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Risk Assessment of Recreational Noise–Induced Hearing Loss from Exposure through a Personal Audio System—iPod Touch

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Abstract

Background: Recreational noise–induced hearing loss (RNIHL) is a major health issue and presents a huge economic burden on society. Exposure to loud music is not considered hazardous in our society because music is thought to be a source of relaxation and entertainment. However, there is evidence that regardless of the sound source, frequent exposure to loud music, including through personal audio systems (PAS), can lead to hearing loss, tinnitus, difficulty processing speech, and increased susceptibility to age-related hearing loss.

Purpose: Several studies have documented temporary threshold shifts (TTS) (a risk indicator of future permanent impairment) in subjects that listen to loud music through their PAS. However, there is not enough information regarding volume settings that may be considered to be safe. As a primary step toward quantifying the risk of RNIHL through PAS, we assessed changes in auditory test measures before and after exposure to music through the popular iPod Touch device set at various volume levels.

Research Design: This project design incorporated aspects of both between- and within-subjects and used repeated measures to analyze individual groups.

Study Sample: A total of 40 adults, aged 18–31 years with normal hearing were recruited and randomly distributed to four groups. Each group consisted of five males and five females.

Data Collection and Analysis: Subjects underwent two rounds of testing (pre- and postmusic exposure), with a 30-min interval, where they listened to a playlist consisting of popular songs through an iPod at 100%, 75%, 50%, or 0% volume (no music). Based on our analysis on the Knowles Electronic Manikin for Acoustic Research, with a standardized 711 coupler, it was determined that listening to the playlist for 30 min through standard earbuds resulted in an average level of 97.0 dBC at 100% volume, 83.3 dBC at 75% volume, and 65.6 dBC at 50% volume. Pure-tone thresholds from 500–8000 Hz, extended high-frequency pure tones between 9–12.5 kHz, and distortion product otoacoustic emissions (DPOAE) were obtained before and after the 30-min music exposure. Analysis of variance (ANOVA) was performed with two between-subjects factors (volume and gender) and one within-subjects factor (frequency). Change (shift) in auditory test measures was used as the outcome for the ANOVA.

Results: Results indicated significant worsening of pure-tone thresholds following music exposure only in the group that was exposed to 100% volume at the following frequencies: 2, 3, 4, 6 and 8 kHz. DPOAEs showed significant decrease at 2000 and 2822 Hz, also only for the 100% volume condition. No significant changes were found between pre- and postmusic exposure measures in groups exposed to 75%, 50%, or 0% volume conditions. Follow-up evaluations conducted a week later indicated that pure-tone thresholds had returned to the premusic exposure levels.

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Conclusions: These results provide quantifiable information regarding safe volume control settings on the iPod Touch with standard earbuds. Listening to music using the iPod Touch at 100% volume setting for as little as 30 min leads to TTS and worsening of otoacoustic emissions, a risk for permanent auditory damage.

Key Words: iPod, personal audio systems, pure-tone thresholds, recreational noise–induced hearing loss, temporary threshold shift

Abbreviations: ANOVA = analysis of variance; DPOAE = distortion product otoacoustic emissions; IRB = Institutional Review Board; KEMAR = Knowles Electronic Manikin for Acoustic Research; NIOSH = National Institute for Occupational Safety and Health; OSHA = Occupational Safety and Health Administration; PAS = personal audio systems; PTS = permanent threshold shift; RNIHL = recreational noise–induced hearing loss; TEOAE = transient-evoked otoacoustic emissions; TTS = temporary threshold shifts

INTRODUCTION

Recreational noise–induced hearing loss (RNIHL) refers to hearing loss resulting from exposure to community experiences or activities such as firing guns, playing musical instruments, attending concerts, involvement in motorsports, community noise from airports or construction sites, commuter noise, and even listening to personal audio systems (PAS); for example, iPods, mP3 players, and cell phones (Fligor, 2011; Rawool, 2012). The World Health Organization (2015) estimates that 1.1 billion young people between the ages of 12–35 years old worldwide are at risk for hearing loss from unsafe use of personal audio devices and exposure to damaging levels of sound at noisy entertainment venues.

Exposure to loud levels of noise, even for a short duration, can lead to mechanical trauma and metabolic stress in the organ of Corti (Henderson et al, 2006). Ryan et al (2014) showed that the loss of threshold sensitivity depends on the initial shift from exposure, and the degree of recovery is based on the characteristics of the noise exposure, including, intensity, duration, frequency, and the individual characteristics of the person exposed. Threshold shifts that recover to baseline levels within weeks after exposure are termed temporary threshold shifts (TTS). However, more injurious exposures from continuous or repeated encounters can produce threshold sensitivity losses that may not recover (Eldredge et al, 1973; Ryan and Bone, 1978; Lonsbury-Martin et al, 1987), thus, leading to a measurable permanent threshold shift (PTS). TTS results often show worsened hearing thresholds within one to two octaves above the source frequency of the noise. After repeated exposure, a notched pattern begins to formulate in the 2–4 kHz region, eventually leading to PTS that represents a permanent hearing loss. When PTS occurs, it leads to long-term communication difficulties, especially if the hearing loss is not addressed and is allowed to progress. In mice experiments, Kujawa and Liberman (2009) showed that even in cases where the induced TTS recovered and no hair cells were lost, there was acute loss of synapses between inner hair cells and spiral ganglion neurons innervating them, thus, setting the stage for neurodegeneration. More recently, Liberman and Kujawa (2017) argued that well before any hearing loss can be documented from noise exposure, synaptic communication between inner hair cells and a subset of cochlear nerve fibers are permanently damaged. This condition, termed cochlear synaptopathy, is where there is neural degeneration and dysfunction of synapses even without hair cell loss. This in turn can lead to a variety of perceptual problems, including tinnitus, hyperacusis, and difficulty understanding speech in noisy situations.

A wide variety of hobbies can expose people to unsafe levels of noise, leading to cochlear synaptopathy. An ever increasing and commonly popular activity is the use of the PAS. Since the introduction of the PAS, such as personal radios, cassette players, CD players, and MP3 players, there has been an increase in access to sound exposure at an individual level. There are now many more listening methods and an even larger number of products and styles that are available. The possibility of hearing damage from PAS usage among adolescents and young adults has been a cause of concern for many years (Serra et al, 2005). Several studies have indicated that adolescents and young adults who regularly listen to music through their PAS devices have significantly elevated pure-tone thresholds, weaker otoacoustic emissions, or both (Peng et al, 2007; Kim et al, 2009; Le Prell et al, 2011; Sulaiman et al, 2013). By contrast, some studies have reported no such differences (Pugsley et al, 1993; Trzaskowski et al, 2014). However, it must be noted that methodological differences, including the type of listening device investigated and the variability in the volume-level settings, play a significant role in the outcomes of these studies.

In a recreational setting, multiple studies have shown that individuals exposed to recreational noise on a regular basis have other auditory-related symptoms such as tinnitus, hyperacusis, and difficulty understanding speech in noise (Chung et al, 2005; Williams, 2005; Goggin et al, 2008; Zocoli et al, 2009; McNeill et al, 2010; Muhr and Rosenhall, 2010; Derebery et al, 2012; Gilles et al, 2012; Muchnik et al, 2012; Feder et al, 2013; Gilles et al, 2013; Sulaiman et al, 2013;

Degeest et al, 2014; Balanay and Kearney, 2015; Keppler et al, 2015; Silvestre et al, 2016). Various researchers have reported on PAS use and the risks involved in high-intensity and long duration exposures, and have recommended further education and public awareness (Bulbul et al, 2009; Hoover and Krishnamurti, 2010; Vogel et al, 2010; Henderson et al, 2011; Vogel et al, 2011; Danhauer et al, 2012; Fligor et al, 2014). Sulaiman et al (2013) showed that the PAS users had significantly higher pure-tone thresholds at extended high frequencies and significantly lower distortion product otoacoustic emissions (DPOAE) and transient-evoked otoacoustic emissions (TEOAEs). They also found that longer PAS usage corresponded with poorer hearing thresholds. Similarly, several studies have documented decreased otoacoustic emissions in PAS exposures (LePage and Murray, 1998; Montoya et al, 2008) and showed that decreased otoacoustic emissions may perhaps precede the occurrence of music-induced hearing loss (Bhagat and Davis, 2008).

Across the world, the popularity of PAS has grown, as devices have become smaller and more accessible. Many college students are at risk of music exposure levels high enough to initially cause TTS, which eventually can lead to PTS. Peng et al (2007) showed that 14.1% of university students in their study had hearing loss at standard clinical frequencies following PAS exposures, even after a 24-hour recovery period. Hoover and Krishnamurti (2010) reported 66% of college students listened to their PAS three or more days per week, approximately, 10% of the students listened at 75–100% volume, 36.6% reported listening at full volume in certain situations, and only half reported concerns of hearing loss following listening periods. It should be noted that college students may be at risk for RNIHL not only just from PAS usage, but also from additional routine exposure to loud noise at bars, clubs, discotheques, concerts, and music classes (Hanson and Fearn, 1975; Trask et al, 2006; Peng et al, 2007; Holland, 2008; Torre, 2008; Danhauer et al, 2009; Kumar et al, 2009; Hoover and Krishnamurti 2010; McNeill et al, 2010; Le Prell et al, 2011; Levey et al, 2011; Le Prell et al, 2012; Gopal et al, 2013; Le Prell et al, 2013; Degeest et al, 2014; Spankovich et al, 2014; Balanay and Kearney, 2015; Tronstad and Gelderblom, 2016; Washnik et al, 2016).

RNIHL is a major health issue and presents a huge economic burden on society. Determining the effects of specific output levels from various systems is a complicated task, however, one that is desperately needed for regulatory purposes and prevention of RNIHL. The recommended exposure limit for noise is 85 decibels of A-weighted noise (dBA) over an eight-hour time-weighted average, with a 3-dB exchange rate that either halves or doubles the permissible exposure time based on the decibel level (NIOSH, 1998). The 85-dBA limit assumes daily exposure more than eight hours over a period of 40 years. NIOSH (1998) found that using their recommended exposure limit of 85 dBA versus 90 dBA resulted in a 17% reduction is the risk of developing occupational noise–induced hearing loss. Although this was originally created for industrial noise exposure settings, studies in the area of music-induced hearing loss have adopted the same formula. The National Institute for Occupational Safety and Health (NIOSH) exposure limit is the most widely used formula for calculating the daily noise dose (Jiang et al, 2016). To clearly link PAS usage and risk of hearing loss, and to encourage safe listening habits in the general public, well-controlled studies are needed. Consistent with this notion, we designed a study with the aim of quantifying the risk of hearing loss from the widely used Apple iPod Touch listening device (Apple Inc., Cupertino, CA) with its standard earbuds. The goals of this study were to (a) assess the risk of hearing loss from iPods set at various volume levels and (b) identify safe listening levels that can support regulatory policies. The risk of hearing loss was assessed by measuring changes in hearing thresholds and DPOAEs in young adults exposed to controlled music levels for 30 min through an iPod Touch with standard earbuds.

METHODS

This study was approved by the university institutional review board (IRB). Participants were recruited from within and around the university campus. Based on the inclusion criteria, our subject pool comprised young adults with no complaints of hearing loss, no history of neurological disorders, no use of medications that may affect cognitive function, history of regular usage of a PAS at maximum volume for at least 30 min once a week, and no exposure to occupational noise exposure. All subjects exhibited a willingness to take part in audiological testing twice, both pre- and postmusic exposure, and agreed to listen to music at loud levels, possibly at maximum (100%) volume. All subjects signed the IRB approved consent form before the collection of data.

Subjects and Grouping

A total of 40 subjects were included in this study. The subjects were randomly placed in one of four groups consisting of ten subjects: Group 1 consisted of subjects that listened to music at 100% volume level, Group 2 listened to music at 75% volume level, Group 3 listened to music at 50% volume level, and Group 4 did not listen to music (0 volume level).

Procedure

Before any testing, subjects filled out an adult case history form along with an additional questionnaire (see Appendix) that was used to elicit more details regarding the individuals' auditory symptoms, music exposure history such as their music-listening habits, and their willingness to change their listening habits if counseled. After obtaining assurance from subjects that they had not been exposed to loud music or noise in the last 24 hours, testing commenced. First, otoscopy was completed on all subjects. If cerumen was found that would affect probe microphone measures, it was removed with a sterilized curette. This was followed by premusic exposure testing that included the following tests: tympanograms (GSI TympStar; Grason-Stadler, Eden Prairie, MN), pure-tone thresholds (Madsen Astera; GN Otometrics, Schaumburg, IL), and DPOAEs (IHS Smart DPOAE; Intelligent Hearing Systems, Miami, FL). All testing was carried out in a double-walled sound-treated booth using calibrated equipment. Using the modified Hughson–Westlake procedure, air-conduction thresholds were obtained at 500 Hz, 1, 2, 3, 4, 6, and 8 kHz. Extended high-frequency testing included 9, 10, 11.2, and 12.5 kHz. DPOAEs were recorded and assessed by simultaneously presenting two primary tones (frequencies $f1$ and $f2$) at an $f2$:$f1$ ratio of 1.22. The DPOAE data were obtained for the frequencies of 499, 1003, 1409, 2000, 2822, 3991, and 5649 Hz, with the intensity levels ($L1$ and $L2$) set to 65/55 dB SPL.

Music Exposure

Following the premusic exposure testing, subjects assigned to the music-listening groups (Groups 1, 2, and 3) listened to music for 30 min, and subjects in Group 4 did not listen to any music during that period. For subjects in the music-listening groups, a probe microphone from a real-ear measurement system (Verifit; Audioscan, Dorchester, Ontario, Canada) was placed within 5 mm of the tympanic membrane and verified by otoscopy. An Apple iPod Touch (6th generation) was chosen as the music device because of its popularity as a music-listening device. Standard Apple Earpod earphones (Apple Inc.) fitted with Earhoox (Earhoox, Orlando, FL) were used to deliver music and were sanitized each time before each use. Earhoox ensured that the Earpods would not fall out of the ear or move the probe microphone during the 30-min music exposure. Songs used for the study were ripped from CDs (Now That's What I Call Music! 53 and 54; Sony Music Entertainment; New York City, NY) into WAV format using Windows Media Player. The songs were chosen based on their high rankings in the Billboard Top 100 during March 2015. The songs were then digitally altered using Audacity 2.0.5, a free audio recording and editing software (Audacity Team, Pittsburgh, PA). First, songs were merged into one track and then silent periods of more than one second were truncated. The songs were then dynamically compressed using the Dynamic Compressor 1.2.6 plug-in. These changes ensured consistent music exposure and decreased variability in intensity between songs. There was no perceived difference in the songs after these changes. The playlist was exactly 30 min in duration and included nine songs.

To ensure safety and Occupational Safety and Health Administration/NIOSH compliance, and obtain IRB approval, the loudness levels for the playlist were measured using a Knowles Electronics Manikin for Acoustic Research (KEMAR) head-and-torso simulator fitted with Zwislocki artificial ears. The iPod earphones were coupled to standard adult ear simulators on the KEMAR and connected to a sound level meter (Larson-Davis 824; PCB Piezotronics, Inc., Provo, UT). Based on the analysis, it was identified that the output level for 100% volume (Group 1 exposure level) was 97.0 dBC (range 78–102.4), output for 75% volume (Group 2 exposure level) was 83.3 dBC (range 60.8–88.4), and output for 50% volume (Group 3 exposure level) was 65.6 dBC (range 49.3–71.7). None of these levels exceeded the NIOSH or Occupational Safety and Health Administration standards for time-weighted maximum noise exposure limits.

Real-ear measurements were obtained during music exposure from all subjects in Groups 1, 2, and 3 and were converted to dBA values using a clinical probe microphone technique suggested by Portnuff et al (2013). Song times were then broken down into seconds, and using Random.org (Haahr, 2016), each song was assigned a 12-sec test sample. The subjects were instructed to not touch the earbuds, iPod, or alter the music in any way, including pausing, volume changes, and/or song changes. They were also reminded that they could discontinue participation at any point, if the volume level became uncomfortable. After the playlist ended, pure-tone thresholds and DPOAEs were obtained a second time in random order. The subjects were also asked about any ear- or hearing-related symptoms they may have experienced soon after listening to the playlist. The subjects were then asked to return for follow-up testing within a week, where pure-tone thresholds were reevaluated.

Changes between pre- and postexposure test results were obtained for each subject separately and averaged across both ears at each frequency. Means and standard deviation scores were obtained for each group. Repeated measures analysis of variance was performed with outcome measures as the within-subject factor, and volume and gender as between-subjects factors.

RESULTS

All subjects in this study were adults between the ages of 18–31. The mean ages for each group were 21.30 ± 2.3 (Group 1), 21.2 ± 4.24 (Group 2), 21.8 ± 2.82 (Group 3), and 24.8 ± 3.2 (Group 4). Each group had five males and five females. All had normal otoscopic results, normal-hearing thresholds at frequencies between 250 and 8000 Hz, and type A tympanograms in both ears.

Questionnaire

Questionnaire responses (Table 1) collected from the subjects gave information on their listening habits, ear-related problems, and willingness to change their habits. Of the 40 individuals that served as subjects in this study, 30% had preexisting tinnitus. All participants reported using commercially available PAS, with a majority of them using Apple iPhones/Apple iPods with Apple earbuds. About 90% of the participants reported listening to music through their device for more than five years, and 82.5% reported listening to their devices three or more times per week. Most participants (85%) reported listening to music ≥3 hours per week, seven participants reported listening to ≥3 hours of music continuously in one setting, and the remaining participants reported listening to music ≤2 hours in one setting. More than 75% reported experiencing a variety of auditory symptoms such as ringing/buzzing, ear fullness, hearing loss or muffled hearing, soreness in the ears, limited concentration, or decreased tolerance or annoyance with certain environmental sounds after listening to music through their PAS. All participants reported listening to their devices while doing other activities such as walking, jogging, studying, and exercising. When the participants were asked if they were concerned about possible hearing loss from their listening device, 63% were found to be slightly/moderately concerned, but none were extremely concerned. An interesting finding was that 93% of these subjects were willing to decrease volume on their PAS and 72.5% of the subjects were willing to decrease listening time if educated on the risk of hearing loss.

When asked what the best way to provide information to the public is, a majority of the participants (82.5%) said the internet. When asked what information would be the most valuable to provide on a website about listening devices, 60% said appropriate volume levels would be the most beneficial.

Real-Ear Measures

Every participant in Groups 1, 2, and 3 was tested at the same 20 sample times during the real-ear measurement, one sample for the right ear and one for the left, during each of the ten songs in the stimulus track. For example, the outputs in all participants were measured at 1:02 min for the right ear and 1:35 min for the left ear during the first song. Because of the limitation of the available equipment, real-ear recordings were obtained consecutively rather than simultaneously, meaning that songs were sampled at different points during each song for right and left ears. In selecting track samples for real-ear measures, all samples times within each song were chosen randomly for each ear using random.org. Because the samples were obtained randomly and at different parts of the song, slight differences in overall dBA across samples were expected. Average overall dBA across participants for all song samples showed right and left ear exposures of 97.7 (±3.57) and 98.3 (±3.89) dBA for Group 1, 83.4 (±2.04) and 83.3 (±4.04) dBA for Group 2, and 69.9 (±3.17) and 69.4 (±3.48) for Group 3, respectively. The real-ear measures obtained from the music-listening groups while listening to the playlist during the study are shown in Figure 1. Recorded levels averaged across right and left ears were as follows: Group 1: 97.9 (±3.63) dBA; Group 2: 83.3 (±3.11) dBA; and Group 3: 69.6 (±3.18) dBA. These levels were within 1–4 dB of the loudness levels measured on KEMAR for the same song list set at 100%, 75%, and 50%, respectively.

Pure-Tone Thresholds

Shifts in thresholds for regular clinical frequencies, 500–8000 Hz, as well as for the extended high frequencies, 9000–12500 Hz, are shown in Figure 2. The shifts/changes in pure-tone thresholds following music exposure were most often seen in the mid-frequencies, especially for Group 1 (100% volume condition). Statistically significant shifts were seen only in Group 1 at frequencies 2000–8000 Hz and are denoted with an asterisk in

Table 1. Summarized Questionnaire Responses from Study Subjects Based on Group Membership

	Group 1 (100%)	Group 2 (75%)	Group 3 (50%)	Group 4 (Control)
Mean age in years (standard deviation)	21.30 (2.31)	21.20 (4.24)	21.80 (2.82)	24.80 (3.19)
Preexisting tinnitus	20%	40%	40%	20%
Apple iPod usage	70%	40%	50%	60%
Weekly listening of 3+ Days	100%	100%	70%	60%
Auditory symptoms*	80%	100%	60%	70%
Willing to decrease volume	90%	90%	100%	90%
Willing to decrease listening time	80%	60%	80%	70%

SD = standard deviation.

*Includes symptoms of ear fullness, muffled hearing, sore ears, or decreased tolerance to certain sounds.

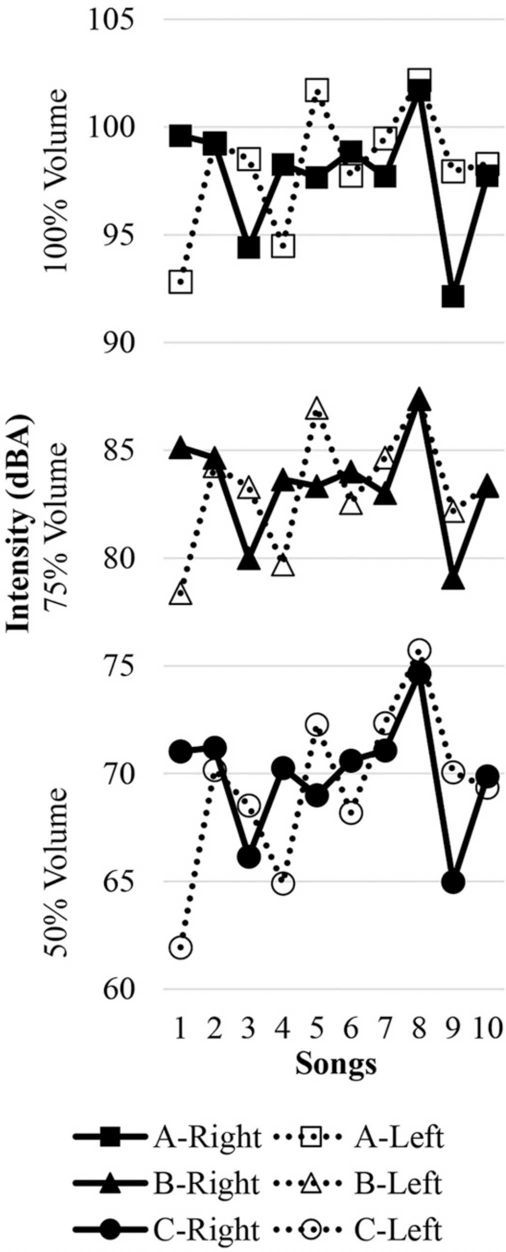

Figure 1. Average real-ear measures for each of the three music exposed groups. "R" is right ear, "L" is left ear, Group 1 is 100% volume, Group 2 is 75% volume, and Group 3 is 50% volume.

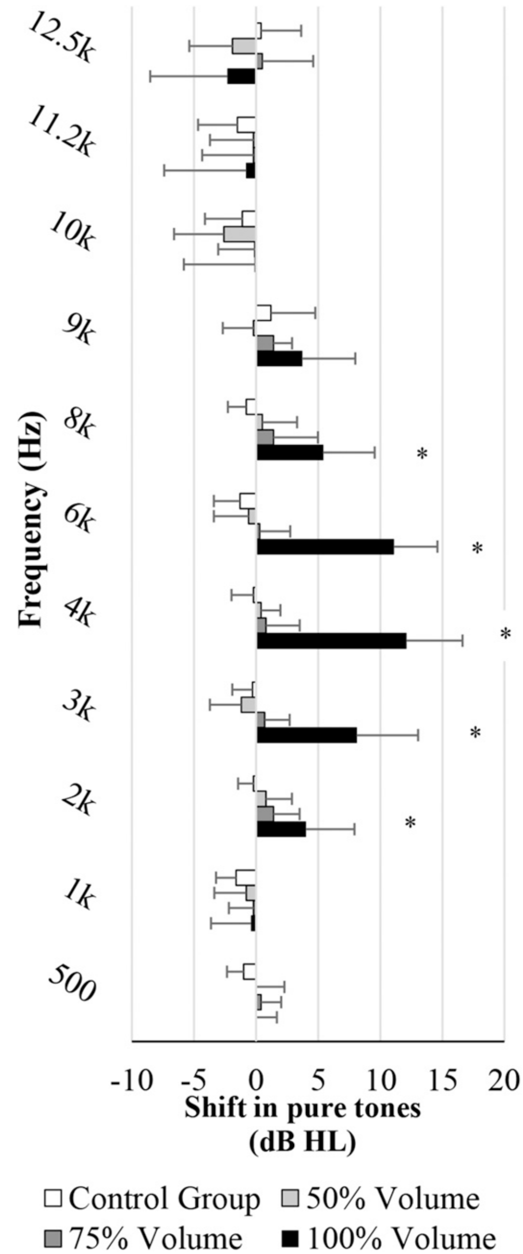

Figure 2. Shift in pure-tone thresholds (postmusic exposure minus premusic exposure) averaged across right and left ears. Significant increase in thresholds was obtained only for Group 1 at 2, 3, 4, 6, and 8 kHz. Group 1 is 100% volume, Group 2 is 75% volume, and Group 3 is 50% volume.

Figure 2. These changes were considered temporary because follow-up testing showed that the thresholds reverted to their premusic exposure levels within a week.

DPOAE Results

Shifts in DPOAEs were assessed at the following frequencies: 499, 1003, 1409, 2000, 2822, 3991, and 5649 Hz (Figure 3). Significant shifts were found only in Group 1 at frequencies 2000 and 2822 Hz. Further details on the statistical analysis are described in the following paragraphs.

Statistical Analyses

The outcome measures used in the analysis to identify significant differences between pre- and postmusic exposure test results were changes (shifts) in pure-tone thresholds (dB HL) and DPOAEs (dB SPL). These measures were grouped into three categories. The first category consisted of seven measures: pure-tone threshold shifts at 500 Hz, 1, 2, 3, 4, 6, and 8 kHz. The second category consisted of four measures: pure-tone threshold shifts at 9, 10, 11.2,

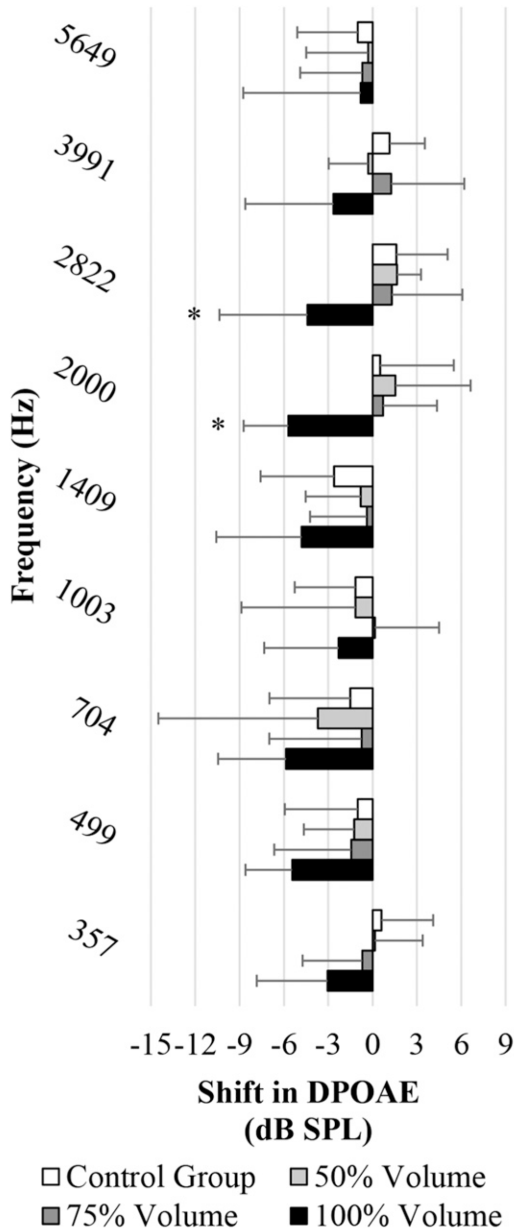

Figure 3. Shift in DPOAE data (postmusic exposure minus premusic exposure) averaged across right and left ears. Significant decrease in DPOAEs were obtained only for Group 1 at 2000 and 2822 Hz. Group 1 is 100% volume, Group 2 is 75% volume, and Group 3 is 50% volume.

and 12.5 kHz. The third category consisted of seven measures: DPOAE changes at 499, 1003, 1409, 2000, 2822, 3991, and 5649 Hz. Repeated measures analysis of variance (ANOVA) was performed on each category with outcome measures as the within-subject factor, and volume and gender as between-subject factors. With regard to volume levels, 0 volume (no music exposure) was set as the reference and the other three volume levels, 100%, 75%, and 50%, were set as three dummy variables. For the violation of the sphericity assumption in the covariance matrix, the *p*-values were adjusted using Greenhouse–Geisser or Huynh-Feldt-Lecoultre correction. Summarized ANOVA results from all three categories of measures are shown in Tables 2 and 3.

Category 1 (Pure-Tone Thresholds at 500 Hz, 1, 2, 3, 4, 6, and 8 kHz)

There was no evidence of any interaction between volume and gender; hence, these were excluded from the model. The ANOVA analysis showed that the volume was highly significant for the measures in this category; however, gender was not significant (Table 2). The effect of interaction between test frequency and gender was not significant after adjusting for assumption violation in the covariance matrix using either Greenhouse–Geisser or Huynh-Feldt-Lecoultre correction. The effect of frequency and the interaction between frequency and volume were highly significant, which meant that the main effect of volume varied depending on the frequency (Table 3).

The individual effects of different volume levels (setting zero as reference) for each frequency were then analyzed. As expected from the ANOVA results depicting the interaction between frequency and volume, it was found that the effect of volume indeed changed depending on the frequency in question. However, a consistent theme was that the strongest effect of volume on auditory thresholds was at 100% volume level. Even after correcting for multiple testing, auditory thresholds were significantly poorer after listening to music at 100% volume at frequencies 2, 3, 4, 6, and 8 kHz. Below is the interaction plot (Figure 4) and regression coefficients for the statistically significant outcome measures (Table 4).

Category 2 (Pure-Tone Thresholds at 9, 10, 11.2, and 12.5 kHz)

Because there was no evidence of any interaction between volume and gender, it was excluded from the model. Table 2 shows that volume and gender are not significant for the measures in this category. Among the within-subjects factors, only frequency was significant. The effect of interaction between frequency with volume and gender were not significant after adjusting for assumption violation in the covariance matrix using either Greenhouse–Geisser or Huynh-Feldt-Lecoultre correction.

When individual effects of different volume levels (setting zero as reference) for each frequency were scrutinized, it was found that because of the lack of significance of the overall between-subject factors, results for individual frequencies did not show any statistical significance and are thus not presented here.

Table 2. Repeated Measures ANOVA Results for between Subjects

Source	Category	DF	Type III SS	Mean Square	*F* Value	Pr > F
Volume	Category 1	3	1,858.200000	619.400000	35.23	<0.0001
	Category 2	3	60.525000	20.175000	0.40	0.7536
	Category 3	3	696.588393	232.196131	4.58	0.0083
Gender	Category 1	1	18.514286	18.514286	1.05	0.3118
	Category 2	1	90.000000	90.000000	1.79	0.1901
	Category 3	1	4.758036	4.758036	0.09	0.7611
Error	Category 1	35	615.342857	17.581224		
	Category 2	35	1,763.950000	50.398571		
	Category 3	35	1,774.145536	50.689872		

Category 1 includes pure-tone changes for frequencies 500 Hz, 1, 2, 3, 4, 6, and 8 kHz. Category 2 includes pure-tone changes for frequencies 9, 10, 11.2, and 12.5 kHz. Category 3 includes DPOAE changes for frequencies 499, 1003, 1409, 2000, 2822, 3991, and 5649 Hz.

Category 3 (DPOAE Changes at 499, 1003, 1409, 2000, 2822, 3991, and 5649 Hz)

Again, there was no evidence of any interaction between volume and gender; hence, these were excluded from the model. Table 2 shows volume to be highly significant. Frequency showed no main effect. The interactions between frequency and volume, and frequency and gender were also found to not be significant.

Following this, individual effects of different volume levels (setting zero as reference) for each frequency were scrutinized. After correcting for multiple testing, statistical significance at maximum level (100%) was found only for DPOAEs at 2000 and 2822 Hz. Hence, for this category of measurements, the effect of volume is weak at best (Table 4).

In summary, we find that the effects are the most dominant for Category 1 outcomes. However, one interesting finding from the analysis is the fact that most of the results are consistently in one direction for Group 1 (100% volume level), even when not significant.

DISCUSSION

PAS are capable of producing high sound levels that can lead to hearing loss (Portnuff, 2016). This may have led to a higher prevalence of hearing loss in subjects that listen to their PAS devices (Peng et al, 2007; Montoya et al, 2008; Figueiredo et al, 2011; Le Prell et al, 2011; 2012; 2013; Sulaiman et al, 2013; Keppler et al, 2015; Kumar and Deepashree, 2016). Earlier studies have reported PAS usage at high-volume settings among 37–95% of the listeners (Torre, 2008; Vogel et al, 2008; Hodgetts et al, 2009; Hoover and Krishnamurti 2010). Jiang et al (2016), in their review paper on PAS usage and hearing loss in adolescents and young adults, concluded that up to 58% of listeners exceeded 100% of the daily noise dose, especially in background noise. They also reported significantly worse hearing thresholds and weaker otoacoustic emissions in PAS users. In terms of frequencies affected, long-term use of PAS has shown to exhibit hearing loss at clinical frequencies (Kim et al, 2009; Le Prell et al, 2011), extended high frequencies (Le Prell et al, 2013; Sulaiman et al, 2013), or both (Peng et al, 2007).

Several studies have also reported weaker otoacoustic emissions in this population (Montoya et al, 2008; Figueiredo et al, 2011; Le Prell et al, 2012; Kumar and Deepashree, 2016). An earlier study by Sulaiman et al (2013) reported that young PAS users who listened to

Table 3. Repeated Measures ANOVA Results for within Subjects

Source	Category	DF	Type III SS	Mean Square	*F* Value	Adj Pr > *F*
Frequency	Category 1	6	469.242857	78.207143	12.46	<0.0001
	Category 2	3	167.4750000	55.8250000	7.31	0.0007
	Category 3	6	198.837500	33.139583	1.62	0.1676
Frequency × Volume	Category 1	18	1,089.300000	60.516667	9.64	<0.0001
	Category 2	9	136.9750000	15.2194444	1.99	0.0659
	Category 3	18	288.605357	16.033631	0.78	0.6751
Frequency × Gender	Category 1	6	81.785714	13.630952	2.17	0.0886
	Category 2	3	18.7000000	6.2333333	0.82	0.4617
	Category 3	6	78.298214	13.049702	0.64	0.6474
Error (Frequency)	Category 1	210	1,317.957143	6.275986		
	Category 2	105	801.3500000	7.6319048		
	Category 3	210	4,294.473214	20.449872		

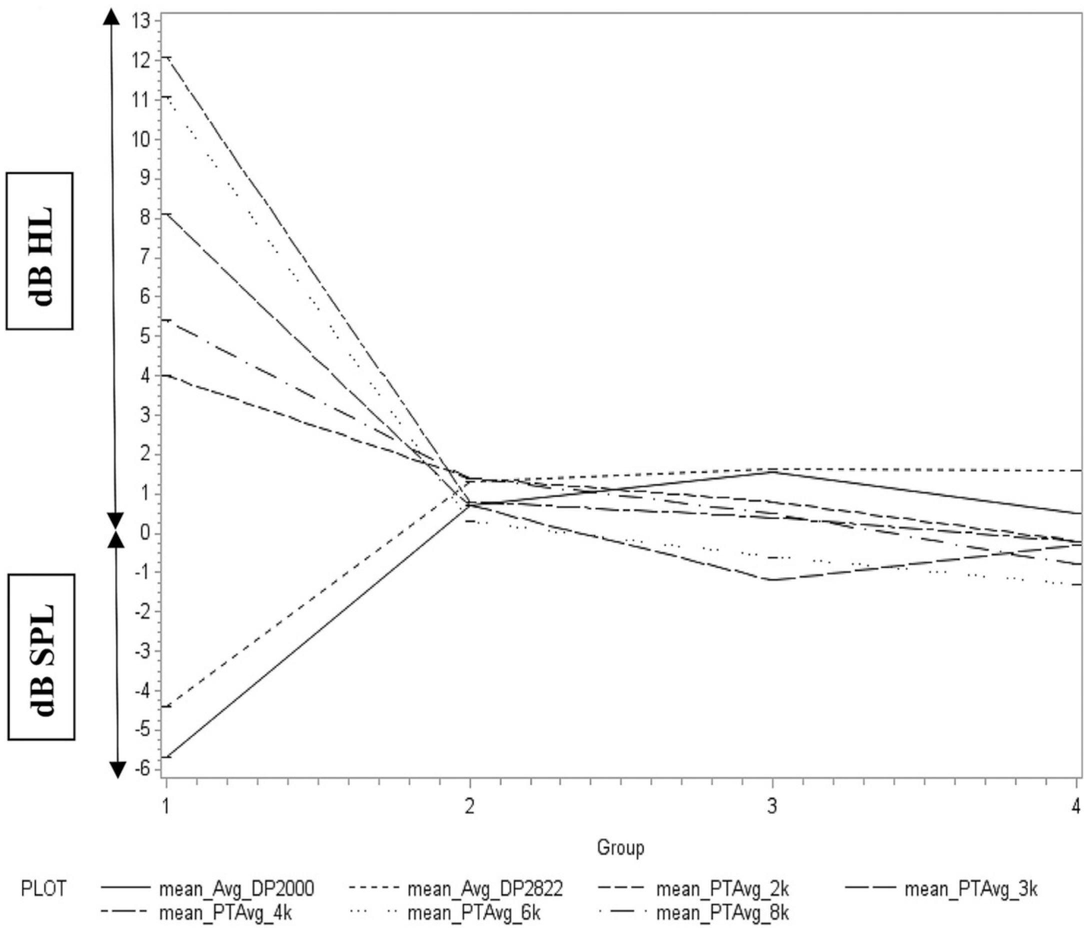

Figure 4. Interaction plot and regression coefficients for the seven significant outcome measures.

more than 1 hour/day at higher than 50% volume setting had worse thresholds for TEOAE and DPOAE results, as well as poorer extended high-frequency thresholds. Bhagat and Davis (2008) found that normal-hearing adults exposed to 30 min of music through MP3 players, set at an average level of 85 dBC ± 3 dB, showed significantly reduced DPOAEs in half-octave bands centered around 1400–6000 Hz. They described this reduction in DPOAEs as a possible early indication of cochlear hair cell damage.

Although the listening devices examined and research protocols used across research studies are different, the consensus is that listening to loud music through PAS for long durations can lead to hearing loss. Audiologists are often asked about safe listening levels and optimum listening durations for various PAS in the market. There are no simple answers to these questions because there are so many different choices of PAS devices, earphone types, and listening habits. When the wide variety of music genre and individual susceptibility

Table 4. Regression Coefficients of the Different Volume Levels Relative to Volume Zero for Each of the Significant Outcomes

Outcomes	Volume 50%	Volume 75%	Volume 100%
Avg_DP2000	1.05	0.2	−6.20 (0.004)
Avg_DP2822	0.05	−0.3	−6.00 (0.005)
PTAvg_2k	1.00	1.60	4.20 (0.001)
PTAvg_3k	−0.90	1.00	8.40 (<0.0001)
PTAvg_4k	0.60	1.00	12.30 (<0.0001)
PTAvg_6k	0.70	1.60	12.40 (<0.0001)
PTAvg_8k	1.30	2.20	6.20 (0.0002)

The *p*-values for coefficients that are significant are included in parenthesis.

are added to this equation, the issue gets even more complex. We undertook this experimental investigation to find some practical solution to this complex problem.

The purpose of this study was to identify if people listening to music with an iPod at high volume levels are at risk for hearing loss. The temporary shifts in pure-tone thresholds and DPOAEs were used as test measures for assessing the risk of developing hearing loss with the iPod volume set at 100%, 75%, 50%, or 0% (no music exposure). Music exposure levels were first determined on a KEMAR using a standard playlist of current popular songs. In addition, real-ear measures were obtained while the subjects listened to the playlist during the experimental condition. A sound-field equivalent correction factor was applied to the real-ear measures obtained on the subjects. This accounted for the measurements made in the subject's ear canal, close to the eardrum, as opposed to outside the head (Shotland, 1996; Hammershøi, 2007; Keith et al, 2008; Fligor, 2009a,b). After real-ear measures were made and correction factors applied, the dBA values obtained for the playlist were found to be highly comparable with the measurements made on the KEMAR in dBC values (as required by the IRB).

The present findings indicate that listening through an iPod to the selected playlist for 30 min at 100% volume leads to significant changes in auditory test measures compared with other volume levels. Auditory test measures obtained with 75% and 50% volume levels for 30 min were not significantly different from the 0% level (the no music exposure condition), indicating no foreseeable risks when the volume is set at or below 75%. With 100% volume setting, TTS were seen at frequencies ranging from 2000 to 8000 Hz. However, extended high frequencies (9–12.5 kHz) and lower frequencies (500 and 1000 Hz) did not show significant shifts. Our study also revealed significantly weaker DPOAEs at 2000 and 2822 Hz in subjects that listened to the music at 100% volume level. The variability with DPOAE measures was much greater than for pure-tone measures. Nevertheless, it should be noted that even with the high variability in DPOAEs, the results were all in one direction for the 100% volume group (i.e., weaker emissions following music exposure at all frequencies).

PAS have changed over the years; however, it is interesting to see how the present findings are fairly consistent with some of the earlier studies that set out to identify risky listening behavior with PAS usage. Fligor and Cox (2004) investigated the output levels from many commercially available portable compact disc players in combination with several styles of headphones on a KEMAR. They found that output levels varied across devices, with peak sound pressure levels exceeding 130 dB SPL at times. Based on the recommendations from NIOSH, the authors concluded that the maximum permissible noise dose could be typically reached within one hour of listening when the volume is set at 70%. They indicated that reasonable guidelines would limit supra-aural headphone use to one hour or less per day with a volume set at 60%. Trzaskowski et al (2014) found no significant changes in pure tones, TEOAE, or DPOAE results in their participants that listened to 30 min of a looped audio track at an overall intensity level of 86.6 dBA. Portnuff and Fligor (2006) evaluated five MP3 players from three different manufacturers with stock earbuds and four additional models of earphones with each player, measured across five popular music genres. They reported that for maximum volume settings, periods of up to 18 min/day were safe. Regardless of earphone type, no limit was recommended at volume-control settings below 60%, but for higher volume settings, specific limits ranged from 3 min to 20 hours, depending on the type of earphone. They also reported no significant differences across genres of music. Hodgetts et al (2007) reported that the maximum output levels of the MP3 player they studied could be used for only 1–15 min/day with earbuds and supra-aural earphones. Fligor (2009b) suggested a rule of thumb that limits the volume control of earbuds to 80% of maximum, if the listening time is 90 min or less per day.

Limitations of the study: There is the possibility of slit leaks at lower frequencies during our real-ear measurements, similar to those seen in real-ear-to-coupler differences during hearing aid fittings (Dillon, 2012). There is often a propensity to have slit leaks between the ear canal wall and a hard surface such as an earmold or earbud. Dillon (2012) showed that slit leaks can often account for differences in sound pressure level at 250 and 500 Hz. Second, available equipment forced the real-ear recordings to be consecutive rather than simultaneous, meaning that songs were sampled at different points during each song for right and left ears. This may have led to slight differences in overall dBA across samples between right and left ears. Another limitation is that silent periods of less than one second were not avoided, and these silent periods may have allowed for some recovery. The rationale for truncating silent intervals of more than one second was to provide continuous listening experience and avoid having breaks or long pauses between songs during the 30-min exposure. It must be noted, however, that in real life, songs/playlists have a wide variety of silent periods within and between songs and cannot be completely simulated in an experimental setup.

CONCLUSION

As the objective of this study was to provide operational information on safe listening volume settings for music listening, it was concluded that for the playlist used in this study, 100% volume is not a safe level of exposure for 30 min or more. Listening at 75% volume or lower is considered safe for the conditions used in this study. It is difficult to provide a more specific cutoff level because of a variety of inherent combinations that can possibly occur with different types of PAS and transducers in the ever-changing market, as well as the type of music that people listen to. Despite these challenges, the outcomes in this study clearly indicate that when in-the-ear levels reach 97 dBA, as with the 100% volume setting in this study, even 30 min of exposure can produce TTS in the average listener. The results of this study are even more significant in light of the findings from Kujawa and Liberman (2009), which indicate that TTS sets up the stage for permanent auditory neural system damage. It must be emphasized that these findings are applicable only for the specific PAS device and playlist used in this study. Although this study included additionally compressed music, it is known that recording engineers routinely apply compression in music recordings so that overall levels within and across songs are not highly variable (Hodgetts et al, 2007). Because this study provides guidance on volume control settings on a popular PAS, we are hopeful that these results will aid in setting guidelines and standards for listening devices, and promote healthy listening habits among young adults.

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APPENDIX: Music Exposure Questionnaire

1. What type of device do you use to listen to music with earphones? (Circle all that apply)

   Android Phone
   Apple iPhone
   Apple iPod
   Other (please specify) ________________

2. What type of earphones do you use while listening to music on your device? (Circle all that apply)

   Apple Earbuds
   Other Earbuds
   Headphones
   In-canal earphones
   Other (please specify) ________________

3. How many years have you listened to music through any device?

   <1 year
   1–2 years
   3–4 years
   >5 years

4. How many times a week do you listen to your device?

   Less than once a week
   1 time per week
   2 times per week
   3–4 times per week
   5–6 times per week
   Other (please specify) ________________

5. How many hours do you spend listening to music per week?

   <1 hour
   1 hour
   2 hours
   3–4 hours
   Other (please specify) ________________

6. What is the number of maximum time you continuously listen to music (i.e., without breaks) in a typical week at maximum volume?

   <30 min
   30 min
   1 hour
   2 hours
   3–4 hours
   Other (please specify) ________________

7. What have you experienced (circle all that apply) after listening to music through your device?

   Ringing/buzzing in ears
   Ear fullness
   Hearing loss/muffled hearing
   Soreness of ears
   Limited concentration
   Decreased tolerance or annoyance with certain environmental sounds (hyperacusis)
   None of these

8. During which activities (circle all that apply) do you listen to music through your device?

   Studying
   Sleeping
   Riding on a bus, train, or plane
   Driving
   Walking/Jogging
   Bike Riding
   Exercising
   Working
   Other (please specify) ________________

9. Have you listened to loud music at maximum level on your iPod in the last 24 hours?

   Yes
   No

10. Have you been exposed to loud noise such as machinery, lawn mower, concerts, etc., in the last 24 hours?

    Yes
    No

11. Are you concerned about hearing loss from listening to your devise?

    Not concerned
    Slightly concerned
    Moderately concerned
    Extremely concerned

12. Would you be willing to turn down the volume of your iPod to prevent damaging your ears?

    Yes
    No

13. Would you be willing to decrease the amount of time you listen to your iPod to protect your hearing if advised regarding the risk of hearing loss?

    Yes
    No

14. What do you think would be the best way to provide information on hearing loss to the public? (Circle all that apply)

Family/friends
School
Magazines
Radio
Mail
Internet
Audiologists
Family Doctor
Other (please specify) __________________

15. If there was a Web site that provided information on listening devices, what topic would be most important to include?

Appropriate volume levels
Earphone type
Ideal environments for listening
Interference with communication or personal safety

Adapted and modified from Hoover and Krishnamurti (2010), and Danhauer et al (2009).