, however, no significant difference in mean hearing thresholds were identified between these six subjects and the remaining PLD users. Immediately following PLD use, participants in the PLD group reported having symptoms, including ear pain (51.4 %), tinnitus (42.9 %), difficulty hearing others (37.1 %), headache (8.6 %) and neck stiffness (5.7 %). When the PLD user group and control groups were compared, the mean hearing thresholds of the PLD users were significantly higher at seven frequencies, 2, 9 kHz (P < 0.05), and 10, 11.2, 12.5, 14, and 16 kHz (P < 0.01) in the right ear and three frequencies, 12.5, and 16 kHz (P < 0.05) and 14 kHz (P < 0.01) in the left ear. DPOAEs were significantly lower in the PLD group compared to the control group. When compared at each frequency for DPOAEs, the PLD group had significantly worse thresholds than the control group at 12 of 14 frequencies for the right ear (7 at P < 0.05 and 5 at P < 0.01) and 2 frequencies for the left ear (both at P < 0.05). For TEOAEs, PLD users showed significant differences compared to the control group at 3 frequencies in each ear (right ear showed 2 at P < 0.05 and 1 at P < 0.01, and the left ear showed all three at (P < 0.05). Researchers concluded that longer and more intense levels of PLD use correspond well with worse hearing thresholds.

74. Using a questionnaire and audiological evaluation, Keppler et al. (2015) sought to understand how attitude and believes affect noise exposure, hearing loss and hearing protection device usage (HPDs) for young adults. The five-part questionnaire, including the Youth Attitude to Noise Scale (YANS) and the Beliefs about Hearing Protection and Hearing Loss (BAHPHL), assessed hearing related symptoms, participation in recreational noise exposure, demographic characteristics, and attitudes and beliefs regarding noise. Pure tone thresholds were obtained from 250 – 16,000 Hz and compared to questionnaire results. Participants who recognized the potential dangers of noise exposure had a neutral or negative attitude towards noise, while participants who had a positive attitude towards noise viewed exposure as unproblematic. Despite awareness of the association between reduced communication skills and hearing loss, there has minimal influence on HPD use or behavioral changes. A significant correlation
between attitude towards noise exposure and HPDs was found among those with a positive, less problematic attitude toward noise and worse hearing thresholds, TEOAEs, and DPOAEs. The relationship between attitude towards noise, hearing loss, and HPDs and hearing thresholds provide support for the necessity of education and hearing conservation programs focused towards young adults.

75. To further assess recreational noise exposure in adolescents, Keppler et al. (2015) evaluated the effect of exposure over time in relation to the auditory system. Using a questionnaire, investigators assessed sources of recreational noise, hearing related symptoms, output levels and exposure time to personal music players (PMPs), attitudes regarding hearing loss and hearing protections devices (HPDs), and demographic characteristics. Depending on their self-assessment, participants were grouped by levels of exposure to recreational noise. Audiological and otoacoustic measures did not reveal a significant correlation between hearing thresholds and different types of recreational noise or degrees of exposure. However, PMP users with extended listening time had worse hearing thresholds and greater deterioration in TEOAES and DPOAEs than non-PMP users. Although PMP use has a negative impact on hearing threshold, visiting pubs and nightclubs, musical concerts or festivals, and playing in a band or orchestra are more prevalent sources of recreational noise exposure for young adults. Long-term assessment of the relationship between recreational noise exposure and hearing thresholds of young adults is necessary to fully understand how these factors influence each other.

76. To gain information about adolescent PLD habits, Silvestre et al. (2016) used self-assessment and audiological measures to investigate correlations between usage and the prevention of noise-induced hearing loss. 125 students filled out questionnaires regarding PLD time usage, exposure levels, and symptoms related to the listening experience. Then researchers carried out a high frequency audiological evaluation of 9000, 11,200, 12,500, 14,000, and 16,000 Hz. Hearing thresholds between the 12-14 and 15-17 age group were minimum, only indicating significant differences for the older group at frequencies around 12.5 kHz. The high incidence of otological complaints (392.2%) consistent with PLD exposure indicates an estimated level of risk (10-39%) for noise induced hearing loss, after five or more years of exposure. In conclusion, researchers call for longitudinal data, tracking the effects of PLD usage and hearing threshold over an extended period. Additionally, it is important to set parameters and education system for adolescent PLD users.

77. Sulaiman et al. (2015) investigated the risk of different PLD, volume levels and exposure time on hearing thresholds and perceptions of recreational noise exposure. 282 university students answered a questionnaire regarding their preferred type of PLD, estimated volume levels, and associated indications of hearing damage. Then, they performed high-frequency and extended-frequency pure tone audiometry to attain hearing thresholds for PLD users and non-PLD users. After measuring PLD volume levels using their preferred volume level and device coupled KEMAR, researchers found that 20% of listeners preferred listening levels exceeded 75 dB. Extended-high frequency thresholds on non-PLD users were significantly lower than those who listened at a volume of 75 dB or more. Additionally, participants who listening to their PLD louder than 75 dB had a significantly higher incidence of tinnitus and hearing difficulty after
listening to their device. Correlations between listening levels, early signs of noise-induced hearing loss, and elevated thresholds support the necessity for volume regulations and education for PLD users.

78. Colon et al. (2016) conducted a multi-part study consisting of distributing questionnaires and surveys to 9th grade students in Regensburg, Germany. They were looking at the effects of personal music player (PMP) use at high levels and trying to determine if this would result in weaker DPOAE as an early predictor of NIHL. Questionnaires relating to socio-demographic info, general noise exposure, hearing ability, and tinnitus, were distributed. Students fell into one of four categories based on self-reported noise exposure. DPOAE, tympanometry, and audiometry testing was completed at the Department of Otorhinolaryngology of the University Hospital Regensburg in Regensburg, Germany; however, one of the co-authors, Twardella, had previous reported the tympanometry and audiometric results in another published article. Of those tested with DPOAEs, 840 students (57.2%) were found to have reliable data (SNR > 6) 1098 students (74.8%) had <80 dBA, 128 (8.72%) had 80–85 dBA, 72 (4.9%) had >85 to <90 dBA, and 170 (11.6%) had ≥90 dBA. Statistical analysis of the DPOAE groups was performed showing no significant results among groups. Researchers determined that DPOAE data alone was not an adequate predictor of NIHL when looking at multiple levels of exposure.

79. Kumar et al. (2016) examined the impact of PLD exposure and listening habits on hearing thresholds. First, they divided participants between frequent- and non-frequent PLD users. Then, output sound pressure levels were measured based on preferred volume control settings, in a quiet or noisy environment, depending on their reported most used PLD condition. Researchers used a KEMAR manikin, to assess sound pressure levels of preferred PLD volume in quiet and noisy listening conditions in 60 participants. Based on these intensities, participants were split between regular PLD based on average listening levels above or below 80 dB. Conventional and extended high-frequency pure tone thresholds indicate significantly worse hearing thresholds for the group who listening at levels higher than 80 dB. No significant threshold differences were found between PLD users who listened at levels lower than 80 dB and non-PLD users. Additionally, PLD users had poorer syllable identification in noise, intensity discrimination threshold than non-users; and PLD users listening louder than 80 dB had poorer frequency discrimination and modulation detection thresholds compared to non-PLD users. In support of these findings, transient evoked otoacoustic emissions (TEOAE) were significantly smaller in the group listening at levels higher than 80 dB. With an increased rate of PLD use among youth, implementing hearing safety programs is necessary in promoting hearing health and minimizing high volume exposure.

80. Jiang et al. (2016) reviewed studies on PLD use and effects among young adults and adolescents. Evidence indicated excessive preferred listening levels (PLLs), with 58.2% of participants more than the 100% daily noise dosage recommendations, particularly in the presence of background noise. Worse audiological thresholds were obtained among PLD users, with increased damage occurring over years of exposure. Additionally, hearing difficulty, tinnitus and other hearing symptoms were apparent among 5.9% to 58.8% of PLD users. A recommendation for increasing background attenuation in earphones could result in lower
preferred listening levels. The high prevalence of PLDs among adolescents and young adults, association of hearing related symptoms considering excessive noise supports the importance of educational programs and regulations on permissible noise dosage levels.

81. Portnuff (2016) reviewed articles about noise-induced hearing loss and associated risks of overexposure to PLDs, and approaches for increasing healthy listening habits among adolescents. Previous research indicates potentially dangerous exposure levels of PLDs, per NIOSH standards. With PLDs reaching intensity levels between 91-121 dB, and a correlation of poorer hearing thresholds between PLD users and non-users, the implementation of hearing health programs is necessary to educate and reduce the risks of dangerous listening levels.

82. Yu et al. (2016) assessed preferred volume levels of PLD users across a variety of mobile phone programs. Using 74 randomly recruited participants, researchers evaluated listening levels among varying age, gender, frequency sound levels and mobile application programs, in the presence of environmental noise. While presenting simulated subway interior noise, participants listened through earphones to randomly selected programs, such as digital multimedia broadcasting (DMB), music, or an online game. Using a sound level meter via 2cc coupler and an artificial ear, subject-selected volume levels were measured. Results indicate an effect of age, with the 20s-age group having a significantly higher volume level than the 50s and 60s-age group. There was no significant gender difference. DMB had the highest volume levels, while mobile phone games had the lowest. Between frequency effects, 400 Hz had the highest volume level at about 93 dB and 12.5 Hz had the lowest volume level around 18 dB. Researchers suggest the development of public regulation and information on noise exposure levels and the risk of noise-induced hearing loss, and the necessity for more supporting evidence from research studies.
**Sporting Events ( Arenas)**

83. Hodgetts and Liu (2006) performed a study of sound pressure levels during the 2006 Stanley Cup Finals series (hockey). Ambient noise levels in the arena were also measured during games 4 and 6. There were two subjects for the testing, the second author and his wife. During the entirety of the game, the second author wore a noise dosimeter at the level of the ear, and the dosimeter took constant measurements of the noise the author experienced. Pure tone audiometry and DPOAEs were performed pre- and post-game in a double-walled audometric booth. During game 3, the average exposure for just over a three-hour game was 104.1 dBA. Games 4 and 6 were averaged at 100.7 dBA and 103.1 dBA, respectively. People watching game 3 with no hearing protection would technically receive about 8100% of their daily allowance, which indicates that thousands of fans are at risk for hearing damage. After game 3, both subjects reported mild tinnitus and muffled hearing. Both showed pure tone threshold deterioration by 5-10 dB at most frequencies, with the biggest decline (a change of 20 dB) seen at 4000 Hz. Subject 1 showed a decrease in DPOAE amplitude with greater reductions in the higher frequencies. Subject 2 had very strong DPOAEs for pre- and post-game conditions that any decrease in emission may have been masked by the equipment ceiling effect. The authors concluded that even brief exposure to leisure noise can have effects on individuals’ hearing.

84. Swanepoel and Hall III (2010) performed a study at a South African football (soccer) match to determine the noise exposure levels at the match and identify changes in the auditory function following the match. This sports event was uniquely characterized by sounds produced from blowing the horn-like instrument called the vuvuzela, which can average 131 dBA at the horn opening and 113 dBA at a 2 meter distance from the horn. There were 11 participants in this study; however only 21 ears were assessed due to one participant having a perforated tympanic membrane in one ear. Otoscopy, tympanometry, pure tone audiometry, high-frequency pure tone audiometry and DPOAEs were completed both before and after the match. During the match, 10 out of the 11 participants wore a personal sound exposure meter on their shoulder to measure their level of noise exposure. Results showed that the peak sound level exceeded 140 dBA for 8 out of the 10 participants. The average sound level during the match was 100.5 dBA. Changes in pure tone audiometry demonstrated that more than 50% of the ears used in this study showed threshold shifts after the match; however, the only statistically significant change was observed at 2000 Hz, with an average threshold shift of 3.4 dB. There was also a statistically significant decrease of 2 dB SPL in DPOAE amplitudes averaged across emissions obtained at 1266, 3163 and 5063 Hz.

85. England and Larsen (2014) completed a study on hearing threshold shifts after a collegiate basketball game. In this study, researchers tested hearing thresholds and DPOAEs in 20 normal hearing participants ranging in age from 21-55 years. The average maximum sound level that was measured using a dosimeter across 10 games was found to be 135 dBA. Hearing thresholds of the participants was found to be, on an average, 4.43 dB worse at all frequencies tested (1000 Hz to 6000 Hz) after the game compared to their thresholds obtained prior to the games. The average decrease in DPOAE across frequencies was 2.02 dB with a range from 0 dB to 5.67 dB across frequencies (1000 Hz to 8000 Hz).
Adams et al. (2016) completed a study looking at the noise effects on hockey officials during collegiate and junior hockey games. Following audiological assessment, participants filled out a noise exposure questionnaire. Noise dosimetry was performed separately using 23 hockey officials and was found to be within acceptable limits based on Occupational Safety and Health Administration (OSHA) recommendations. However, when noise dosimetry was measured based on American Conference of Governmental Industrial Hygienists (ACGIH), 65% of the hockey officials were found to be overexposed to noise. 55.6% experienced a greater than 10 dB temporary threshold shift (TTS). Of those with TTS, 70% had TTS in both ears and/or at more than one frequency and 20% experienced a 15 dB TTS. A correlation was found between TTS and personal exposure with higher postgame audiometric results at 4 kHz and 2 kHz, which agreed with previous studies.

**Conclusion**

The above review provides an overview of the investigations carried out in the area of recreational noise exposure. The authors of these studies have used a variety of different approaches to quantify risk in this vulnerable population. For instance, the subject age range is rather wide, the audiological tests used in risk assessment are dissimilar, questionnaires used are distinctive and venue of testing is not uniform. Although these articles are highly valuable and a lot can be learned from them, comparison of results across these studies is difficult. It is imperative that a universal assessment protocol is needed so that future risk assessment studies can follow somewhat of a uniform methodology in order to allow for better comparison across studies.
References


