



Original Article

Hearing Risk among Young Personal Listening Device Users: Effects at High-Frequency and Extended High-Frequency Audiogram Thresholds

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OBJECTIVE: The usage of personal listening devices (PLDs) is associated with risks of hearing loss. The aim of this study is to evaluate the effects of music exposure from these devices on high-frequency hearing thresholds of PLD users.

MATERIALS and METHODS: A total of 282 young adults were questioned regarding their listening habits and symptoms associated with PLD listening. Their audiogram thresholds were determined at high (3–8 kHz) frequencies and extended high frequencies (EHFs, 9–16 kHz). The preferred listening volumes of PLD users were used to compute their overall 8-h equivalent music exposure levels (L_{Aeq8h}).

RESULTS: Approximately 80% of the subjects were regular PLD users. Of these, 20.1% had L_{Aeq8h} of ≥ 75 dBA, while 4.4% of them had L_{Aeq8h} of ≥ 85 dBA, which carries a high risk of hearing damage. Compared with those exposed to L_{Aeq8h} of < 75 dBA, subjects who had L_{Aeq8h} of ≥ 75 dBA reported a significantly higher incidence of tinnitus and difficulty in hearing others immediately after using PLDs. PLD users who were exposed to L_{Aeq8h} of ≥ 75 dBA and had been using their devices for ≥ 4 years also showed significantly higher mean audiogram thresholds compared with non-users at most EHFs tested. In addition, the thresholds of PLD users at EHFs showed a weak but significant positive correlation with their L_{Aeq8h} .

CONCLUSION: The present findings suggest that excessive exposure to music among PLD users may lead to initial effects on their hearing at very high frequencies.

KEYWORDS: Noise-induced hearing loss, high-frequency audiometry, MP3 player

INTRODUCTION

The usage of personal listening devices (PLDs) such as stand-alone MP3 players and other multifunctional electronic devices with an audio playback function (e.g., mobile phones, laptops, and media tablets) has become increasingly popular, particularly among the younger generation^[1]. Compared with older technology, current PLDs are highly portable, permit the storage of a large number of digital audio files, and have a longer battery life, which are features that enable users to listen to their favorite songs for longer durations on a regular basis^[1]. With the increasing trend in the usage of PLDs, concerns have been raised over the possible impact of these devices on the hearing of listeners^[2, 3].

The sound output measured from PLD earphones easily exceed 100 dBA at higher gain settings and are often reported in free-field corrected levels^[2–4]. The free-field levels, when taken together with the duration of listening, can be used to calculate the music exposure levels of an individual in time-weighted averages^[5]. For an 8 h/day equivalent exposure to free-field noise (L_{Aeq8h}), levels between 75 dBA and 85 dBA carry a minimal risk of hearing damage, while levels of > 85 dBA carry a high risk of hearing damage^[6]. Based on the music levels measured from PLDs, users listening at high volume settings can easily exceed these L_{Aeq8h} noise exposure safety limits within a short period^[2–4].

Although output levels from PLDs can potentially harm hearing, the extent of hearing damage among PLD users is still unclear^[7]. Exposure to loud sounds can lead to a permanent loss of hearing sensitivity, which is termed as noise-induced hearing loss (NIHL). While it is possible to damage one's hearing from a single exposure to an extremely loud sound, most NIHLs are caused by recurring exposure to loud sounds over a period of time. These hearing losses often affect the high-frequency hearing component, which is localized at the basal part of the cochlea. Studies have reported that PLD users have poorer hearing thresholds at high frequencies than non-users^[8–11]. Other studies, however, did not find any evidence of NIHL among PLD users,^[12–16] and audiogram thresholds of PLD users were comparable with those of non-users^[13, 16].

The preliminary data from this study was presented at the 10th International Congress on Noise as a Public Health Problem (ICBEN) 24–28 July 2011, London, UK.

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With the increasing trend of PLD usage, it is imperative to clearly determine the effects of loud music exposure from these devices on the hearing of listeners. Prior studies often involve a small number of PLD users [10, 11, 13]. In addition, study subjects are often exposed to other noisy recreational activities, and it is often difficult to relate their hearing effects, if any, with the usage of their PLDs alone [8, 9, 17].

The aim of the present study was to assess the hearing status of young PLD users using a combination of high-frequency (HF, 3–8 kHz) and extended high-frequency (EHF, 9–16 kHz) audiometry. A larger sample of subjects was recruited to allow the stratification of the user group according to their levels of music exposure and duration of PLD usage. Due to socio-cultural differences, participation in other noisy recreational activities were not common among the present study subjects.

MATERIALS and METHODS

Study Subjects

The subjects were university students who had responded to e-mails and flyers. Initially, all subjects underwent a face-to-face interview in which they were asked about the usage of their PLDs. They were considered PLD users if they owned and used their devices (with earphones or headphones) at least once a week in the previous six months. Those who do not own a PLD or listened to their PLDs for less than once a week were considered as non-users. On confirming that they were PLD users, further details were obtained regarding the type of device, duration of usage, and time of listening in a typical week. They were also asked to indicate their usual listening volumes by marking on a scale which corresponded to a 0–100% volume setting on their devices. In addition, they were asked about the presence of the following five symptoms immediately after using PLDs: tinnitus, difficulty in hearing others, ear pain, headache, and neck stiffness.

Subjects were excluded from the study if they had a history of ear disorders, had been taking any ototoxic drugs, or if they had regular exposure (more than once in a month) to other sources of loud noise (e.g., discotheques, concerts, music bands, noisy equipment, musical instruments, loud home stereos, and shooting sports). All subjects signed informed consent forms to participate in this study, and the study protocol was approved by our University's medical ethics committee (Ref No: 714.10).

Hearing Evaluation

All subjects underwent an otoscopic examination and a screening tympanometry (Otowave 102, Amplivox, Oxford, UK) to establish normal outer and middle ear functions. Pure tone audiometry was conducted inside an audiometric booth using a diagnostic audiometer (SD28HF, Siemens, West Sussex, UK), which has a smallest step size of 1 dB. The hearing of the subjects was first screened at frequencies between 0.5 kHz and 2 kHz at 20 dB HL. A detailed audiometry was then conducted at HFs (3–8 kHz) and EHF (9–16 kHz) using the modified Hughson–Westlake procedure. The hearing test was performed using a HDA 200 headphone (Sennheiser, Wedemark, Germany) under similar testing conditions for all subjects, and the sound level in the examination booth was within the permissible levels for audiometric testing. The sound output from the HDA 200 headphone was calibrated using the International Organization for Standardization 389-8:2004 Reference Equivalent Threshold Sound Pressure Levels, and hearing thresholds were reported in dB SPL and dB HL. For EHF testing, if a subject failed to detect even the loudest tone produced by the audiometer, the max-

imum output level was taken as their hearing threshold. The subjects were told to abstain from listening to their devices and exposure to loud noises for 24 h prior to the test.

Estimation of Music Exposure Levels

The listening levels of PLD users were estimated using an iPod test. The subjects listened to an iPod Nano™ (4th generation, Apple Inc.; Cupertino, CA, USA) playing a 40-s clip of a pre-selected song ("Just like Heaven.mp3" by The Cure) in a quiet room. The iPod was coupled to an insert earphone (MDR-EX51LP, Sony, Tokyo, Japan), and the iPod equalizer was turned off (default setting). The subjects were told to set the volume to their usual listening level without considering their preference to the song, and they were blinded from seeing the volume indicator of the iPod.

The preferred listening levels of the subjects for the 40 s of the test song were measured using the Knowles Electronics Manikin For Acoustics Research (KEMAR) ear-and-cheek simulator (43AG, G.R.A.S. Sound and Vibration, Holte, Denmark) connected to a type 1 integrating sound level meter (nor140, Norsonic, Tranby, Norway). The ear simulator was equipped with a right KEMAR pinna (Shore 00-55), and only one recording for each volume setting was done as a trial of repetitive measurements, with the removal and reinsertion of the insert phone on the KEMAR ear showed minimal variation (± 1 dB) in recorded music levels. The 1/3 octave band sound levels measured from the artificial ear were transformed to equivalent free-field levels using the inverse KEMAR head-related transfer function provided by an earlier study [18], and the overall A-weighted sound levels (L) were computed. Following procedures by other studies [12, 13], the 8-h equivalent continuous exposure levels (L_{Aeq8h}) were then calculated using the following formula: $L_{Aeq8h} = L + 10 \log_{10}(T/8)$, where L is the free-field corrected listening level (dBA) and T is the mean daily listening duration (h/day) calculated from total listening duration of the subject in a week.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) software 17.0 (SPSS Inc.; Chicago, IL, USA). Data for continuous variables were reported as mean \pm standard deviation. The differences in listening habits (e.g., listening duration, volume level, and overall music exposure) between genders and audiogram thresholds between the user and non-user groups were tested using the unpaired t test. Chi-square analysis was used to compare categorical variables. The correlation analyses were conducted by Pearson's correlation test. Significance level was set at $p < 0.05$.

RESULTS

After the exclusion of 19 subjects due to the abnormalities of middle ear function or a history of exposure to other sources of loud noise, a total of 282 (95 males and 187 females) subjects participated in this study. All subjects had hearing thresholds of at least 20 dB HL at 0.5–2 kHz test frequencies. They were aged 22.5 ± 2.5 (range: 18–30 years) and comprised 228 (80.8%) PLD users and 54 (19.2%) non-users. Many PLD users used more than one type of device. The most common types of PLDs used were mobile phones with a music playback function (77.2%), followed by portable computing devices (e.g., laptops) (64.9%), and stand-alone MP3 (including iPods) (45.6%) and CD players (0.4%).

The sound output levels of the 40-s test song recorded at different volume settings (% of maximum volume) from the iPod Nano is shown in Figure 1a, while the frequency spectrum of the test song played at the maximum volume level of the iPod is shown in Figure

1b. After applying the free-field correction, the iPod output levels at 5–100% volume settings ranged from 42.9 dBA to 102.9 dBA and were within the levels reported by others [3, 4].

Table 1 shows the summary of data regarding PLD usage in the user group. There was no significant difference in the duration of PLD usage, average listening time per day, listening volumes, as well as the overall L_{Aeq8h} between genders. The listening levels shown in Table 1 are based on the following two measures: the self-reported mark-

Table 1. Summary of data regarding usage of personal listening devices

	Male	Female	p-value ^b
Subjects, n (%)	79 (34.6)	149 (65.4)	
Duration of usage (years)			
Mean±SD	3.2±1.8	3.1±1.8	NS
Range	0.5–9.0	0.5–10.0	
Listening time (h/day)			
Mean±SD	1.9±1.7	2.5±2.5	NS
Range	0.1–8.0	0.1–17.1	
Self-reported volume level (% from maximum setting)			
Mean±SD	53.0±24.4	53.8±21.6	NS
Range	7–96	7–100	
Measured listening level (dBA) ^a			
Mean ± SD	70.3±12.0	69.9±11.3	NS
Range	43.0–94.0	45.7–94.0	
L_{Aeq8h} (dBA)			
Mean±SD	62.2±13.0	62.6±13.7	NS
Range	29.9–89.0	29.5–92.0	

^aA-weighted free-field corrected levels

^bunpaired t-test

SD: standard deviation; NS: not significant ; L_{Aeq8h} =8 h/day equivalent exposure level

ings on a scale during the interview (converted to % from maximum volume setting) and measured levels from the iPod test in decibels. There was a strong correlation between the self-reported and measured levels (Pearson's correlation test, $r=0.764$, $p<0.001$). Although two female subjects had indicated that they used their device at 100% volume setting on the self-reported scale, none of the subjects set their listening volume at the maximum level during the iPod test.

There was a weak but significant positive correlation between measured listening levels and average listening time per day of the subjects (Pearson's correlation test, $r=0.160$, $p<0.05$). From the 228 PLD users, 20.1% (18 males, 28 females) of the subjects had L_{Aeq8h} of ≥ 75 dBA, while 4.4% (3 males, 7 females) were exposed to L_{Aeq8h} of ≥ 85 dBA, which surpassed the safety limit in the occupational setting; these subjects may be at high risk of developing NIHL [5, 6].

The relationship between L_{Aeq8h} and self-reported symptoms among PLD users is shown in Table 2. Subjects with L_{Aeq8h} of ≥ 75 dBA reported a significantly higher incidence of tinnitus and difficulty in hearing others immediately after their PLD use, compared with those exposed to safe music levels ($L_{Aeq8h} < 75$ dBA).

When the audiogram thresholds of the subjects at HF were analyzed, 34 PLD users (14.9%) and 7 non-users (13.0%) had abnormal thresholds (>20 dB HL) at one or more test frequencies in either ear. The chi-square test did not reveal a significant association between the incidence of subjects with abnormal thresholds and usage of PLDs ($p=0.8802$).

Because there were minimal right–left ear differences in the audiogram thresholds, data from both ears were averaged at individual test frequencies for all subsequent analyses. When the audiogram data from the PLD users with L_{Aeq8h} of ≥ 75 dBA (age: 22.6 ± 2.5) were compared with those from the non-users (age: 22.8 ± 2.7), the mean hearing thresholds of the users were significantly higher at the following EHF: 11.2, 12.5, 14, and 16 kHz (Figure 2a). On the other hand, the mean hearing thresholds of users exposed to L_{Aeq8h} of < 75 dBA (age: 22.1 ± 2.4) were only significantly higher than the mean thresholds of the non-users at the highest EHF tested (16 kHz) (Figure 2b). When the duration of PLD usage was taken into account, users with L_{Aeq8h} of ≥ 75 dBA and who had been using their devices for ≥ 4 years (age: 23.2 ± 2.5) had significantly higher thresholds at six of the test frequencies (8, 10,

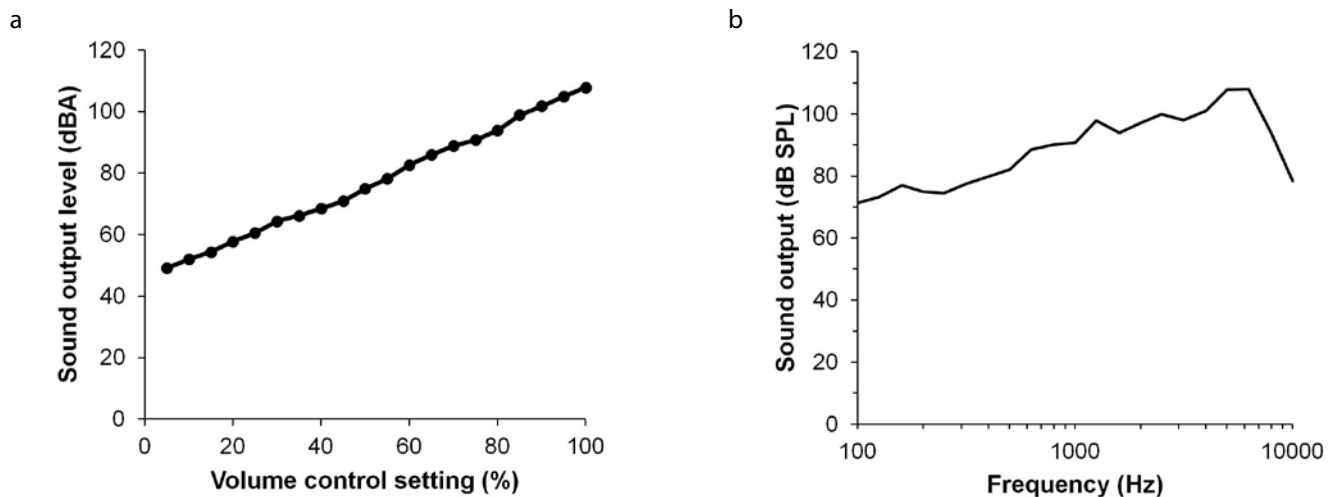


Figure 1. a, b. Sound output levels (dBA) of the test song played from the iPod Nano at different volume settings (a). Frequency spectrum of the test song (dB SPL) recorded from the iPod at the maximum volume setting (b)

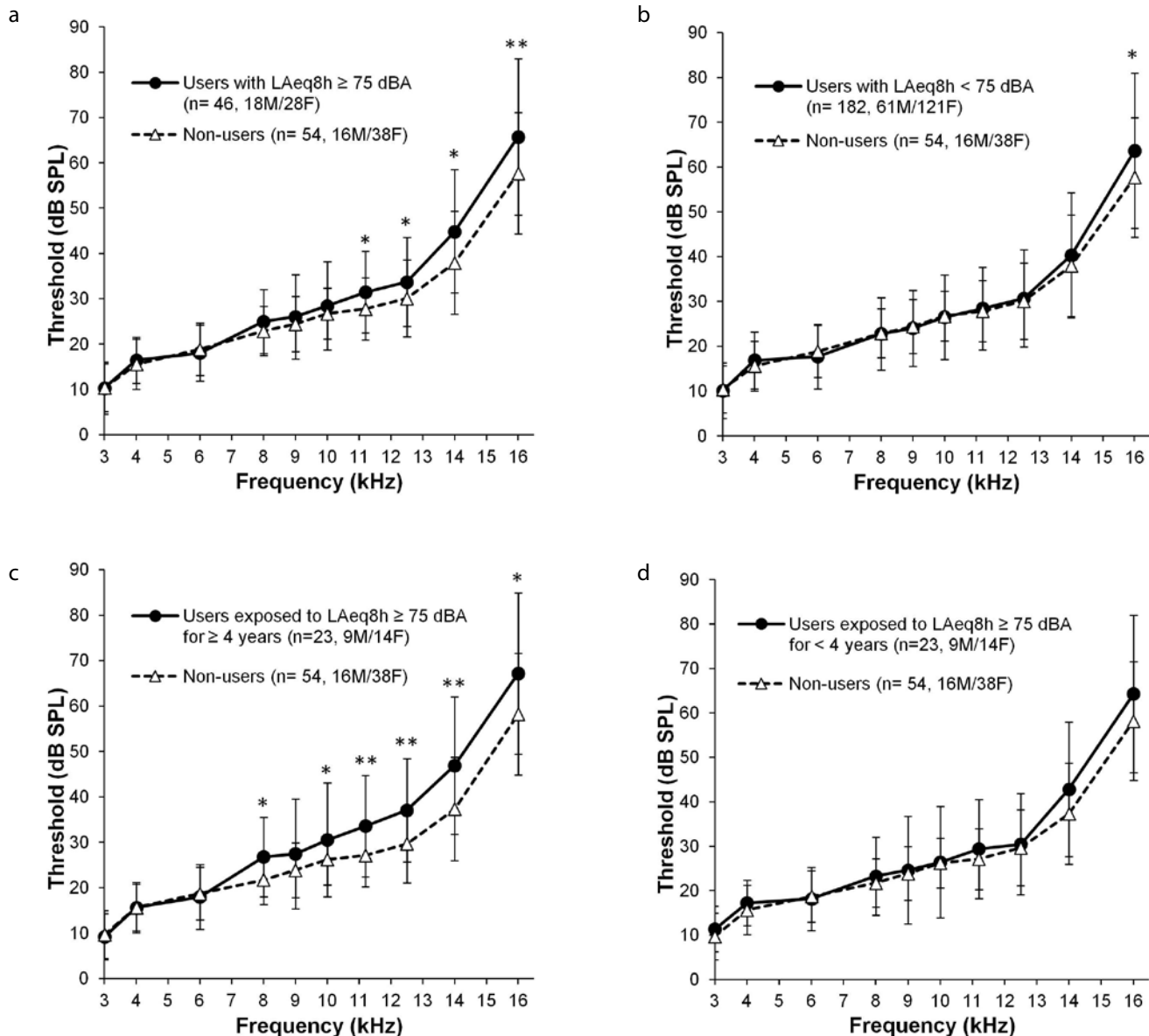


Figure 2. a-d. Audiogram thresholds (mean \pm SD) of PLD users exposed to L_{Aeq8h} of ≥ 75 dBA (a), PLD users exposed to L_{Aeq8h} of <75 dBA (b), PLD users exposed to L_{Aeq8h} of ≥ 75 dBA and who used their devices for ≥ 4 years (c), PLD users with L_{Aeq8h} of ≥ 75 dBA and who used their devices for <4 years (d), plotted against the non-users at 3–16 kHz in dB SPL. Data at each test frequency for each subject is the average threshold from their left and right ears (* $p < 0.05$, ** $p < 0.01$, M: males, F: females)

11.2, 12.5, 14, and 16 kHz) compared with the non-users (Figure 2c). However, those with L_{Aeq8h} of ≥ 75 dBA but who used their PLDs for <4 years (age: 22.0 ± 2.5) did not show any significant difference in their thresholds compared with those of the non-users (Figure 2d). Further statistical analysis showed no significant differences in the age and gender distribution among the different groups.

The averaged left–right hearing thresholds at each test frequency (in dB HL) from all PLD users were pooled from HFs and EHF and were correlated with L_{Aeq8h} of PLD users (Figure 3). While thresholds at HFs did not reveal any relationship with L_{Aeq8h} of the subjects (Figure 3a), thresholds at EHF showed a weak but significant positive correlation with their music exposure levels (Figure 3b). Further correlation analysis between L_{Aeq8h} and audiogram thresholds at individual test frequencies of the subjects showed that the correlation was significant at the following three EHF: 11.2, 12.5, and 14 kHz (Table 3).

DISCUSSION

The present study investigated hearing risk related to PLD usage among a selected population of university subjects who had not been subjected to significant exposure of other loud noise sources. The average listening volume of approximately 70 dBA reported in this study is in close agreement with the mean listening volumes in a quiet background reported by other studies involving teenage and young adult PLD users [3, 17, 19]. In addition, the average listening duration of the subjects in this study is also within the range of 1.5–3.2 h/day reported in previous studies comprising young PLD users [3, 13, 19–21]. In agreement with two recent studies [12, 17], the present study subjects who listened to longer durations also tended to listen at higher volume levels, but this correlation was weak. Contrary to previous reports which reported that males tended to use PLDs at louder volume levels [12, 19, 21], the present study did not reveal any difference in music exposure levels between genders.

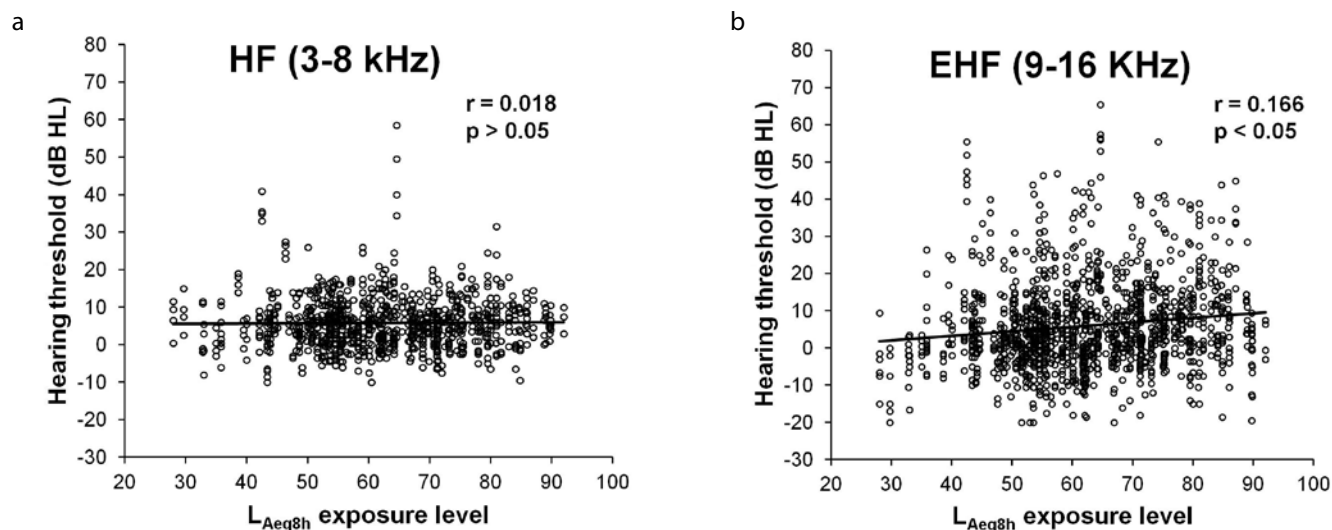


Figure 3. a, b. Overall correlation between L_{Aeq8h} ($n=228$) and averaged audiogram thresholds (in dB HL) of PLD users from both ears at HF (a) and EHF (b). (Pearson's correlation test, r =correlation coefficient)

Table 2. Relationship between L_{Aeq8h} in personal listening device users and their self-reported symptoms

Symptoms	Users with L_{Aeq8h} of <75 dBA	Users with L_{Aeq8h} of ≥ 75 dBA	p value ^a
Tinnitus			
Yes	35	23	
No	147	23	
	$\chi^2=18.328$	df=1	<0.0001
Difficulty hearing others			
Yes	45	20	
No	137	26	
	$\chi^2=6.336$	df=1	<0.05
Ear pain			
Yes	73	21	
No	109	25	
	$\chi^2=0.466$	df=1	NS
Headache			
Yes	29	7	
No	153	39	
	$\chi^2=0.014$	df=1	NS
Neck stiffness			
Yes	30	6	
No	152	40	
	$\chi^2=0.327$	df=1	NS

^achi-square test

NS: not significant

L_{Aeq8h} =8 h/day equivalent exposure level

While most PLD users appeared to be listening at L_{Aeq8h} of <75 dBA for which there is little-known risk of NIHL, approximately 20% of the subjects exceeded L_{Aeq8h} of 75 dBA, which carries a possible risk of hearing damage [6]. These PLD users reported a higher incidence of tinnitus and difficulty in hearing others immediately after using

Table 3. Pearson's correlation test between L_{Aeq8h} and average audiogram thresholds of users from both ears ($n=282$)

Frequency (kHz)	r	p value
3	-0.026	0.700
4	-0.078	0.244
6	0.020	0.761
8	0.106	0.109
9	0.122	0.066
10	0.110	0.097
11.2	0.156	0.018*
12.5	0.170	0.010*
14	0.175	0.008**
16	0.113	0.089

* $p<0.05$, ** $p<0.01$

r: correlation coefficient

PLDs compared with the non-risk group (L_{Aeq8h} <75 dBA). Although these symptoms are suggestive of exposure to hazardous music levels, the evaluation of the hearing of subjects showed that the hearing thresholds of PLD users at risk were comparable with those of non-users at 3–6 kHz test frequencies, which is the frequency region usually affected in cases of NIHL. Clear signs of hearing losses at these frequencies were not detected even in high-risk users with L_{Aeq8h} of ≥ 85 dBA. These findings are consistent with results reported by other studies [8, 11, 12, 14-16].

Compared with non-users, PLD users with L_{Aeq8h} of ≥ 75 dBA, however, did show poorer mean hearing thresholds at four EHF test frequencies. The changes at the high-frequency hearing thresholds in users with L_{Aeq8h} of ≥ 75 dBA were more apparent when their duration of PLD usage was taken into account. Compared with the non-users, audiogram thresholds of users with L_{Aeq8h} of ≥ 75 dBA and who used the devices for ≥ 4 years were significantly higher at 8 kHz and at five out of the six EHF test frequencies with approximately 4–10 dB differences in

the mean thresholds between both groups. In addition, the hearing thresholds of PLD users at EHF had a weak but significant correlation with the music exposure levels of the subjects, particularly at 11.2, 12.5, and 14 kHz. Taken together, these findings suggest that while PLD users do not show any clear clinical signs of NIHL at conventional audiogram test frequencies (<8 kHz), unsafe usage of PLDs may lead to subtle early effects on the hearing of subjects at EHF.

The conclusion of the present study is also supported by results reported elsewhere^[8, 11, 12]. An earlier study that involved a smaller group of young adults showed that PLD users have significantly higher hearing thresholds at many EHF (9–16 kHz) compared with those of age- and sex-matched non-users^[11]. Another study among high school students reported a significant correlation of the hearing thresholds of PLD users and their L_{Aeq8h} at two EHF (11.2 and 14 kHz)^[12]. Finally, a recent study that retrospectively analyzed audiogram thresholds from their laboratory database showed that subjects who reported the usage of PLDs for >5 years show significantly higher EHF thresholds (10–16 kHz) than those who used PLDs for shorter durations^[8].

How significant are these early effects in the cochlea at EHF due to music exposure from PLDs? For most individuals, the deterioration of hearing thresholds at very high frequencies will likely go unnoticed as these frequencies are not involved in day-to-day listening. However, the deterioration of hearing thresholds at EHF may represent an early warning sign of an apparent NIHL^[22, 23]. NIHL is an accumulative process, and it is possible for the early effects at EHF in these subjects to progress into a more severe hearing loss that extends to lower frequencies after many years of music exposure^[8]. In addition, subtle hearing damage from excessive music exposures could also have an additive effect on age-related hearing loss^[24] and may contribute to the development of permanent tinnitus or hyperacusis in the later part of one's life^[25].

Future follow-up studies should be conducted to ascertain the long-term effects of these devices. In addition, it is necessary to intervene and educate young users at the earliest possible time about long-term hearing risks related to the unsafe use of their PLDs.

Ethics Committee Approval: Ethics approval was received from the University of Malaya Medical Ethics Committee (Ref No: 714.10).

Informed Consent: Written informed consent has been obtained from all participants.

Peer-review: Externally peer-reviewed.

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