The Effect of Various Patterns of Personal Listening Devices on Hearing Among University Students in Saudi Arabia

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ABSTRACT

Background: The long-term use of earphones at high volume levels is a major risk factor for noise-induced hearing loss. Aim: To compare the hearing of university students who use personal listening devices (PLDs) at extremes (upper & lower quartiles) with respect to a) Duration of use/day b) The number of years since use c) Volume level. Methods: This cross-sectional study was conducted in the Department of Physiology, College of Medicine, at Imam Abdulrahman bin Faisal University (IAU), from September 2021 to April 2022. An online survey was distributed among IAU medical students on the subjects’ patterns of earphone use. Forty participants volunteered to participate in the hearing tests: Pure Tone Audiometry (PTA), Tympanometry, and Transient Evoked Otoacoustic Emission (TEOAEs) at the ENT clinic of the King Fahd Hospital of the University (KFHU). Results: The pure tone audiometry and TEOAE showed no significant differences in the hearing thresholds/levels of participants in upper quartiles vs lower quartiles of both ears, in any of the PLD use pattern categories. However, in the TEOAE two observation were detected: a) Significantly lower amplitude in the upper quartile of the category “duration of PLD use/day” at a frequency of 1.0 kHz in the left ear (p-value 0.04) b) Significantly lower amplitude in the upper quartile of the category “volume of PLD use” at a frequency of 1.0 kHz in the left ear (p-value 0.03). Conclusion: The present findings suggest that hearing threshold/level and cochlear outer hair cells’ functions do not differ significantly in the participants belonging to the upper and lower quartiles of PLD use pattern (volume level, duration of use/day, and the number of years since use).

Keywords: Auditory threshold, Pure-Tone audiometry, hearing tests, noise-induced hearing loss.

1. BACKGROUND

Hearing loss is defined as a partial or total inability to hear. People with an average hearing threshold of 20dB HL or less are considered to have “normal” hearing and those with an average threshold of 25dB HL or more are classified as having hearing loss (1). The World Health Organization (WHO) reported that more than 1.5 billion people globally live with hearing loss and the number could rise to 2.5 billion by 2030 (2).

Loud noise is one of the major contributing factors to noise-induced hearing loss (NIHL), and employees exposed to loud noises in industrial workplaces comprise a high-risk group (3). Therefore, occupational noise is the focus of governmental noise standards and interventions (4). The maximum daily occupational noise exposure limit is set at an A-weighted equivalent continuous noise level (L Aeq ) of 85 dB over 8 hours (5).

However, there is increasing evidence that high noise exposure can occur in multiple environments beyond the workplace, including recreational settings (6). Listening to music, and videos and playing games via personal listening devices (PLDs) has become a common practice amongst the youth (7). PLDs include (headphones and earbuds), which are connected to an audio playback function (e.g., mobile phones, laptops, computers, MP3 players, and media tablets) (8).

The long-term usage of PLDs could induce hearing loss because, at higher
volume settings, the sound pressure levels (SPLs) recorded from PLDs can range from 100–139 dB HL (9-11). Based on SPLs measured from PLDs, users listening to high volume settings can easily exceed L Aeq8h noise exposure safety limits within a short period (5).

Various studies suggest that exposure to loud sounds over a longer period can lead to sensorineural deafness, which is termed noise-induced hearing loss (NIHL) (12). Continuous exposure to loud sounds over a long period can cause irreversible damage to the cochlear hair cells; by promoting oxidative stress, stimulating apoptosis, and producing strong inflammatory reactions (13). These hearing losses mostly affect the high-frequency hearing component of the basilar hair cells of the cochlea (14).

With the increasing trend of PLD usage, it is imperative to determine the effects of PLDs on the hearing of listeners. But the existing data is inconclusive and inadequate to make any conclusion. Therefore, we designed this study which tests the effect of PLD use on hearing function.

2. OBJECTIVE

The present study compared the hearing function of university students who use personal listening devices (PLDs) at extremes (upper & lower quartiles) with respect to a) duration of use per day b) the number of years since use c) and volume level, using the following hearing tests:
- Pure tone audiometry
- Transient Evoked Otoacoustic Emission (TEOAEs)
- Tympanometry

3. METHODS

Study setting and Participants

This cross-sectional study was conducted in the Department of Physiology, College of Medicine, at Imam Abdulrahman bin Faisal University (IAU), from September 2021 to April 2022, in collaboration with the ENT clinic of the King Fahd Hospital University, Al Khobar. The sample size was calculated by the EPI Info Software app, by putting values as the frequency of hearing problems at 50%, the margin of error at 5%, and the confidence interval at 95%. The total student population in our college was 1227. The calculated sample size was 384 which was increased to 480 students keeping in mind a response rate of 80%. Our inclusion criteria were IAU students using PLDs. The exclusion criteria were a) not using PLDs b) previously diagnosed with hearing loss c) suffering from any acute/chronic ear disease d) hearing aids user. The sampling technique was convenience sampling. An online survey was created on Google forms which asked about subjects’ patterns of PLDs use (the duration of use per day and “PLDs volume level”).

Procedure and ethical considerations

Ethical approval was obtained from the research committee (IRB) of IAU (letter number: IRB-UGS-2021-01-351). Informed consent was obtained from the participants electronically. Volunteered participants for hearing tests were assigned appointments for Pure Tone Audiometry (PTA), Tympanometry, and Transient Evoked Otoacoustic Emission (TEOAEs) tests at the ENT clinic of the King Fahd Hospital of the University, Al Khobar. All tests were conducted by a certified audio vestibular consultant. Participants were briefed about the procedures regarding tympanometry, PTA, and TEOAEs tests.

Measures

Pure Tone Audiometry

AC40 Audiometer with a calibration date of 10th Feb 2022 was used and the British Society of Audiology recommended procedure (2018) was followed during the testing process (16). A stimulus consisting of a pure tone of a single frequency was presented to the participant until finding the air conduction hearing threshold at each frequency (0.250, 0.5, 1, 2, 4, 8 kHz). According to WHO, the normal hearing threshold was 20 dB HL or less (calculated as an average of the threshold at 025, 0.5,1,2,4,8 kHz) (1).

Transient Evoked Otoacoustic Emission (TEOAEs)

TEOAE was recorded using ILOv6 Otodynamic Analyzer (Otodynamics Ltd., Hatfield, UK) following ILO V6 User Manual Issue 17 (17). The stimuli were nonlinear clicks that were presented at an 80 dB signal pressure level (SPL). The Analyzer averaged the results and presented them as signal-to-noise ratio (SNR) over a range of frequency bands (1.0–4.0 kHz). The normal response was considered if SNR had a value of 6 or more in at least 3 frequencies.

Tympanometry

GSI-Grason-Stadler Middle ear Analyzer (V2) was used, and the British Society of Audiology recommended procedure (2014) was followed (British Society of Audiology, 2014). (18). A click sound was presented into the ear canal through a probe and the changes in the pressure of the middle ear were recorded by the machine. Tympanometry was recorded using a 226 Hz probe signal maintained at an 85 dB sound pressure level (SPL). The results of tympanometry were presented as the letters A, Ad, AS, B, and Statistical analysis.

Statistical Analysis

IBM SPSS software (Version 27) was used to analyze the
4. RESULTS

432 study participants fulfilled the inclusion criteria and were included in the analysis (out of a total of 511 study participants). Dividing the participants into quartiles yielded 108 participants in each of the upper and lower quartiles. The cut-off values of various patterns have been shown in Table 1.

Study participants who volunteered for hearing tests at the ENT clinic were mostly males (62.5%) and belonged to the age group 23 years old (45%) (age range: 20-24 years). The results of tympanometry showed that all the participants had bilateral type A (normal compliance and pressure of the middle ear) except one participant who had type Ad in the right ear (excessive compliance of the middle ear). External ear examination was also normal. The results of their pure tone audiometry tests have been shown in Table 2. In each category of PLD use pattern, the hearing threshold was “normal” at each frequency. No significant differences were observed in the hearing thresholds of participants in upper quartiles vs lower quartiles in both ears, in any of the PLD use pattern categories (Table 2).

The results of TEOAE have been presented in Table 3 and Figure 1. In each category of PLD use pattern, the response was “normal”. No significant differences were observed in responses of upper quartile participants vs lower quartiles in both ears, in any of the PLD use pattern categories (Table 2).

5. DISCUSSION

Our results showed that hearing threshold/level and cochlear hair cells’ functions are perfectly normal and do not differ significantly in the participants belonging to the upper and lower quartiles of PLD use pattern except for two TEOAE results a) lower amplitude in the upper quartile of the category “duration of PLD use/day” at 1.0 kHz in the left ear (Table 3 and Figure 1, p-value 0.04) b) significantly lower amplitude in the upper quartile of the category “volume of PLD use” at 1.0 kHz in the left ear (Table 3 and Figure 1, p-value 0.03).

| Quartiles | Number of years since the use | Volume level | Frequency of use in hours/day |
|-----------|-------------------------------|-------------|-------------------------------|
| Lower quartile (25%) | < 5 years | ≤ 30 | < 1 hour |
| Upper quartile (75%) | ≥ 6 years | ≥ 60 | ≥ 5 hours |

Table 1: The cut-off value of quartiles related to Personal Listening Devices use pattern

| Frequency | Upper quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI | Lower quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI |
|-----------|------------------------------------------------------|-------|------------------------------------------------------|-------|
| N=21      | (7.2, 12.1) 0.55                                     |       | (3.5, 10.7) 0.96                                     |       |
| N=25      | (7.8, 15.1) 0.21                                     |       | (3.9, 10.1) 0.58                                     |       |
| N=15      | (1.0, 5.0) 0.55                                     |       | (1.0, 5.0) 0.55                                     |       |
| N=14      | (1.2, 7.7) 0.27                                     |       | (1.2, 7.7) 0.27                                     |       |

Table 2: Pure Tone Audiometry results of upper and lower quartiles in right and left ears with respect of “Duration of PLDs use/day”, “Number of years since using PLDs”, and “PLDs volume level”.

| Lower quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI | Lower quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI |
|------------------------------------------------------|-------|------------------------------------------------------|-------|
| N=22 | (7.2, 12.1) 0.55                                     |       | (3.5, 10.7) 0.96                                     |       |
| N=18 | (7.8, 15.1) 0.21                                     |       | (3.9, 10.1) 0.58                                     |       |
| N=14 | (1.0, 5.0) 0.55                                     |       | (1.0, 5.0) 0.55                                     |       |
| N=13 | (1.2, 7.7) 0.27                                     |       | (1.2, 7.7) 0.27                                     |       |

Table 3: The cut-off value of quartiles related to Personal Listening Devices use pattern

| Frequency | Upper quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI | Lower quartile Hearing threshold (Mean ± SD) (dB HL) | 95% CI |
|-----------|------------------------------------------------------|-------|------------------------------------------------------|-------|
| N=21      | (7.2, 12.1) 0.55                                     |       | (3.5, 10.7) 0.96                                     |       |
| N=25      | (7.8, 15.1) 0.21                                     |       | (3.9, 10.1) 0.58                                     |       |
| N=15      | (1.0, 5.0) 0.55                                     |       | (1.0, 5.0) 0.55                                     |       |
| N=14      | (1.2, 7.7) 0.27                                     |       | (1.2, 7.7) 0.27                                     |       |

Table 4: Pure Tone Audiometry results of upper and lower quartiles in right and left ears with respect of “Duration of PLDs use/day”, “Number of years since using PLDs”, and “PLDs volume level”.

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PTA (less than 8kHz) when compared with age and sex-matched non-users or those who used PLDs for shorter durations/less volume (19-23). Few studies used extended high frequencies (EHFs) in PTA and reported significantly higher hearing thresholds at many EHF frequencies (9-16 kHz) in PLD users compared with non-users or those who used PLDs for shorter durations/less volume (19-20, 14). Another study also reported insignificant differences in the hearing thresholds between participants choosing a higher listening volume (≥85 dB LAeq8h) vs participants choosing a lower level (<85 dB LAeq8h) (LAeq8h=8-hr continuous equivalent sound exposure levels) vs participants or those never using a PLD, whereas in our study all the participants were PLD users. On the contrary, another study examined the effects of music listening on OAE and revealed insignificant differences in post- and pre-2 h continuous music listening on OAE amplitudes at frequencies up to 4 kHz in PLD users compared to controls (19). The reason for this could be due to the fact that their control group consisted of subjects who never used a PLD, whereas in our study all the participants were PLD users. On the contrary, another study examined the effects of music listening on OAE and revealed insignificant differences in the amplitude of TEOAE at 1.0 kHz, however, included significant differences at frequencies up to 4 kHz in PLD users compared to controls (19). The reason for this could be due to the fact that their control group consisted of subjects who never used a PLD, whereas in our study all the participants were PLD users. On the contrary, another study examined the effects of music listening on OAE and revealed insignificant differences in the amplitude of TEOAE at 1.0 kHz, however, included significant differences at frequencies up to 4 kHz in PLD users compared to controls (19). The reason for this could be due to the fact that their control group consisted of subjects who never used a PLD, whereas in our study all the participants were PLD users. On the contrary, another study examined the effects of music listening on OAE and revealed insignificant differences in the amplitude of TEOAE at 1.0 kHz, however, included significant differences at frequencies up to 4 kHz in PLD users compared to controls (19). The reason for this could be due to the fact that their control group consisted of subjects who never used a PLD, whereas in our study all the participants were PLD users. On the contrary, another study examined the effects of music listening on OAE and revealed insignificant differences in the amplitude of TEOAE at 1.0 kHz, however, included significant differences at frequencies up to 4 kHz in PLD users compared to controls (19). The reason for this could be due to the fact that their control group consisted of subjects who never used a PLD, whereas in our study all the participants were PLD users.

### 6. CONCLUSION

The present study concludes that the existing pattern of PLD use among our university students is generally safe for hearing. However, this study also revealed an affected left ear hearing threshold at 1.0 kHz in relation to the duration per day and volume level using TEOAE. The strength of our study is that we used an Audiological test battery consisting of pure tone audiometry and otoacoustic emissions, both of which are very important for the diagnosis of hearing loss. Our limitations include self-reported listening habits (frequency of use, volume setting). Moreover, self-reported volume levels were not correlated with real-time measured sound levels. Ideally, sound volume in dB reflecting students’ preferred listening volume should be identified by using a specialized instrument (KEMAR head and torso simulator (KEMAR) manikin). Due to the non-availability of this instrument in our lab, we couldn’t do so.

### Table 3: Transient Evoked Otoacoustic Emission (TEOAE) results of upper and lower quartiles

| Frequency | Upper quartile SNR | Lower quartile SNR |
|-----------|--------------------|--------------------|
|           | (Mean ± SD) 95% CI | (Mean ± SD) 95% CI |
| 1.0 kHz   | Right ear (N=21)   | Left ear (N=19)    |
| 1.0 kHz   | 9.9 ± 6.6 dB (6.8, 12.9) | 12.2 ± 5.9 dB (8.9, 15.5) |
| 1.4 kHz   | 16.6 ± 5.4 dB (14.0, 19.2) | 18.5 ± 7.0 dB (14.6, 22.3) |
| 2.0 kHz   | 19.2 ± 6.0 dB (16.5, 22.0) | 20.7 ± 5.4 dB (17.7, 23.7) |
| 2.0 kHz   | 17.2 ± 4.9 dB (14.9, 19.4) | 18.4 ± 5.4 dB (15.4, 21.3) |
| 4.0 kHz   | 11.7 ± 6.6 Db (8.6, 14.7) | 15.5 ± 6.6 Db (11.8, 19.2) |
| Total OAE | 13.5 ± 5.6 dB (11.0, 16.0) | 15.0 ± 4.7 dB (12.4, 17.5) |

| Frequency | Right ear (N=25)   | Left ear (N=14)    |
|-----------|--------------------|--------------------|
| 1.0 kHz   | 8.6 ± 9.2 dB (4.4, 12.6) | 14.4 ± 6.2 dB (10.9, 17.8) |
| 1.4 kHz   | 16.9 ± 5.5 dB (14.3, 19.4) | 19.2 ± 5.8 dB (16.0, 22.4) |
| 2.0 kHz   | 20.5 ± 6.1 dB (17.7, 23.3) | 20.7 ± 4.6 dB (18.1, 23.2) |
| 2.8 kHz   | 19.0 ± 5.7 dB (16.4, 21.5) | 18.1 ± 5.2 dB (15.2, 21.0) |
| 4.0 kHz   | 14.7 ± 4.6 dB (12.6, 16.8) | 14.7 ± 7.7 dB (10.4, 18.9) |
| Total OAE | 13.8 ± 4.4 dB (11.8, 15.8) | 14.4 ± 5.8 dB (11.2, 17.7) |

| Frequency | Right ear (N=22)   | Left ear (N=18)    |
|-----------|--------------------|--------------------|
| 1.0 kHz   | 11.1 ± 7.6 dB (8.0, 14.3) | 11.5 ± 4.6 dB (8.8, 14.2) |
| 1.4 kHz   | 17.2 ± 7.5 dB (14.2, 20.3) | 18.1 ± 5.0 dB (15.2, 21.0) |
| 2.0 kHz   | 20.6 ± 5.8 dB (18.3, 23.0) | 18.2 ± 5.6 dB (15.0, 21.4) |
| 2.8 kHz   | 18.0 ± 5.1 db (15.9, 20.1) | 17.7 ± 5.3 dB (14.7, 20.8) |
| 4.0 kHz   | 13.9 ± 7.9 dB (10.7, 17.2) | 14.0 ± 4.8 dB (11.3, 16.8) |
| Total OAE | 14.5 ± 5.8 dB (12.1, 16.9) | 13.7 ± 3.4 dB (11.6, 15.8) |

| Frequency | Right ear (N=22)   | Left ear (N=10)    |
|-----------|--------------------|--------------------|
| 1.0 kHz   | 9.8 ± 9.3 dB (6.0, 13.6) | 14.6 ± 5.1 dB (11.7, 17.6) |
| 1.4 kHz   | 17.5 ± 6.6 dB (15.2, 19.8) | 18.2 ± 6.1 dB (14.7, 21.7) |
| 2.0 kHz   | 20.9 ± 5.4 dB (18.6, 23.1) | 20.1 ± 5.3 dB (17.0, 23.2) |
| 2.8 kHz   | 19.0 ± 5.3 dB (16.8, 21.2) | 18.3 ± 4.7 dB (15.5, 21.0) |
| 4.0 kHz   | 15.2 ± 5.5 dB (13.0, 17.5) | 15.1 ± 6.6 dB (11.3, 18.9) |
| Total OAE | 14.4 ± 5.8 dB (12.3, 16.5) | 13.7 ± 4.5 dB (11.1, 16.3) |

*Patient Consent Form: All participants were informed about subject of the study.

**Author’s Contribution:** R.S., F.T., H.M., A.G., R.L and N.R gave substantial contributions to the conception or design of the work in acquisition, analysis, or interpretation of data for the work, and had a part in the article preparing for drafting or revising it critically for important intellectual content. A.S, R.S, F.T, H.M. and A.G. collected all data related to participants’ Audiological assessment including TPa, Tympanometry & TEOAE. In addition, had a part in article preparation.
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