Daily music exposure dose and hearing problems using personal listening devices in adolescents and young adults: A systematic review

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Abbreviations

EHF	Extended high frequency
HTL	Hearing threshold level
MeSH	Medical subject heading
NIOSH	National Institute for Occupational Safety and Health
OAE	Otoacoustic emission
PEL	Permissible exposure limit
PLD	Personal listening device
PLL	Preferred listening level
PTA	Pure tone audiometry
REL	Recommended exposure limit
TWA	Time-weighted average

Abstract

Objective: This systematic review aimed to explore the evidence on whether the Preferred Listening Levels (PLLs) and durations of music listening through Personal Listening Devices (PLDs) in adolescents and young adults exceed current recommended 100% daily noise dose, together with the impact on hearing and possible influential factors of such listening behaviours. *Design:* A systematic search was conducted using multiple online bibliographic databases. *Study sample:* The 26 studies were included on the basis of the inclusion and exclusion criteria. *Results:* The results showed that up to 58.2% of participants exceeded the 100% daily noise dose, particularly in the presence of background noise. Significantly positive correlations were found among BGN levels and mean PLLs, as well as the proportion of participants exceeding the 100% daily noise dose. Moreover, significantly worse hearing thresholds were found in PLD users using conventional and extended high-frequency audiometry, and significantly poor results in Otoacoustic Emission (OAE), even in the participants with self-reported 'normal hearing'. *Conclusion:* It is crucial to develop appropriate standard and safe recommendations for daily music exposure dose in future studies. Providing an essential guide and effective education to adolescents and young adults will help raise awareness, increase knowledge, and consequently change attitudes and listening habits.

Key Words： Music, hearing loss, personal listening device, noise induced hearing loss, adolescents, young adults

Introduction

Music-induced hearing loss has been shown primarily in professional musicians, and in people working in music venues (Zhao et al., 2010). However, there is substantial evidence in the literature showing an increasing potential risk of music-induced hearing loss in the general public, particularly among adolescents and young adults when they listen to music using PLDs (Serra et al., 2005, Kepper et al., 2009, Mariola and Adrian, 2012). PLDs (referred to as personal music, or mp3 players) have become increasingly popular over the last two decades. The ubiquity of these devices is such that they were hailed as the most popular ‘gadget’ after mobile phones, with 74% Americans under the age of 18 owning an MP3 player (Reiter, 2008). The most frequently used PLD by young adults was the mobile phone (Sulaiman et al., 2014, Sulaiman et al., 2013). In addition, a higher proportion of undergraduate, post-graduate and community college students own PLDs (84%, 86% and 72% respectively), as compared to individuals not in higher education (64%) (Smith et al., 2011). These findings are supported by other studies reporting that as many as 82% of students use PLDs (Ahmed et al., 2007). The possibility of music induced hearing damage due to such a high proportion of PLD ownership among adolescents and young adults has been a cause of concern for many years (Serra et al., 2005). Besides convenience to access PLDs, the preference to to listen at a loud volume level is another concern which causes music-induced hearing loss in adolescents and young adults. Various studies have found that exposure to music at a high intensity is likely to be associated with several hearing symptoms, such as TTS, tinnitus, hyperacusis, recruitment, distortion or abnormal pitch perception,eventually resulting in permanent hearing loss (Zhao et al., 2010, Rice et al., 1987, Meyer-Bisch, 1996, Petrescu, 2008, Figueiredo et al., 2011).

Currently the majority of countries in the world use a permissible exposure limit (PEL) of 85dBA and the 3-dB exchange rate as the formula for calculating an individual’s daily noise dose and durations, i.e., the recommended maximum (or 100%) daily noise dose over an 8-hour period should not exceed an average of 85dBA (Arenas and Suter, 2014). According to the equal-energy rule, when the sound energy increases 3dB (e.g., from 85 to 88dBA), it is approximately doubling in sound level, and the exposure duration is consequently reduced by a half (NIOSH, 1998). This exposure time, which is a 100% daily noise dose, is calculated using the formula below, i.e., $T = \frac{8}{2^{(L-85)/3}}$ (T=the number of hours, L=the level of exposure) (NIOSH, 1998). Based on scientific studies, NIOSH (1998) recommendations, with a recommended exposure limit (REL) of 85 dBA and the 3-dBA exchange rate, are more conservative and protective of hearing.

Several studies have demonstrated that maximum volume outputs of PLDs can be over 125dBA (Breinbauer et al., 2012), and the average listening level adopted by young adults has been reported to be from 71 to 105dBA (Sulaiman et al., 2014, Sulaiman et al., 2013, Serra et al., 2014). It implies that a listener would exceed the recommended 100% daily noise exposure dose by listening for five minutes at the exposure level of 105dBA (NIOSH, 1998).

However, it is noteworthy that this recommended maximum (or 100%) daily noise exposure dose is calculated on the basis of evidence obtained from industrial noise exposure, and is currently adopted in all studies related to music exposure in order to estimate an individual’s daily music exposure dose for people who use PLD because there is no specific guidance for PLD users.

Therefore, it is important to explore existing evidence on relationships between the recommended daily noise exposure dose using PLDs and hearing problems, consequently developing appropriate standards and safe recommendations for daily music exposure dose in future studies. It will provide an essential guide and effective education to adolescents and young adults for developing healthy hearing attitudes and listening habits.

Adolescence is a critical time of learning, growth, and development because they are in a unique stage of psychosocial development (Erikson, 1963, 1968). For their psychosocial development, adolescents are concerned with how they appear to others, and intend to develop their own identity by experimenting with a variety of behaviours and activities, which eventually involve further development of self-conceptualizing as well as further psychosocial development (Erikson, 1963, 1968). Therefore, listening behaviours appear associated with psychosocial development. Schwartz and Fouts (2003) pointed out that adolescents prefer listening to loud music, which reflects their specific personalities and the development issues that they have to deal with. The review by Vogel et al. (2003) has also identified that several psychosocial developmental aspects correlate to adolescents exposure to loud music. Therefore, learning and adopting healthy hearing habits at this stage has shown to be a strong determinant for future health (Lee et al., 2003).

Research Aims

This systematic review will explore the evidence on whether the PLLs and durations of music listening through PLDs in adolescents and young adults exceed current recommended 100% daily noise dose, together with its impact on hearing and possible influential factors of such listening behaviours. The significant outcome will contribute to developing specific recommendations for regulation and education of music listening using PLDs.

Search Strategy

In order to retrieve evidence to achieve the aim of the present study, a systematic search was conducted using search databases(PubMed, Web of Science, Cochrane Library, and other sources, e.g. Google scholar) during April 2015. Initial search words included “personal listening device,” “personal music player,” and “iPod,” and the medical subject heading (MeSH) terms “MP3-Player,” which were ‘exploded’ and then collated into a group using the Boolean term “OR.” Similarly, a second group was formed using the same Boolean term with the exploded MeSH terms “Hearing”, “Hearing loss,” “Hearing loss, bilateral,” “Hearing loss, high frequency,” “Hearing loss, Noise induced,” and “Hearing loss, Sensorineural.” The third group was formed using the Boolesan term with the exploded MeSH terms “adolescent,” “adolescents,” “youth,” “youths,” “young adult,’ “young adults,” “students,” and “students.” The resulting three groups were combined using the Boolean term “AND.”

Inclusion and exclusion criteria

The search strategy resulted in identification of 169 papers, and the flow chart for the search and retrieval process for articles to include and exclude is shown in Figure 1. In order to fulfill the aim and make an appropriate conclusion on the basis of sufficient evidence, each paper found from databases was screened for inclusion. For inclusion in this study, papers were required to:

1) Address the association between the use of PLDs in adolescents/young adults and hearing symptoms/hearing loss;
2) Explore the evidence on whether the PLLs and durations of music listening through PLDs in adolescents and young adults exceed current recommended 100% daily noise dose;
3) Investigate the evidence on music listening in relation to recommended daily noise exposure dose;
4) Include significant outcomes to develop specific regulation recommendations and education for PLDs users.

By contrast, studies were excluded if they were not related to PLDs and hearing symptoms, or not related to adolescents or young adults or if only an abstract was available. Furthermore, after screening full texts, studies were also excluded if the sample data were inappropriate, such as the age of the sample not falling in the categories of adolescence or young adult, or if the data were duplicated due to being already published in other relevant studies. Non-English publications and unpublished work were automatically excluded.

(Insert Figure 1 near here)

Study analysis and critical appraisal

According to the aim and study design/search strategy for this review, the 26 studies included in this review aimed towards providing evidence of a high proportion of adolescents and students at risk of exceeding the 100% daily noise dose, particularly in the presence of background noise (for more details of these studies, please see Appendix). In order to answer a clear and focused question, sufficient quality of these studies was evaluated in several key aspects, such as appropriate study design, sample size, PLD uses in relation to hearing problems, and PLD uses in relation to recommended daily exposure dose.

Study design

In the present review, there were 6 cross-sectional surveys suitable for investigating self-reported listening habits, and 20 prospective cohort studies aimed to determine noise doses and hearing thresholds (Table 1). It is noteworthy that the response rates of the cross-sectional surveys ranged from 86.14% to 89.9%, together with the response rate from the cohort studies that included a survey, are both high in comparison to the mean response rate of 60% noted in mail surveys published in medical journals (Asch et al., 1997). In addition, the response rates were unable to be calculated in some studies as participants were acquired through advertising with posters or through websites. Such a study design is likely to introduce a high risk of sample recruitment bias, as participants may have extreme views or habits regarding their PLD use, thereby prompting their participation.

(Insert Table 1 near here)

Sample size and quality

Sample size varied greatly across the studies, ranging from 20-8710 participants (Table 1). Because of no provision of power calculations in some studies, it was unclear whether these sample sizes were sufficient to attribute hearing loss or related symptoms to PLD uses, or accurately portray listening habits, thereby threatening internal validity. Furthermore, most studies obtained the samples from a single institution, introducing sampling bias, whereas only three studies by Kim et al. (2009), Muchnik et al. (2012) and Gilliver et al. (2012) had their samples from four or more institutions thereby improving external validity. Despite this, according to Erikson’s stages of psychosocial development, adolescents ranging from 12-19 years and young adults ranging from 19-39 years, the age range of the samples appeared appropriate exceptfor a few participants in Levey's study who were out of this range. Although the proportion of the age range 40-53 in this study was not listed, the average age was 22.2 years, and they were all college students more likely to use PLDs.

Experimental materials and methods

All studies used preselected songs chosen on the basis of their popularity and equality of their sound levels, except for McNeill et al. (2010) who allowed participants to use their favourite songs. Using different experimental materials may have significant impact on the PLLs, as participants have been noted to increase their PLLs by up to 76% when listening to their favourite song, as compared to one selected by the authors (Danhauer et al., 2009). Despite using different experimental materials, all included studies adopted the same criteria to define the outcome of the 100% daily noise dose with the time-weighted average (TWA) of 85dBA for an 8-hour listening duration.

As shown in Table 2, in the presence of high background noise (approximately 61-80dBA) and low background noise (approximately 40-60dBA), the daily noise dose ranged from 21.0% to 33.3% (mean=27.4%, n=4), and 0% to 58.2% (mean=15.9%, n=5), respectively, while in quiet, the daily noise dose ranged from 4.5% to 17.0% (mean=9.5%, n=3) only.

(Insert Table 2 near here)

Critical analysis on PLLs in the presence of background noise and daily noise exposure dose

Because the majority of participants (83% or more) tended to use PLDs in noisy environments (Muchnik et al., 2012), it is important to understand the relationship between PLLs and background noise, and therefore the daily noise exposure dose. For example, Levey et al. (2011) found that a large proportion of PLD users increased their volume levels in the presence of background noise, potentially up to 121dBA, which would exceed the 100% daily noise dose after seven seconds. It is noteworthy that the increasing volume levels are likely to be due to the use of earbud type earphones, which have a poor quality of background noise isolation.

Table 2 shows that 0% to 58.2% (mean = 18.1%, n=12) of participants exceeded the 100% daily noise dose in background noise levels below 80dBA. Further analysis showed positive correlation between background noise levels and the mean PLLs (r_s=0.65, p<0.05), and these two variables with the percentage of subjects exceeding 100% dose (r_s=0.90, p<0.001; r_s=0.59, p<0.05) (Table 2). As shown in Figure 2, through the measurement of background noise, mean PLL, and the proportion of participants exceeding the 100% daily noise could be predicted with the linear fit function as PLL=52+0.45BGN (R^2=0.48, Correlation=0.70) (Figure 2), and these two variables with the percentage of subjects exceeding 100% dose, with the power fit function as PLL=50.18(dose%)^0.15 (R^2=0.86, Correlation=0.92) and BGN=25.75(dose%)^0.26 (R^2=0.52, Correlation=0.72) (Figure 3).

(Insert Figures 2 and 3 near here)

It is noteworthy that no participants exceed this noise dose in the presence of background noise at 43-52dBA in the study by McNeill et al. (2010). This discrepancy may be attributed to the PLL measurement methodology, as this study failed to blind the participants to the volume control display. Subjects may have used visual cues to select a volume level, rather than to reflect the true PLLs based on sound perception alone (Sulaiman et al., 2013, Lee et al., 2014, McNeill et al., 2010) as a result of apprehension to be assessed (Kantowitz et al., 2014). It may also threaten the reliability of estimating/calculating the daily noise dose, as it depends on self-reported listening durations, which may be underestimated.

Vogel et al. (2010) reported estimates of individuals' noise dose based on self-reported listening volumes, which may not be reliable due to the fact that individuals often underestimate their listening volumes (Hodgetts et al., 2009). It is consistent with the finding by Sulaiman et al. (2013), showing a significant difference between self-reported and objectively measured PLLs ($p<0.001$).

Critical analysis on hearing symptoms and hearing thresholds associated with PLD use and daily noise exposure dose

Figure 4 shows the hearing symptoms (e.g., hearing difficulty, tinnitus, and other issues), and their proportions in the PLD users across different studies, ranging from 5.9% to 58.8%. Moreover, significantly worse hearing thresholds were found in PLD users using conventional

PTA, EHF audiometry, together with significantly poor results in OAE (Biassoni et al., 2014, Le Prell et al., 2013, Sulaiman et al., 2014), even in the participants with self-reported ‘normal hearing’ (Le Prell et al., 2013) (Table 3).

(Insert Figure 4 near here)

(Insert Table 3 near here)

It is noteworthy that there was a discrepancy in the studies on the relationship between hearing sensitivity changes and the PLD uses (Table 3). For example, Le Prell et al. (2013) and Levey et al. (2011) did not find a statistically significant correlation between hearing threshold changes and PLD uses when using conventional and EHF audiometry tests, while there was a significant correlation when using an EHF audiometry test in a large-scale retrospective analysis (24-year period, 8710 sample size) (Berg and Serpanos, 2011). In addition, several recent studies have demonstrated a significantly positive correlation between hearing thresholds at certain frequencies and daily noise exposure dose (Sulaiman et al., 2014).

Further effect size (Cohen's *d*) analysis was performed in order to investigate the music exposure effect on the hearing thresholds by PLD uses in five individual studies that included the hearing threshold data (Table 4). Small to large effect sizes were found across various frequencies in all these studies, indicating hearing threshold deterioration when having music exposure via PLD use. For example, in the studies comparing PLD users with controls (PLD non-users) (Sulaiman et al., 2014; Peng et al., 2007), significantly worse hearing thresholds were found in PLD users than in control subjects, particularly in some individuals who were exceeding the 100% daily noise dose. In terms of effect size, there was substantive and significant hearing threshold deterioration in higher frequencies between 12.5 kHz and 16kHz (Peng et al., 2007). A longitudinal study by Biassoni et al. (2014) also found significant hearing changes and positive large *d* values at frequencies from 0.25 to 16 kHz by comparing hearing threshold changes over a three year period with music exposure. In addition, similar results were obtained in the studies by Kim et al. (2009) and Le Prell et al. (2013), showing significantly worse hearing thresholds in participants who used PLDs for 5 years or more than for those who had less experience of using PLD. However, it is noteworthy that only a small effect size was found in the studies of Kim et al. (2009) and Le Prell et al. (2013), which is mainly due to a different comparison design and the sample size.

(Insert Table 4 near here)

General Discussion

Although many previous studies have raised awareness that exposure to loud music would cause hearing symptoms and consequent hearing loss (Serra et al., 2005, Keppler et al., 2010, Mariola and Adrian, 2012), most of them failed to report the proportion of PLD users exceeding the recommended 100% daily noise dose according to current occupational standards (i.e., maximum daily noise dose with listening levels of 85dBA for an 8-hour noise exposure). This review highlighted correlation between the proportion of participants exceeding the 100% daily and PPLs, particularly in the presence of background noise, together with the mostinfluential factors affecting daily noise exposure dose of PLD use.

The results showed that 27.4% of adolescents and students exceeded 100% daily noise dose in the presence of high-level background noise (61-80dBA), and 15.9% of those in the presence of low-level background noise (40-60dBA). By contrast, very few individuals (9.5%) were at risk of exceeding the 100% noise dose in a quiet environment. Therefore, attenuating the background noise levels appears to be an effective way to reduce PLLs, and consequently reduce the risk of exceeding 100% daily noise dose when using a PLD (Portnuff et al., 2011, Muchnik et al., 2012). For example, Portnuff et al. (2011) found that significantly lower PLLs were selected with the use of isolator (or insert) earphones compared to earbud or supra-aural earphones (p <0.01). Moreover, they also found a lower proportion of participants exceeding the 100% daily noise dose in higher levels of background noise compared to other studies using only earbud type earphones, which are usually supplied with new PLDs such as Apple's iPod. Therefore, in order to encourage lower PLLs and protect the hearing of PLD users, various types of earphones for greater attenuation of background noise (such as noise cancelling headphones) should be strongly recommended to protect the hearing for PLD users (Liang et al., 2012).

However, it is noteworthy that a subset of PLD users had high PLLs even at lower levels of background noise, and consequently could easily be exceeding the 100% noise dose (Sulaiman et al. 2014) (mean PLL of 81.3dBA in quiet). This is likely due to the influences caused by psychosocial factors, music preference, and listening habits (Vogel et al., 2010).

Additionally, the other possible influential factor appears to be gender differences for both PLLs and durations of use (Le Prell et al., 2011, Vogel et al., 2010, McNeill et al., 2010). For example, Vogel et al. (2010) reports that males are more likely to select higher PLLs than females, which is supported by McNeill et al. (2010) reporting male PLLs to be a median of 7dBA higher than those of females. Le Prell et al. (2011) also found that males using PLDs had significantly elevated hearing thresholds compared to females. Therefore, it is of vital importance that this group of individuals are made aware of immediate and future dangers, and provided with essential influence and education that will motivate and encourage a change in their listening habits.

Furthermore, the initial noise exposure standard was developed with the expectation that average hearing loss can be controlled after prolonged industrial noise exposure over years under 20 dB for the test frequency of 4 kHz. Because of differences in sound energy and frequency spectrum between industrial noise and music, there is a concern whether it is appropriate to use current occupational standards as the recommendation for daily music exposure. In addition, there is also a debate on whether it is safe to recommend a 100% daily noise dose for music exposure by considering the possibility of exposure to other noise sources. For example, Le Prell et al. (2011) noted that 25-30.6% of participants reported at least three or more sources of noise exposure. Therefore, with evidence of statistical power, it would be useful to investigate the relationship between hearing status and music exposure in terms of music intensity and listening durations using meta-analysis in future studies. Consequently, a model will be developed for calculating maximum music exposure standards.

Conclusion and Future study

This review mainly focuses on exploring the risk of listening to music through PLDs in relation to recommended daily noise exposure dose (100% daily noise dose) for adolescents and young adults. The current data suggests that a large proportion of adolescents and students using PLDs are at risk of noise induced hearing loss when listening to music with background noise greater than 65dB. The listening habits of PLD users have a significant effect on hearing thresholds compared to those who do not use PLDs, although the extent of this impact is unclear. Awareness should be raised regarding correlations between daily noise exposure dose with PLD use and the risk of hearing damages. It is crucial to develop appropriate standards and safe recommendations for daily music exposure dose in the future studies. Providing essential guidance and effective education to adolescents and young adults will help raise awareness, increase knowledge, and consequently change attitudes and listening habits. Moreover, longitudinal research would be useful and viable to demonstrate the long-term impact of PLD use on hearing. Such studies may provide further insight into information which would include variables contributing to a more complete characterization of the causality of hearing damage in PLD users.

Conflicts of Interest

No conflicts of interest were reported.

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Figure Legends

Figure 1: Flow chart for the search and retrieval process for articles to include and exclude

Figure 2: Correlation between the mean preferred listening level (PLL) and the background noise

Figure 3: Relationship between the percentage of participants exceeding recommended 100% noise exposure dose and sound levels

Figure 4: Self-reported hearing symptoms in PLD users

Table 1: Study design and sample size

Study	Study design	Age range in years	Sample size (response rate)
Serra *et al.* (2005)	Cohort study / Cross sectional survey	14 - 17	106
Peng *et al.* (2007)	Cohort study / Cross sectional survey	19 - 23	150
Kim *et al.* (2009)	Cohort study / Cross sectional survey	13 - 18	490
Danhauer *et al.* (2009)	Cross sectional survey	17 - 30	609 (89.6%)
Hodgetts *et al.* (2009)	Cohort study / Cross sectional survey	18 - 30	24
Vogel *et al.* (2010)	Cross sectional survey	12 - 19	1512 (89.9%)
Hoover and Krishnamurti (2010)	Cross sectional survey	19 - 25	428 (NA)**
McNeill *et al.* (2010)	Cohort study / Cross sectional survey	17 - 23	28
Levey *et al.* (2011)	Cohort study / Cross sectional survey	18 – 53*	189
Vogel *et al.* (2011)	Cross sectional survey	12-19	1687
Portnuff *et al.* (2011)	Cohort study / Cross sectional survey	13 - 17	28
Berg and Serpanos (2011)	Cohort study	12-20	8710 females
Keith *et al.* (2011)	Cohort study	10-17	219
Le Prell *et al.* (2011)	Cohort study / Cross sectional survey	18-31	57
Rekha *et al.* (2011)	Cohort study / Cross sectional survey	18-20	563 (86.14%)
Muchnik *et al.* (2012)	Cohort study / Cross sectional survey	13 - 17	Survey 289 (NA); Test 85

Gilliver *et al.* (2012)	Cross sectional survey	12-22	486 (NA)
Le Prell *et al.* (2013)	Cohort study / Cross sectional survey	18-31	87
Sulaiman *et al.* (2013)	Cohort study / Cross sectional survey	13-16	177
Tung and Chao (2013)	Cross sectional survey	Average 18.9	1878 (NA)
Biassoni *et al.* (2014)	Cohort study	Test 14-15; Retested 17-18	Test 172; Retested 59
Hannah *et al.* (2014)	Cohort study	19-30	28
Lee *et al.* (2014)	Cohort study	16-21	1928
Serra *et al.* (2014)	Cohort study	14-15	188
Sulaiman *et al.* (2014)	Cohort study	18-30	35
Trzaskowski *et al.* (2014)	Cohort study	22-27	20

*Although the number of the age range 40-53 is not listed in the paper, the average age was 22.2, and they were all college students more likely to use PLDs.

** No accurate response rate due to the unaccountable response to the advertisements or e-mails.

Table 2: The listening habits of PLD users and the percentage exceeding the daily noise dose

Noise Condition	**Study**	**Measured mean PLL(dBA)**	**Self-reported mean PLL(dBA)**	**8-h equivalent PLL(dBA)**	**Background noise (dBA)**	**Subjects exceeding 100% Dose (%)**
Quiet	Hodgetts *et al.* (2009)*	72.1±9.1				
	Portnuff *et al.* (2011)*	68.3±10.9			13[#]	
	(Portnuff *et al.* 2011)*		74.1±10.8 (52.3-91.8)		35[**]	6.9
	Sulaiman *et al.* (2013)	72.2±1.1		61.6±12.9	35[**]	4.5
	Sulaiman *et al.* (2014)	81.3±9.0		76.2±9.8	35[**]	17
Low	Muchnik *et al.* (2012)*	82±9.0			40-44	
	Muchnik *et al.* (2012)*			74.0±11.0 (62-96)	40-44	9
	Muchnik *et al.* (2012)*			70.0±10.0 (59-90)	40-44	9
	Keith *et al.* (2011)	56.0 (45-113)			40-52	3.2
	Portnuff *et al.* (2011)*	70.6±9.2			50 pink noise	
	Portnuff *et al.* (2011)*	74.6±7.3			60 pink noise	
	Levey *et al.* (2011)*			87.2 (60-115)	60.6±3.1 (56.0-68.1)[##]	58.2
	Levey *et al.* (2011)*	92.6±10.7			60.6±3.1 (56.0-68.1)[##]	

	McNeill *et al.* (2010)		71 (55-85)		43-52	0
High	Portnuff *et al.* (2011)*	79.1±5.3			70 bus noise	
	Portnuff *et al.* (2011)*	81.3±4.1			75 airplane noise	
	Portnuff *et al.* (2011)*	84.3±3.0			80 pink noise	
	Muchnik *et al.* (2012)*	89.0±9.0 (74-103)			61-70	
	Muchnik *et al.* (2012)*			80.0±10.0 (65-10)	61-70	26
	Muchnik *et al.* (2012)*			77.0±10.0 (62-98)	61-70	21
	Hodgetts *et al.* (2009)*	89.3±4.9			75	29.2
	Hodgetts *et al.* (2009)*	91.8±4.6			75	33.3

*Papers duplicated to show results by level of BGN.

**In this data analysis, 35dB was assumed as it was measured in the laboratory setting.

13dB was measured in a sound-treated laboratory room while it seems too low to be realistic.

BGN was the ambient street noise, not the actual listening environment noise (in the subway).

Table 3 Hearing change(s) with PLD use and its correlation with PLD use/daily noise exposure dose

	Study	**PTA**	**EHF**	**OAEs**
Hearing change(s)	Trzaskowski *et al.* (2014)	NS	NA	NS
	Sulaiman *et al.* (2014)	NS	*	*
	Serra *et al.* (2014) [#]	**	**	*
	Serra *et al.* (2014)[##]	NS	*	NS
	Biassoni *et al.* (2014)	***	***	***
	Hannah *et al.* (2014)	*	NS	NS
	Tung and Chao (2013)	NS	NA	NA
	Le Prell *et al.* (2013)	*	*	NA
	Kim *et al.* (2009)	*	NA	NA
	Peng *et al.* (2007)	*	**	NA
	Serra *et al.* (2005)	*	*	NA
Correlation with PLD use	Le Prell *et al.* (2013)	NS	NS	NA
	Levey *et al.* (2011)	NS	NS	NA
	Berg and Serpanos (2011)	NA	***	NA
Correlation with Daily noise exposure dose	Sulaiman *et al.* (2014)	*	NS	NS
	Serra *et al.* (2014) [#]	*	*	NS
	Serra *et al.* (2014) [##]	NS	NS	NS
	Biassoni *et al.* (2014)	*	*	NA
	Sulaiman *et al.* (2013)	NS	*	NA

NS=no statistically significant difference; NA= not available.

*p<0.05, **p<0.01, ***p<0.001

Serra et al. (2014) [#]: comparing normal vs. slight shift/significant shift groups;

Serra et al. (2014) [##]: comparing slight shift vs. significant shift groups.

Table 4 Effect of music exposure (PLD use) on hearing changes (Cohen's *d*)

Comparison design	Study	Sample size	Significant frequency	Hearing threshold (PTA: dB HL; EHF: dB SPL)	*d*
PLD users vs. controls (PLD non-users)	***Sulaiman et al. (2014)***	35 vs. 35	***PTA@ Right ear***		
			2kHz	13.03± 4.56 vs. 10.51± 4.78*	0.54
			EHF@ Right ear		
			9 kHz	29.94± 11.41 vs. 24.03± 7.15*	0.62
			10 kHz	32.7± 9.45 vs. 26.7± 6.08**	0.76
			11.2 kHz	33.43±9.72 vs. 27.63± 7.40**	0.68
			12.5 kHz	36.20± 11.33 vs. 29.06± 7.82**	0.74
			14 kHz	45.36±14.62 vs. 35.19± 9.69**	0.82
			16 kHz	68.53± 18.76 vs. 55.59± 11.52**	0.83
			EHF@ Left ear		
			12.5 kHz	35.43± 13.13 vs. 28.91± 8.96*	0.58
			14 kHz	45.61± 16.47 vs. 35.67± 10.68**	0.71
			16 kHz	65.70± 16.60 vs. 57.19± 14.35*	0.55
	Peng et al. (2007)		***EHF@ Ears***		
		34 vs. 60	10 kHz	42.06± 1911 vs. 13.25± 4.86**	2.38
		32 vs. 60	12.5 kHz	61.47± 22.16 vs. 25.75± 8.92**	2.40
		28 vs. 60	16 kHz	82.99± 19.24 vs. 48.50± 17.64**	1.90
		15 vs. 54	20 kHz	97.79± 4.95 vs. 89.92± 7.67**	1.10
PLD use experience: *Over 5 years vs. under 5 years*	***Kim et al. (2009)***	328 vs. 28	***PTA@ Left ear***		
			4 kHz	11.7± 10.3 vs. 7.2± 4.3*	0.45
			PTA@ Right ear		
			4 kHz	9.8± 12.8 vs. 4.8± 4.7*	0.40
	Le Prell et al. (2013)	28 vs. 26	***EHF@ Ears***	**EHF: dB HL**	
			10 kHz	21± 6.5 vs. 18± 7.0*	0.44
			14 kHz	35± 11.5 vs. 30± 10.0*	0.47

Longitudinal study: *Retest 3 years later vs. test*	***Biassoni et al. (2014)***	49 vs. 49	***PTA @ Ears***	NA (*t*-value only) ***	
			0.25 kHz		1.01
			0.5 kHz		0.97
			1 kHz		1.23
			2 kHz		2.17
			3 kHz		1.75
			4 kHz		1.42
			6 kHz		1.23
			8 kHz		2.35
			EHF@ Ears		
			9 kHz		1.87
			10 kHz		1.58
			11.2 kHz		1.58
			12.5 kHz		1.33
			14 kHz		1.59
			16 kHz		1.56

*p<0.05, **p<0.01, ***p<0.001