Research Article

Duration-Dependent Changes in Extended High-Frequency Audiometry and Distortion Product Otoacoustic Emissions for Moderate-Level Personal Listening Device Exposures

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Short running title: Duration-Dependent Changes in Extended…

Highlights:

- Prolonged PLD use elevates EHF thresholds at 14–16 kHz in the ear of exposure
- DPOAE amplitudes show limited sensitivity to early cochlear alterations

ABSTRACT

Background and Aim: Excessive sound exposure can damage the auditory system and, if left undetected, can progress to permanent noise-induced hearing loss. Extended High-Frequency Audiometry (EHFA) and Distortion Product Otoacoustic Emissions (DPOAEs) can detect subtle cochlear changes earlier than conventional audiological measures. This study examined the effect of short-term Personal Listening Device (PLD) use duration on hearing sensitivity using EHFA and DPOAEs.

Methods: One hundred female college students (18–25 years) were grouped based on daily PLD use into 5 categories (1–2, 2–3, 3–4, 4–5, and 5–6 hours). Participants had no history of otological disorders or industrial

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noise exposure. EHFA and DPOAE assessments were performed. Exposure group differences were analyzed using the Kruskal–Wallis test with post hoc comparisons.
Results: PLD use duration significantly affected extended high-frequency thresholds and DPOAE amplitudes. Post hoc analysis showed threshold elevations of 16–40 dB HL at 9–16 kHz in the right ear after 1–2 hours of daily use and 16–25 dB HL at 8–16 kHz in the left ear after 4–5 hours (medium-to-large effect sizes). DPOAE amplitudes differed across durations from 356–5645 Hz (right ear) and 498–5645 Hz (left ear), with a few high-frequency reductions of <6 dB SPL after 3–4 hours of exposure.
Conclusion: Prolonged PLD use adversely affects extended high-frequency hearing sensitivity, whereas DPOAEs show limited sensitivity to early cochlear alterations. EHFA may be a valuable tool for detecting early recreational noise-induced auditory changes.
Keywords: Extended high-frequency audiometry, distortion product otoacoustic emission, earphones

Introduction

The World Health Organization estimates that by 2050, approximately 2.5 billion people worldwide, nearly one in four, will experience some degree of hearing loss [1, 2]. Hearing loss can range from mild to profound in severity. It is a multifactorial condition, with major contributing factors including congenital hearing loss, age-related hearing loss, Noise-Induced Hearing Loss (NIHL), chronic ear infections, and exposure to ototoxic medications [2]. Many of the adverse consequences associated with hearing loss can be reduced through timely identification and appropriate intervention [2].

Among the various sound sources encountered in daily life, the use of Personal Listening Devices (PLDs) has emerged in recent years as a significant contributor to auditory system damage [3]. PLDs, such as Headphones and Bluetooth devices, are becoming increasingly popular among adolescents due to their portability, excellent sound quality, and greater storage capacity, leading to increased use and potentially affecting auditory skills [4]. An increasing number of young individuals frequently use earphones, often with limited awareness of their potential harmful effects. Previous research has investigated several factors, such as listening intensity, duration of use, and types of earphones, to evaluate their impact on hearing health [5]. Exposure to loud sounds, typically exceeding 85 dB, can result in permanent hearing loss [6]. Moreover, prolonged exposure to moderate sound levels (approximately 70 dB SPL) [7] has also been shown to contribute to hearing disability [8].

A recent systematic review and meta-analysis by You et al. [9] indicated that, in addition to hearing impairment, use of PLDs has been associated with other auditory symptoms, including tinnitus, hyperacusis, and loudness recruitment [10]. An earlier study has reported the effects of cellphone radiation on auditory function [11]. Another study suggested that prolonged cell phone use and exposure to emissions from mobile phones and base stations are associated with adverse effects, including sleep disturbances, attentional problems, headaches, irritability, dizziness, hypertension, and other mental health–related disorders [12].

Previous research has documented the effects of PLD use on behavioral hearing assessments, such as pure-tone audiometry, reporting poorer thresholds, particularly at 4 kHz, among PLD users compared with non-users, indicating a risk of NIHL [13]. Beyond pure-tone audiometry, objective measures have also demonstrated the impact of PLD use on auditory function. Otoacoustic Emissions (OAEs), including Transient Evoked Otoacoustic Emissions (TEOAE) and Distortion Product Otoacoustic Emissions (DPOAEs), are sensitive to detecting the early stages of NIHL in PLD users [14]. Specifically, reductions in OAE amplitudes have been observed in individuals who frequently use PLDs [5, 14]. A recent auditory brainstem response study reported a higher wave V/I amplitude ratio in PLD users than in non-users. It was suggested that auditory brainstem responses with ipsilateral masking may serve as an objective measure of auditory brainstem pathway dysfunction in PLD users [15]. However, the testing can be time-consuming in clinical settings; therefore, otoacoustic emissions may be a more practical objective assessment tool.

Further, evidence suggests that early NIHL associated with PLD use may progress to permanent hearing loss if left undetected [16]. The existing literature reveals several inconsistencies and gaps in findings from Extended High-Frequency Audiometry (EHFA) and DPOAE regarding PLD-induced NIHL. While Elmazoska et al. [17] reported no permanent changes in extended high-frequency thresholds or DPOAEs after recreational noise exposure, Sulaiman et al. [18] have reported elevated thresholds (9–16 kHz) and reduced OAE amplitudes in PLD users.

While high-frequency audiometry may be considered sensitive for detecting early NIHL in younger individuals, evidence for OAE measures remains mixed. A recent study suggested that conventional audiometry may remain

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normal, with early changes detectable only at ultra-high frequencies (18–20 kHz) or as a reduced DPOAE signal-to-noise ratio [19]. Importantly, most reported effects are associated with long-term exposure (>4–5 years) and higher listening levels [20], leaving uncertainty about early changes at shorter exposure durations. Dillard et al. [21] estimated that 23.81% of individuals aged 12–34 engage in unsafe PLD listening, emphasizing the need for safe listening policies. Recent research has highlighted the role of EHFA and OAE amplitudes in detecting early hearing changes associated with PLD use, with these changes influenced by exposure intensity and duration. The present study examines the early auditory effects of short-term, moderate-level PLD use in adolescents using EHFA and DPOAEs, while addressing inconsistencies in previous findings by grouping participants by daily listening duration. To date, no studies have systematically evaluated the short-term effects of varying exposure durations using sensitive measures such as EHFA and DPOAEs across different frequencies. The study aimed to examine early auditory changes at extended high frequencies and assess the utility of DPOAEs in detecting subtle hearing changes following moderate-level PLD exposure of relatively shorter duration. Thus, the present study aimed to evaluate the impact of PLD usage duration on hearing using EHFA and DPOAE in young adults.

Methods

Study design

The study employed a cross-sectional between-group design using purposive sampling based on PLD exposure durations and convenience sampling based on participant availability. The independent categorical variable of the study was exposure durations (1-2, 2-3, 3-4, 4-5, and 5-6 hours). The study's dependent variables were EHFA thresholds and DPOAE amplitudes.

Participants

A total of 100 young adult females aged 18–25 years with mean (SD), 20.08±1.49 participated in the study. PLD users were included based on the following criteria: 1) use of earphones for a minimum duration of one and a maximum of two to three years, and 2) self-reported music listening for a minimum of one hour per day at around 60% of the device's maximum volume corresponding to 70–75 dB SPL across earphones (measured on Sound Level Meter). Although higher outputs were possible at full volume, exposure durations were assessed at 60% of maximum volume, which was the volume most participants used. All participants reported using in-the-ear earphones bilaterally; however, one earphone was occasionally removed to improve perception of surrounding speech and environmental sounds. The preferred ear for earphone use was the right ear. All participants were college students and reported no prior exposure to loud occupational noise. Additionally, the subjects had no history of otological or neurological disorders or other significant medical conditions. Table 1 provides basic demographic information and the number of participants in each exposure duration group.

Procedure

Prior to the audiological evaluation, a detailed case history was obtained from each participant to rule out any history or complaint of hearing loss or otological conditions. Individuals with a history of significant otological disorders, a family history of hearing loss, or other relevant medical conditions were excluded from the study. Participants initially underwent otoscopic examination to rule out abnormalities of the outer ear, ear canal, and tympanic membrane, followed by pure-tone audiometry and immittance evaluation. All assessments were conducted in a randomized order for the right and left ears. The testing room was acoustically treated, and all testing procedures followed a standard methodology, with permissible noise levels in accordance with ANSI/ASA S3.1-199 (R2013) [22].

Google Forms were developed to assess patterns of PLD use, including duration and purpose of earphone use, years of use, preferred listening volume, and types of music listened to. The questionnaire is provided in the Appendix A for readers' reference. In addition, the Noise Exposure Questionnaire-based one-minute noise screen [23] and the Edinburgh Handedness Inventory–Short Form [24] were administered. Responses indicated that participants' noise exposure was primarily limited to listening to music through PLDs. All participants obtained one-minute noise screen scores below 4, indicating a low risk of noise-induced hearing loss, and laterality quotients ranging from 61 to 100, consistent with right-handedness on the handedness questionnaire.

Air- and bone-conduction thresholds were assessed bilaterally using calibrated diagnostic audiometers (Inventis Piano, Padova, Italy) with TDH-39 headphones and a Radioear B-71 bone vibrator. Middle-ear function and acoustic reflexes were evaluated using an Inventis Clarinet immittance audiometer. Tympanometry was

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performed using a 226-Hz probe tone, and ipsilateral and contralateral acoustic reflex thresholds were obtained at 500 Hz, 1, 2, and 4 kHz using a 5-dB ascending procedure at peak tympanometric pressure. A compliance change of 0.02– 0.03 ml was considered indicative of reflex presence. All participants demonstrated hearing sensitivity within normal limits at conventional audiometric frequencies, with a pure-tone average (average thresholds at 500 Hz, 1, 2, and 4 KHz) within 15 dB HL in both ears. All of them had either an 'A' or 'As' type tympanogram with present reflexes in both ears (at 80-90 dB SPL).

In addition, two audiological procedures were conducted to assess the effect of PLD use on cochlear hearing sensitivity: EHFA and DPOAEs. EHFA was evaluated from 8 kHz to 16 kHz using a Calibrated Piano Inventis audiometer coupled with Sennheiser HDA-200 headphones at standard permissible ambient noise levels. Thresholds for both pure-tone and EHFA were obtained using the modified Hughson–Westlake procedure [25]. The HDA-200 headphones were calibrated according to the reference equivalent threshold sound pressure levels specified in ISO 389-8 for pure tones presented through circumaural earphones [26]. Extended high-frequency thresholds (at 8, 9, 10, 11.2, 12.5, 14, and 16 kHz) were measured in dB HL using these calibration standards, and the obtained thresholds were interpreted with reference to recently published normative data for young adults [27].

A calibrated Intelligent Hearing Systems Duet (IHS, Miami, FL) was used to record and analyze the DPOAEs. In the present study, a reproducibility of 95% or higher was required for all DPOAE recordings. DPOAEs were elicited with two primary tones, f1 (lower frequency) and f2 (higher frequency), presented at L1=65 dB SPL and L2=55 dB SPL. In humans, the most prominent distortion product typically occurs at 2f1–f2, with an f2/f1 ratio of 1.22. DPOAE measurements were obtained in both ears at 9 frequencies (356, 498, 703, 996, 1416, 1992, 2827, 3994, and 5645 Hz).

Statistical analysis

Statistical analysis was performed using SPSS version 26, employing descriptive and inferential statistics. Normality assessment using the Shapiro –Wilk test revealed that EHFA and DPOAE data were not normally distributed across all frequencies in the five exposure-duration groups ($p < 0.05$). Accordingly, the non-parametric Kruskal–Wallis test was applied to evaluate between-group differences in exposure duration at each frequency for EHFA thresholds and for DPOAE amplitudes in both ears. Significant differences between the duration groups were further explored using Mann–Whitney U tests for post hoc pairwise comparisons.

Results

Figure 1 shows the medians and interquartile ranges of Extended High Frequency (EHF) threshold values across different exposure durations for the right (A) and left ears (B). Figure 2 indicates the median and interquartile ranges of DPOAE amplitudes across different exposure durations for the right (A) and left ears (B), respectively.

Extended high-frequency audiometry

There was a statistically significant effect of exposure duration on EHF thresholds in the right ear at only three frequencies ($p<0.05$). However, in the left ear, significant differences in exposure duration were observed across a wider frequency range ($p<0.05$). Post hoc pairwise comparisons revealed significant differences in EHF thresholds across several exposure-duration groups in both ears. Specifically, hearing thresholds increased progressively with exposure duration, with significant elevations evident from 2–3 hours in the right ear and at 4–5 hours in the left ear ($r>0.30$, medium-to-large effect size).

The right ear showed greater vulnerability to music exposure than the left ear, with more pronounced elevations in EHF thresholds. As exposure duration increased, hearing thresholds in the right ear, initially elevated to 16-40 dB HL only at 14 and 16 kHz, extended to include 12.5 kHz. In contrast, the left ear exhibited normal hearing thresholds at shorter exposure durations, with threshold elevations of 16–25 dB HL emerging only at 14 and 16 kHz during longer exposure durations. Notably, in the right ear, thresholds of 16–25 dB HL were observed at 14 and 16 kHz after 1–2 hours of exposure, these increased to 26–40 dB HL with longer exposure durations. Conversely, the left ear showed threshold elevations of 16–25 dB HL only after 4–5 hours of exposure, indicating a later onset of hearing changes than in the right ear.

Overall, these findings suggest that prolonged music exposure is associated with elevated EHF thresholds, even among individuals who exhibit clinically normal hearing at conventional audiometric frequencies. Specifically, hearing thresholds increased progressively with longer exposure durations, with significant elevations observed

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after 1-2 hours in the right ear and at 4–5 hours in the left ear. Results of significant differences in EHF thresholds across exposure durations and frequencies for the right and left ears are shown in Table 2.

Distortion product otoacoustic emissions

DPOAE amplitudes differed significantly across exposure groups in the right ear for a wider frequency range compared to the left ear ($p<0.05$).

Post hoc pairwise comparisons further confirmed significant differences in DPOAE amplitudes across exposure durations for both ears ($p < 0.05$). However, no distinct pattern of change in DPOAE amplitudes was observed across the different exposure durations in either ear. Reduced DPOAE amplitudes (<6 dB SPL) were observed at a few higher frequencies in both the right and left ears, predominantly from exposure durations of 3–4 hours onward. The corresponding results of the Mann-Whitney U test are presented in Table 3 for the right and left ears.

Discussion

The present study aimed to investigate the effects of varying durations of short-term music exposure from PLDs on EHFA and DPOAE in young adults. Elevated hearing thresholds were observed only at the highest frequencies tested, viz, 14 and 16 kHz, in the right ear, even after one to two hours of exposure. In contrast, in the left ear, measurable hearing loss was evident only after gour to five hours of exposure. With increasing exposure duration, threshold elevations also extended to relatively lower frequencies (12.5 kHz) in the right ear. Overall, the EHFA findings indicated greater susceptibility in the right ear than in the left.

No distinct or consistent pattern in DPOAE amplitudes was observed across exposure durations at different test frequencies. These findings suggest that although prolonged music exposure may influence DPOAE amplitudes and outer hair cell function, these changes may not be readily apparent or well established during the early stages of exposure. The results of the current study are discussed under two headings.

Extended high-frequency audiometry

The higher prevalence of hearing loss [1, 2], even among individuals with shorter exposure durations, may be attributed to variations in listening behaviors and increased reliance on earphones for both academic and recreational activities, particularly since the COVID-19 lockdown period [28]. Findings from the present study, based on high-frequency audiometry, are consistent with extensive literature demonstrating significantly elevated high-frequency thresholds among PLD users with exposure durations of three to five hours [29]. Although limited studies have specifically examined the effect of PLD use duration on high-frequency audiometry, the results align with previous reports of increased high-frequency thresholds among PLD users. Consistent with earlier evidence of threshold elevation at ultra-high frequencies (18 and 20 kHz) [19], the current results underscore the utility of EHFA as a sensitive tool for detecting early cochlear alterations resulting from recreational music exposure. An earlier study reported minimal hearing loss within the conventional audiometric range in 41% of PLD users, predominantly in the right ear [28]. PLD use for up to five years was associated with hearing loss in 14% of subjects within the conventional audiometric range [29]. Higher EHF thresholds were observed in individuals with exposure durations greater than five years, whereas shorter durations were rarely assessed [18].

Deterioration of thresholds in the extended high-frequency region has been proposed as an early marker of NIHL [29]. Early cochlear damage is thought to involve lesions of the outer hair cells in the basal turn of the cochlea, which encode higher-frequency sounds that are not routinely assessed by conventional audiometry [18]. Studies reporting weaker OAEs in the more-exposed ear attribute these reductions to the side of sound exposure rather than to an inherent anatomical ear asymmetry; specifically, ears subjected to higher SPLs or to closer proximity to sound sources exhibited greater EHF threshold deterioration in the more-exposed ear in our study as well [18].

Distortion product otoacoustic emissions

Changes in DPOAE amplitudes were less pronounced and did not follow a consistent pattern across frequencies and exposure durations. Although amplitude decreased across exposure durations, the reductions were not consistently maintained. Barros et al. [30] and Sulaiman et al. [18] showed that OAEs are sensitive to early cochlear changes, particularly reduced amplitudes at mid- and high frequencies. Narahari et al. [31] reported reduced high-frequency DPOAEs (>8 kHz) after short-term music exposure, while Poling et al. [32] noted that early cochlear damage may produce only subtle OAE changes at conventional frequencies. In contrast, the inclusion of higher-frequency DPOAE measurements provides greater clinical utility. The inclusion of fine-

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structure DPOAEs may offer limited use. Overall, OAEs are sensitive markers of early cochlear changes, though findings may vary across conditions.

Earlier reports have reported reduced DPOAE amplitudes in PLD users compared to non-PLD users [18]. Our study did not show a duration-dependent deterioration in DPAOE amplitudes, consistent with studies reporting no significant changes in OAE amplitudes associated with PLD use [33]. Narahari et al. [31] reported reduced DPOAE amplitudes in the 9–12 kHz range following short-term music exposure, suggesting early indicators of NIHL. In contrast, Trzaskowski et al. [33] found no significant changes in OAEs after 30 minutes of noise exposure at 86.8 dBA, highlighting the role of exposure characteristics. In the earlier study [31], short-term music exposure did not alter low-frequency DPOAE amplitudes (2–8 kHz), whereas high-frequency DPOAE amplitudes showed a significant reduction. Our study also shows that short-term music exposure predominantly affects higher frequencies, consistent with earlier research [31].

Evidence from Kumar et al. [34] suggests that short-term music exposure minimally affects low-frequency DPOAEs (2–8 kHz) but significantly reduces higher-frequency distortion products beyond conventional audiometric ranges. Sliwinska-Kowalska and Davis [35] identified personal music players as a significant source of recreational noise exposure, estimating that 5–10% of young users may develop hearing loss after five or more years of exposure. However, short-term music exposure affects the fine spectral details of the high-frequency DP-gram, suggesting that the high-frequency DP-gram is a sensitive measure of music-induced changes in hearing sensitivity [31]. As this study evaluated only short-term exposure (less than 2–3 years), longer use may pose a greater risk of hearing loss, especially given the high sound pressure levels preferred by PLD users. The alterations in EHFA and OAEs may occur before the onset of music-induced hearing loss [10]. These findings are supported by animal studies demonstrating synaptic damage between inner hair cells and cochlear nerve fibers in the absence of clinically detectable hearing loss [15]. Collectively, these results emphasize the utility of EHFA and high-frequency DPOAE analysis for early detection of music-induced cochlear changes. At a ~60% listening level (≈70–75 dB SPL), individual PLD use habits, such as preferential ear use, may explain interaural differences noted in our findings.

Prior studies report that OAEs are sensitive to early cochlear changes [15], and Sulaiman et al. [18] observed reduced OAE amplitudes and reproducibility at mid- to high frequencies. However, Poling et al. [32] noted that early damage may be too subtle to produce consistent DPOAE changes. Accordingly, our study showed an inconsistent DPOAE pattern, suggesting that early cochlear alterations in young PLD users may not always be uniformly detected, reflecting the gradual and variable nature of noise-induced damage and the need for preventive listening strategies in young individuals.

The study is limited by its sample size and cross-sectional between-subject design, highlighting the need for longitudinal cohort studies to examine hearing changes over time. Only female participants were recruited to facilitate enrollment and ensure a homogeneous sample across exposure durations, thereby minimizing potential gender differences. However, this limits the generalizability of the findings to the male counterparts.

Including EHFA, high-frequency DPOAEs, and DPOAE input–output functions to assess adolescent PLD users in future studies may improve the early detection of cochlear dysfunction and facilitate the identification and prevention of permanent music-induced hearing loss by determining critical exposure doses and durations. Noise dosimetry was not feasible in the study; exposure was classified using a self-reported questionnaire and a one-minute noise screening questionnaire. Future studies may use app-based dosimeters to quantify the noise exposure. Addressing the over-use of PLDs requires behavior-based interventions that encourage safe listening, including technology-driven nudges and peer-led initiatives. Increasing awareness and implementing targeted strategies are essential to prevent hearing loss among PLD users.

Conclusion

The findings indicate that prolonged Personal Listening Device (PLD) use is associated with reduced sensitivity in the extended high-frequency range. In the early stages, these effects may not be evident on pure tone thresholds and Distortion Product Otoacoustic Emissions (DPOAE) amplitudes due to the absence of marked cochlear changes detectable by these measures. Therefore, the combined use of extended high-frequency audiometry and high-frequency DPOAE may facilitate the detection of subtle underlying cochlear changes.

Ethical Considerations

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Compliance with ethical guidelines

In the current study, all testing procedures were conducted using a non-invasive technique and adhered to the conditions set by the institutional ethics committee. The institutional ethical approval committee approved the current study, Holy Cross College Ethical Committee (HCC/ERB/EC/PB-08/2023-2024). The test procedures were clearly explained to the participants before testing, and written informed consent was obtained from all participants prior to their involvement.

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Authors' contributions

KS, SN: Were involved in the study design, data collection, analysis of the results, interpretation, and writing the manuscript; KK: Was involved in study design, data collection, analysis of the results, interpretation, and writing the manuscript; BK, SR, and PP: Were involved in study design, analysis of the results, and writing the manuscript.

Conflict of interest

the content and writing of the paper.

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References

1. World Health Organization. 1 in 4 people projected to have hearing problems by 2050. Geneva: World Health Organization;. 2021. Available from: https://www.who.int/news/item/02-03-2021-who-1-in-4-people-projected-to-have-hearing-problems-by-2050
2. World Health Organization. Deafness and hearing loss. World Health Organization. Geneva: World Health Organization;. 2025. Available from: https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss
3. Chen F, Xue H, Wang M, Cai Z, Zhu S. Hearing Care: Safe Listening Method and System for Personal Listening Devices. Int J Environ Res Public Health. 2023;20(3):2161. [DOI:10.3390/ijerph20032161]
4. Sharma S, Shah P, Patel D, Tadvi P, Sharma P. Personal Listening Devices (PLD): A Boon or Bane? Perceptions among the Urban Indian Population. Indian J Otolaryngol Head Neck Surg. 2025;77:3541-7.
5. Jiang W, Zhao F, Guderley N, Manchaiah V. Daily music exposure dose and hearing problems using personal listening devices in adolescents and young adults: A systematic review. Int J Audiol. 2016;55(4):197-205. [DOI:10.3109/14992027.2015.1122237]
6. How Loud is Too Loud? National Institute on Deafness and other Communication Disorders [Internet]. 2025 [cited 2025 April 28]. Available from: https://www.nidcd.nih.gov/health/how-loud-too-loud
7. Pienkowski M, Munguia R, Eggermont JJ. Effects of passive, moderate-level sound exposure on the mature auditory cortex: spectral edges, spectrotemporal density, and real-world noise. Hear Res. 2013;296:121-30. [DOI:10.1016/j.heares.2012.11.006]
8. Fligor BJ, Cox LC. Output levels of commercially available portable compact disc players and the potential risk to hearing. Ear Hear. 2004;25(6):513-27. [DOI:10.1097/00003446-200412000-00001]
9. You S, Kong TH, Han W. The Effects of Short-Term and Long-term Hearing Changes on Music Exposure: A Systematic Review and Meta-Analysis. Int J Environ Res Public Health. 2020;17(6):2091. [DOI:10.3390/ijerph17062091]
10. AlQahtani AS, Alshammari AN, Khalifah EM, Alnabri AA, Aldarwish HA, Alshammari KF, et al. Awareness about the relation of noise induced hearing loss and use of headphones at Hail region. Ann Med Surg (Lond). 2021;73:103113. [DOI:10.1016/j.amsu.2021.103113]
11. Dhami AK. Studies on cellphone radiation exposure inside a car and near a bluetooth device. Int J Environ Res. 2015;9(3):977-80. [DOI:10.22059/IJER.2015.985]
12. Jayaraju N, Kumar MP, Sreenivasulu G, Prasad TL, Lakshmanna B, Nagalaksmi K, et al. Mobile phone and base stations radiation and its effects on human health and environment: A review. Sustainable Technology and Entrepreneurship. 2023;2(2):100031. [DOI:10.1016/j.stae.2022.100031]
13. Gajendran A, Devi Rajendiran G, Prateep A, Satindra H, Rajendran R. Prevalence of High Frequency Noise-Induced Hearing Loss Among Medical Students Using Personalized Listening Devices. J Clin Med. 2024;14(1):49. [DOI:10.3390/jcm14010049]
14. LePage EL, Murray NM. Latent cochlear damage in personal stereo users: a study based on click-evoked otoacoustic emissions. Med J Aust. 1998;169(11-12):588-92. [DOI:10.5694/j.1326-5377.1998.tb123426.x]
15. Divya AP, Prakash P, Konadath S, Hussain RO, Narne VK, Ravi SK. Electrophysiological Evidence of Early Auditory Dysfunction in Personal Listening Device Users: Insights from ABR with Ipsilateral Masking. Diagnostics (Basel). 2025;15(21):2672. [DOI:10.3390/diagnostics15212672]
16. Shah P, Ms V, Raja K. Awareness About Noise Induced Hearing Loss and the Use of Unsafe Listening Practices Among Medical Students. Indian J Otolaryngol Head Neck Surg. 2024;76(4):3458-64. [DOI:10.1007/s12070-024-04727-3]
17. Elmazoska I, Mäki-Torkko E, Granberg S, Widén S. Associations Between Recreational Noise Exposure and Hearing Function in Adolescents and Young Adults: A Systematic Review. J Speech Lang Hear Res. 2024;67(2):688-710. [DOI:10.1044/2023_JSLHR-23-00397]

18. Sulaiman AH, Husain R, Seluakumaran K. Evaluation of early hearing damage in personal listening device users using extended high-frequency audiometry and otoacoustic emissions. Eur Arch Otorhinolaryngol. 2014;271(6):1463-70. [DOI:10.1007/s00405-013-2612-z]
19. Alkharabsheh A, Alshurafa S, Alhanbali S, Garadat S. Personal Listening device (PLD) usage among University Students and their audiometric profile during the shift to online learning post COVID-19. PLoS One. 2025;20(3):e0319665. [DOI:10.1371/journal.pone.0319665]
20. Škerková M, Mrázková E, Kovalová M, Kocurková L, Gottfriedová N. Extended high-frequency audiometry for detecting early hearing effects of personal listening devices: A narrative review. Eur Ann Otorhinolaryngol Head Neck Dis. 2026;143(3):195-200. [DOI:10.1016/j.anorl.2026.01.011]
21. Dillard LK, Arunda MO, Lopez-Perez L, Martinez RX, Jiménez L, Chadha S. Prevalence and global estimates of unsafe listening practices in adolescents and young adults: a systematic review and meta-analysis. BMJ Glob Health. 2022;7(11):e010501. [DOI:10.1136/bmjgh-2022-010501]
22. American National Standards Institute. Maximum permissible ambient noise for audiometric test rooms (ANSI S3.1-1999). New York: American National Standards Institute; 1999.
23. Johnson TA, Cooper S, Stamper GC, Chertoff M. Noise Exposure Questionnaire: A Tool for Quantifying Annual Noise Exposure. J Am Acad Audiol. 2017;28(1):14-35. [DOI:10.3766/jaaa.15070]
24. Veale JF. Edinburgh Handedness Inventory - Short Form: a revised version based on confirmatory factor analysis. Laterality. 2014;19(2):164-77. [DOI:10.1080/1357650X.2013.783045]
25. Carhart R, Jerger JF. Preferred method for clinical determination of pure-tone thresholds. Journal of Speech And Hearing Disorders. 1959;24(4):330-45. [DOI:10.1044/jshd.2404.330]
26. ISO 389-8:2004(en); Acoustics—Reference Zero for the Calibration of Audiometric Equipment—Part 8: Reference Equivalent Threshold Sound Pressure Levels for Pure Tones and Circumaural Earphones. ISO: Geneva, Switzerland, 2004. Available online: https://www.iso.org/obp/ui/#iso:std:iso:389:-8:ed-1:v1:en (accessed on 12 April 2023).
27. Luengrungrus K, Thanawirattananit P, Teeramatwanich W. Normative Data of Extended High Frequency Audiometry in Normal Hearing Subjects with Different Aged Groups. Audiol Res. 2024;14(6):1084-92. [DOI:10.3390/audiolres14060089]
28. Sharma Y, Mishra G, Mahida DA. Effect on hearing due to amplified music exposure. An International Journal of Otorhinolaryngology Clinics. 2022;14(1):22-5.
29. Peng JH, Tao ZZ, Huang ZW. Risk of damage to hearing from personal listening devices in young adults. J Otolaryngol. 2007;36(3):181-5.
30. Barros SM, Frota S, Atherino CC, Osterne F. The efficiency of otoacoustic emissions and pure-tone audiometry in the detection of temporary auditory changes after exposure to high sound pressure levels. Braz J Otorhinolaryngol. 2007;73(5):592-8. [DOI:10.1016/s1808-8694(15)30118-x]
31. Narahari PG, Bhat J, Nambi A, Arora A. Impact of usage of personal music systems on oto-acoustic emissions among medical students. Noise Health. 2017;19(90):222-6. [DOI:10.4103/nah.NAH_75_16]
32. Poling GL, Siegel JH, Lee J, Dhar S. The influence of self-reported noise exposure on $2f_1$-f_2 distortion product otoacoustic emission level, fine structure, and components in a normal-hearing population. J Acoust Soc Am. 2022;151(4):2391. [DOI:10.1121/10.0010105]
33. Trzaskowski B, Jędrzejczak WW, Piłka E, Cieślicka M, Skarżyński H. Otoacoustic emissions before and after listening to music on a personal player. Med Sci Monit. 2014;20:1426-31. [DOI:10.12659/MSM.890747]
34. Kumar A, Mathew K, Alexander SA, Kiran C. Output sound pressure levels of personal music systems and their effect on hearing. Noise Health. 2009;11(44):132-40. [DOI:10.4103/1463-1741.53357]
35. Sliwinska-Kowalska M, Davis A. Noise-induced hearing loss. Noise and Health. 2012;14(61):274-80. [DOI:10.4103/1463-1741.104893]

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Table 1. Demographic information showing the number of participants along with their mean ages (standard deviation) in the different exposure duration groups

Exposure groups (in hours)	Number	Age (in years), mean (SD)
1 to 2	23	20.00(1.34)
2 to 3	19	20.21(1.75)
3 to 4	20	20.15(1.34)
4 to 5	20	20.00(1.65)
5 to 6	18	20.06(1.51)

Table 2. Results of Mann-Whitney U-tests comparing different exposure durations on high frequency thresholds for the right and left ears

Ear tested	Exposure groups (in hours)	Frequency (kHz)	|Z|*	Corrected p†	Effect size (Cohen's r)‡
Right	**1 to 2 and 2 to 3**	16	2.81	0.05§	0.43
	1 to 2 and 3 to 4	9	2.86	0.04§	0.44
	1 to 2 and 4 to 5	9	3.51	<0.01¶	0.54
	2 to 3 and 3 to 4	11.2	2.84	0.05§	0.46
	3 to 4 and 4 to 5	11.2	2.95	0.03§	0.47
Left	**1 to 2 and 3 to 4**	12.5	3.10	<0.01¶	0.47
	1 to 2 and 4 to 5	14	3.02	0.03§	0.46
	1 to 2 and 5 to 6	9	3.37	<0.01¶	0.53
		10	4.81	<0.01¶	0.75
		11.2	3.96	<0.01¶	0.62
	2 to 3 and 4 to 5	14	3.40	<0.01¶	0.53
		10	3.67	<0.01¶	0.58
		11.2	3.32	<0.01¶	0.53
	2 to 3 and 5 to 6	10	4.70	<0.01¶	0.77
		11.2	4.54	<0.01¶	0.75
		12.5	3.46	<0.01¶	0.57
	3 to 4 and 4 to 5	16	2.81	0.05§	0.46
		10	3.70	<0.01¶	0.58
		12.5	3.72	<0.01¶	0.59
	3 to 4 and 5 to 6	8	3.32	<0.01¶	0.54
		9	3.67	<0.01¶	0.60
		10	4.75	<0.01¶	0.75
		11.2	3.10	0.03§	0.50
		12.5	4.24	<0.01¶	0.69
		16	3.26	0.01¶	0.53

* test statistic, † Corrected p-value=(obtained p-value), ‡ Cohen's r=Z/√N; 0.1–<0.3-small, 0.3–<0.5-medium, and ≥0.5=large effect (Cohen, 2009), § p≤0.05, ¶ p≤0.01

Table 3. Results of Mann-Whitney U-tests comparing different exposure durations on distortion product otoacoustic emission amplitudes for the right and left ears

Ear tested	Exposure groups (in hours)	Frequency (Hz)	|Z*|	Corrected p†	Effect size (Cohen's r)‡
Right	1 to 2 and 2 to 3	703	2.85	0.04§	0.44
		996	3.02	0.03§	0.46
		3994	3.60	<0.01¶	0.55
		5645	3.18	0.01¶	0.49
	1 to 2 and 3 to 4	356	3.48	<0.01¶	0.53
		996	3.80	<0.01¶	0.58
		1416	3.33	<0.01¶	0.50
		3994	3.53	<0.01¶	0.54
		5645	3.18	0.01¶	0.49
	1 to 2 and 4 to 5	498	4.65	<0.01¶	0.71
		3994	4.12	<0.01¶	0.63
	1 to 2 and 5 to 6	3994	3.92	<0.01¶	0.61
	2 to 3 and 3 to 4	356	3.95	<0.01¶	0.63
		1416	3.62	<0.01¶	0.58
	2 to 3 and 4 to 5	498	4.16	<0.01¶	0.66
	3 to 4 and 4 to 5	356	3.38	<0.01¶	0.53
	3 to 5 and 5 to 6	356	3.43	<0.01¶	0.56
		1416	3.70	<0.01¶	0.60
	4 to 5 and 5 to 6	498	5.02	<0.01¶	0.81
Left	1 to 2 and 3 to 4	498	3.74	<0.01¶	0.57
		1992	4.26	<0.01¶	0.65
		3994	2.82	0.05§	0.43
	1 to 2 and 5 to 6	2827	3.18	0.01¶	0.50
		5645	3.21	0.01¶	0.50
	2 to 3 and 3 to 4	1992	3.60	<0.01¶	0.58
		5645	3.68	<0.01¶	0.59
	2 to 3 and 5 to 6	3994	2.85	0.04§	0.47
	3 to 4 and 4 to 5	1992	3.51	<0.01¶	0.55
		3994	3.40	<0.01¶	0.54
		5645	3.60	<0.01¶	0.57
	3 to 4 and 5 to 6	498	3.51	0.04§	0.57
		1992	4.00	<0.01¶	0.65
		2827	3.72	<0.01¶	0.60

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	3994	3.85	<0.01¶	0.62
	5645	4.89	<0.01¶	0.79

* test statistic, † Corrected p-value=(obtained p-value), ‡ Cohen's r=Z/√N; 0.1–<0.3-small, 0.3–<0.5-medium, and ≥0.5=large effect (Cohen, 2009), § p≤0.05, ¶ p≤0.01

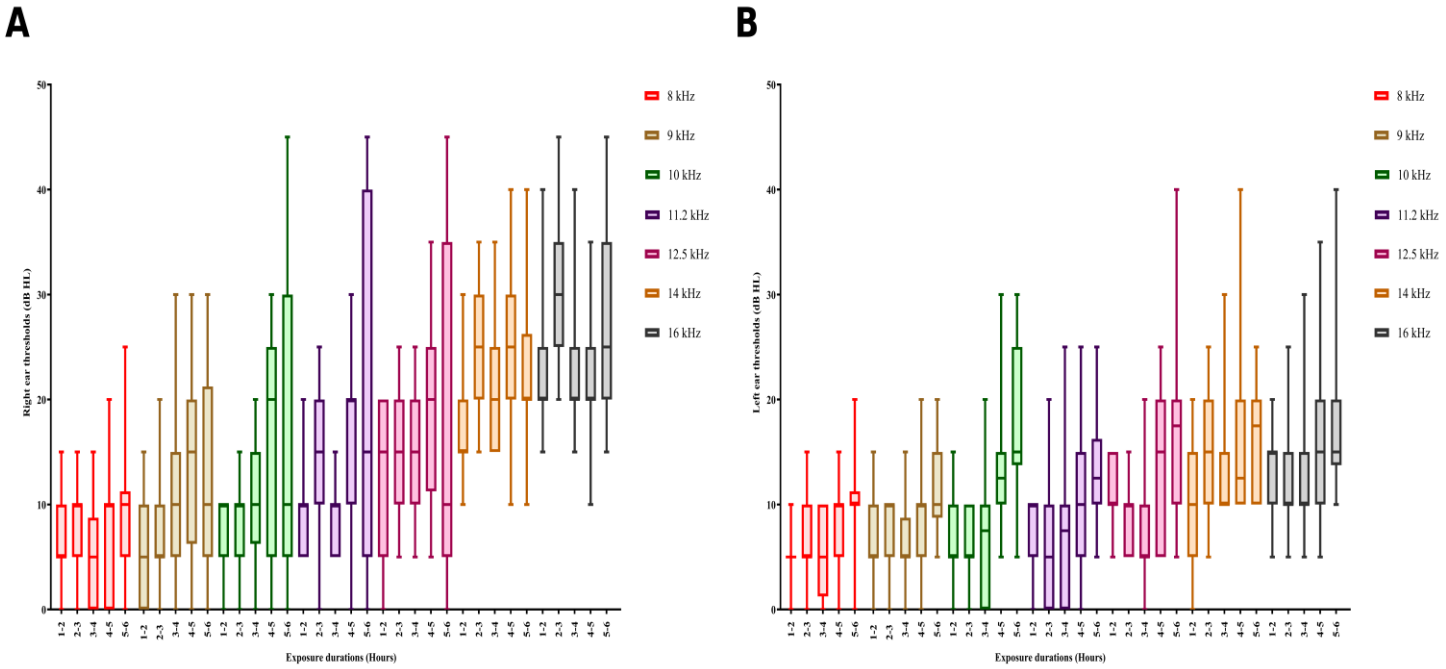


Figure 1. Panel showing the median and interquartile ranges of the extended high-frequency thresholds across different exposure durations in the right (A) and left ears (B)

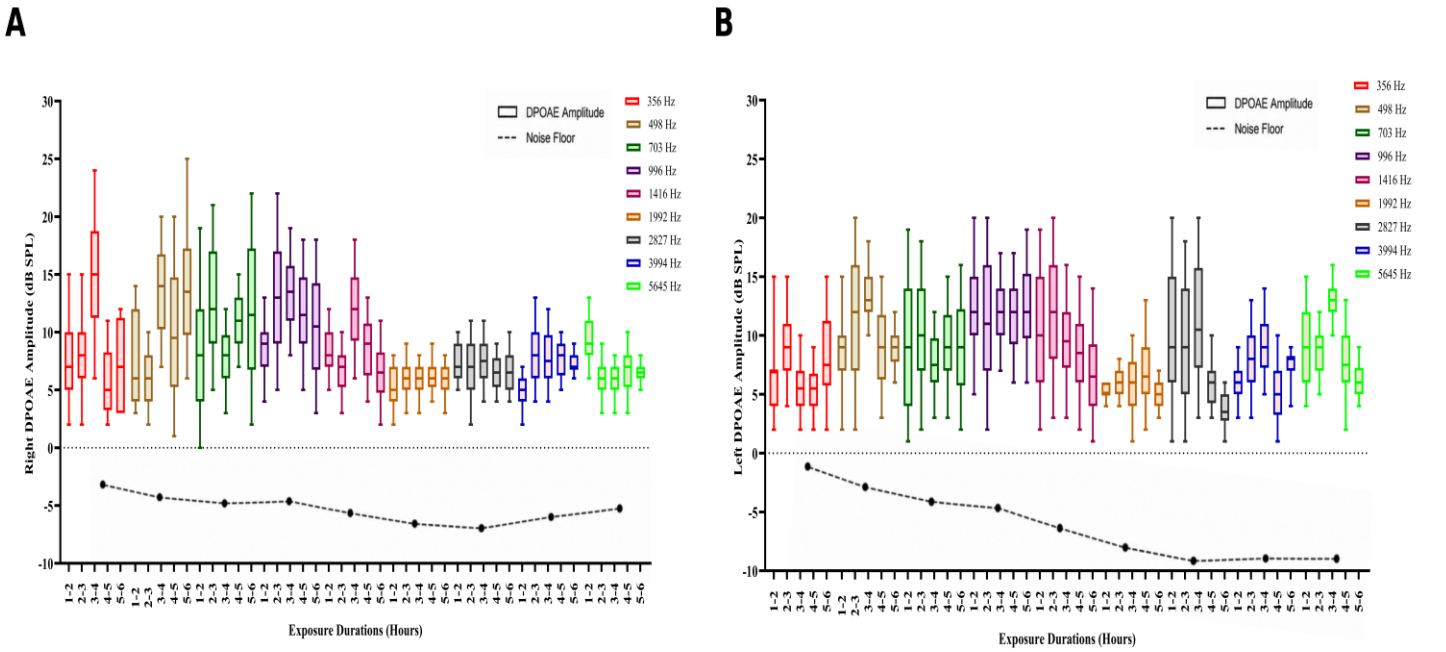


Figure 2. Panel showing the median and interquartile ranges of the distortion product otoacoustic emission amplitudes across different exposure durations in the right (A) and left ears(B)

Appendix A

QUESTIONNAIRE

A. Patient information
a. Name
b. Age
c. Any history of earphone infection/ hearing loss
B. Music exposure
a. Volume kept while using the earphones
b. How long have you been using earphones? (years)
i. Less than 1 year
ii. 1–3 years
iii. More than 3 years
c. On average, how many days per week do you use earphones?
d. On a typical day, how many hours do you use earphones?
e. What is the primary purpose of earphone use?
f. Do you increase volume in a noisy environment (Yes/No)
g. Which environment do you prefer using earphones
i. Traveling
ii. Studying
iii. Exercising
iv. Sleeping
h. Are you aware of safe volume? (Yes/No)
i. Did you feel discomfort while using earphones (Yes/No)
j. Would you be willing to change your listening habits if advised by a professional (Yes/No)
k. At what time do you mostly use earphones (Morning/Afternoon/Evening/Night)
l. How do you rate the usage of earphones on a basis?
i. Safe
ii. Moderate
iii. Excessive
m. Do you listen to earphones while:
i. Studying
ii. Playing games
iii. Watching videos
iv. Traveling
v. Before sleeping

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