The Journal of Laryngology & Otology (2016), ***130***, *717–729.*

doi:10.1017/S0022215116001031

MAIN ARTICLE

Personal music systems and hearing

U A KUMAR, S R DEEPASHREE

Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore, India

Abstract

Objectives: To measure the output sound pressure levels of personal music systems and evaluate their effect on hearing.

Methods: Output sound pressure levels at preferred volume settings and listening environment were measured using a manikin. Effects of personal music system use on hearing were evaluated using pure tone audiometry (in conventional and extended high frequency ranges), transient evoked otoacoustic emissions, syllable identification in noise, intensity discrimination, frequency discrimination and temporal modulation transfer function.

Results: Results showed, alarmingly, that large proportions of young adults are using personal music systems at levels higher than the safety limits set by regulatory bodies. Individuals who listened to personal music systems at levels higher than 80 dB LAeq exhibited poorer extended high frequency thresholds, reduced transient evoked otoacoustic emission amplitudes, poorer frequency discrimination, reduced modulation detection thresholds at 32 Hz modulation frequency, and reduced syllable identification in noise at −5 dB signal-to-noise ratio. Listening levels were significantly correlated with extended high frequency thresholds and transient evoked otoacoustic emission amplitudes.

Conclusion: These results suggest that listening to music through personal music systems at higher volume levels may be hazardous to hearing.

Key words: Music; Auditory Perception; Noise; Audiometry; Otoacoustic Emissions

Introduction

There are growing concerns over hearing deterioration following noise exposure via personal music system use. Loud music, if listened to for long durations at increased volume levels, might result in permanent noise-induced hearing loss. The habit of listening to loud music is very common among young adults.[1,2] Most young adults prefer using personal music systems when travelling or before sleeping, and in either condition the listening duration might be long. Music is typically listened to at high volume during travelling in an attempt to restore audibility in concurrent vehicle noise. As there has been a massive increase in the popularity of personal music systems, an alarming proportion of young adults may be at risk of hearing loss, and this will be an important social concern to the next generation.

The National Institute for Occupational Safety and Health guidelines for workplace settings specify that any exposure of 85 dBA for more than 8 hours exceeds the maximum daily allowable noise level criterion.[3] As the intensity of the signal increases, the maximum allowable duration of exposure decreases. Although this standard is based on industrial noise, it is currently used as the guideline for recreational noise exposure, including listening to music. In India, the Ministry of Environment and Forests (2000) has imposed the guidelines for maximum allowable noise levels.[4] According to these guidelines, the maximum allowable noise dose for an 8-hour period is 90 dBA per day, with a '5 dB exchange rule'. In adherence to this guideline, every 5 dB increase in the exposure level will be compensated by halving the exposure time, to keep the risk constant. The maximum permissible levels are not considered completely harmless, as a few people may still incur a permanent hearing loss if exposed to these levels of noise.

Since the invention of personal music systems, researchers have tried to investigate the deleterious effects of these devices on hearing. There are a few published reports in the literature on the hazardous output sound pressure levels generated by personal music systems.[5,6] These investigators found maximum sound pressure levels as high as 124 dBA and 110–128 dBA respectively for compact disc (CD) and cassette players. Based on these reports, it can be concluded that personal music systems using either CD or cassette players can produce sound levels that are hazardous to hearing.

Accepted for publication 13 January 2016 First published online 25 May 2016

Fligor and Cox systematically explored the output levels of the different commercially available CD players in combination with a variety of earphone styles on a manikin.[7] Free-field equivalent sound pressure levels measured at maximum volume control settings ranged from 91 to 121 dBA. Output sound pressure levels varied for different configurations of earphone styles and were greater for the insert type of earphones. They concluded that in most of the CD player models, the maximum permissible noise dose would be reached within 1 hour of listening to music at 70 per cent of the volume control setting. Torre measured the output sound pressure levels of personal music systems in the ear canal of 32 participants at 4 loudness categories: low, medium, loud and very loud.[8] The findings revealed mean output sound pressure levels of 62, 72, 88 and 98 dB SPL for low, medium, loud and very loud categories, respectively. Based on these measurements, it was concluded that output sound pressure levels produced by personal music systems at medium or loud volume control settings may not be hazardous if listened to for 1–3 hours a day. All these early studies concentrated on measuring the output sound pressure levels of the personal music devices and seldom evaluated their effect on hearing.

Lee *et al*. reported on the hazardous effects of personal music systems on hearing.[9] In a pilot study, the hearing thresholds of 16 young volunteers were evaluated after they had listened to 3 hours of music through a personal music system. Six volunteers showed temporary threshold shifts.[9] Kumar *et al*. measured the mean output sound pressure levels at preferred listening settings in quiet conditions, in the presence of 65 dB SPL bus noise and at maximum volume control settings, for mobile phones, iPods™ and locally made 'MP3' players.[10] The mean loudness equivalent exposure levels (Leq) for continuous 8-hour durations at the volunteers' preferred volume control settings in quiet conditions were: 73 dBA for mobile phones (range, 40–93 dBA), 76 dBA for iPods (range, 56–86 dBA) and 79 dBA for locally made MP3 players (range, 70–84 dBA). The output sound pressure levels in the presence of bus noise were similar to those in the quiet condition, but at the maximum volume control settings the output levels were higher compared to the volunteers' preferred volume control setting. They reported a significant negative correlation between listening levels and distortion product otoacoustic emission amplitudes at high frequencies. Individuals who tended to listen at higher levels had poorer otoacoustic emission (OAE) amplitudes. The study demonstrated subclinical cochlear damage in individuals who listened to music at higher levels through personal music systems.[10] Peng *et al*. reported that the hearing thresholds in the 3, 4, 6 and 8 kHz frequency range were significantly increased in personal music system users, though hearing thresholds in low frequencies were within the normal range.[11]

As the popularity of personal music systems is increasing, the damage caused by listening to personal music systems is of social concern. This study aimed to measure the output sound pressure levels of commercially available personal music systems, and to evaluate their effect on hearing using various subjective and objective tests. If the listening levels are above damage risk criteria and if there is an effect on hearing then this warrants strict laws to limit the output of these personal music systems.

Materials and methods

Participants

Sixty participants aged between 15 and 30 years participated in the current study. The participants were selected from different schools and colleges in Mysore, a city in South India. The study consisted of two groups: regular users of personal music systems and non-users of personal music systems. There were 30 participants in both groups.

Selection criteria

The participants were selected after administering a custom-made questionnaire on personal music system use, developed as a part of the current study. From the pool of 1000 school and college students surveyed, 60 individuals who met the inclusion criteria were randomly selected for the study.

The inclusion criteria were as follows: no history of otological problems, occupational noise exposure, or ototoxicity; both ear canals were free from cerumen, debris and any foreign body, as observed from otoscopic examination; speech identification scores were greater than 90 per cent at 40 dB SPL (using the average of pure tone hearing thresholds at 0.5, 1, 2 and 4 kHz as a reference), as assessed using phonetically balanced word lists; and normal middle-ear functioning, as indicated by a type 'A' tympanogram,[12] with the presence of acoustic reflex for broadband noise above 75 dB SPL but within 90 dB SPL.

The participants were assigned to two groups. Personal music system non-users did not use or rarely used (once a week for less than 1 hour at a time) personal music systems. Personal music system users were regular users of the devices, having listened to music through personal music systems for at least 2 hours per day for a minimum of 2 years.

The purpose and nature of the study was explained to each participant and written consent was obtained. The study adhered to the All India Institute of Speech and Hearing Ethics Committee 'ethical guidelines for bio-behavioural research involving human subjects', and ethical committee approval was obtained.

Procedure

The study was carried out in two phases. In phase I, the output sound pressure levels produced by different personal music systems were measured using a Knowles

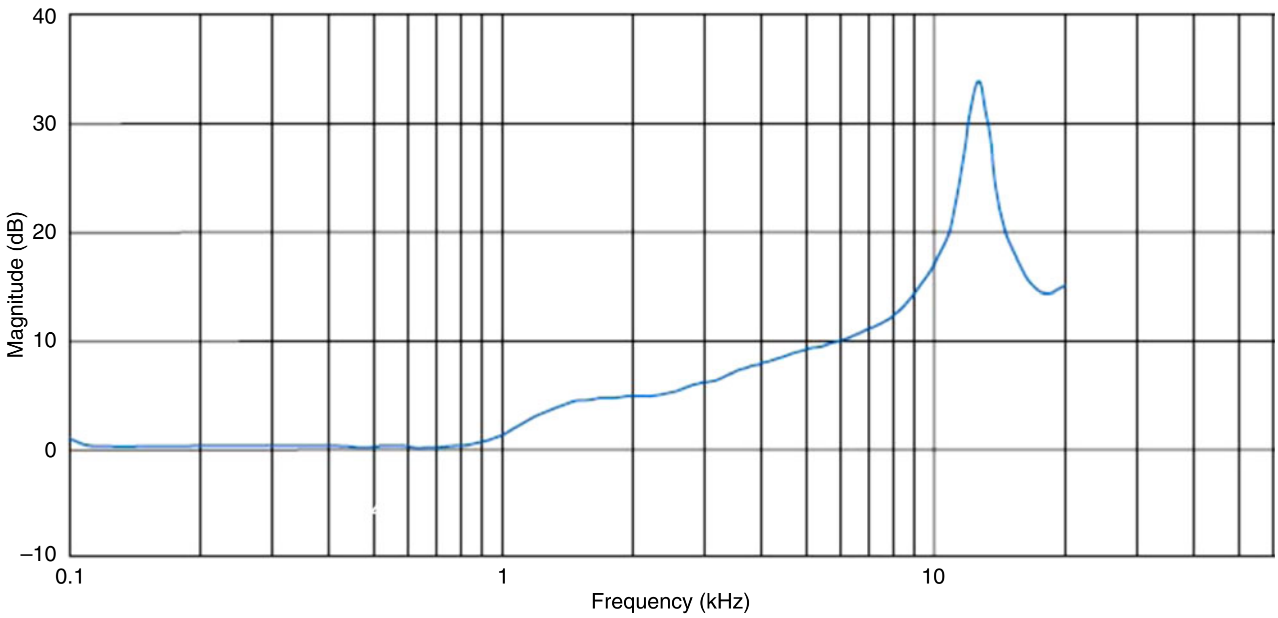

FIG. 1
Typical frequency response characteristics of coupler.

electronic manikin for acoustic research (Kemar 45BB-1; GRAS, Holte, Denmark). In phase II, the effect of listening to music using personal music systems on hearing was measured using various behavioural and physiological tests.

Phase I

Phase I involved measurement of the output sound pressure levels produced by different personal music systems using a Kemar. This phase was carried out only for the personal music system users group. Output of the personal music systems was recorded in situations where participants reported that they used it most (e.g. in quiet conditions or in the presence of bus noise).

Experimental set-up. A Kemar, with an ear simulator (RA0045), connected to a sound level meter (type 2270; Brüel & Kjær, Nærum, Denmark), was used to measure the output sound pressure levels of the personal music systems. The GRAS Kemar 45BB-1 manikin is a human head and torso model for in situ measurement of hearing aids, earphones and communication devices. It simulates the way an average human influences a sound field. The Kemar is fitted with a pinna simulator, ear canal extension and ear simulator that have similar acoustic impedance to that of the human ear. The ear simulator comprises an externally polarised (polarisation voltage of 200 V) pressure microphone (model 40AG) and an occluded ear simulator. Figure 1 shows the frequency response of the ear simulator coupled to a standard ear canal extension and pinna. The output of the Kemar was connected to the sound level meter via a 12AK power module.

Output sound pressure levels of the personal music systems were recorded in situations where participants reported that they used it most. The majority of participants reported using their personal music systems either in quiet conditions during their leisure time or while commuting. In those who reported using their personal music systems in quiet conditions, the output of the personal music system was measured in a quiet environment. In those who reported using their personal music systems while commuting, the output was measured in the presence of background bus noise.

To replicate the commuting condition, bus noise produced by a front engine bus was recorded using a sound level meter attached to a 12.7 mm (0.5 inch) free-field microphone. The sound level meter was kept at a distance of 1 m from the engine, and the noise was recorded for 15 minutes. The average A-weighted equivalent continuous noise level (LAeq) value for the bus noise was found to be 80 dB SPL. Out of the recorded sample, a 2-minute steady portion was selected and used as the stimuli. This was presented at 80 dB SPL through the calibrated loudspeaker placed at a distance of 1 m from each participant.

In both listening conditions (in the quiet environment and in the presence of 80 dB SPL bus noise (to simulate noise while travelling)), the output sound pressure levels were measured at preferred volume control settings. Each participant was asked to play the music of their choice through their own personal music system, using their own earphones or headphones, and adjust the volume control levels to their most preferred settings in a quiet environment or in the presence of bus noise as the case may be.

Subsequently, each personal music system's earphones or headphones were mounted onto the Kemar pinna and the same music was played at the volume control settings noted earlier. Output sound pressure levels of the personal music systems were recorded in

https://doi.org/10.1017/S0022215116001031 Published online by Cambridge University Press

dB LAeq units. In addition, overall ear canal LAeq, and LAeq at individual frequencies between 0.1 and 20 kHz (two points per octave), were recorded. These ear canal output values were converted into equivalent diffuse field sound pressure levels by subtracting the head-related transfer function of the Kemar, in order to assess exposure levels in terms of damage risk criteria.

The LAeq values for 8-hour durations were obtained for each participant in the experimental (personal music system user) group. Using these values, the personal music system users were subdivided into two groups: those whose LAeq values for 8-hour durations were lower than 80 dBA and those whose values were greater than or equal to 80 dBA.

Phase II

Both the users and non-users of personal music systems participated in phase II of the study, in which the effects of personal music system use on hearing were assessed using both behavioural and physiological measures. Behavioural measures included: standard pure tone audiometry in a conventional frequency range (0.25–8 kHz) and extended high frequency range (9–16 kHz), syllable identification in noise, and psychophysical measures (intensity discrimination, frequency discrimination and temporal modulation transfer function). Physiologically, the effects of listening to music on hearing were assessed through transient evoked OAEs (TEOAEs).

Pure tone audiometry. Pure tone hearing thresholds were measured at a conventional audiometric frequency range (0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz) and an extended high frequency range (9, 10, 11.2, 12.5, 14 and 16 kHz). Pure tone audiometry was carried out using a calibrated two-channel diagnostic audiometer (Piano; Inventis, Padova, Italy). The audiometer was calibrated at the beginning of the experiment using a sound level meter (model 2270; Brüel & Kjær) connected to an artificial ear (type 4152), with a 25.4 mm (1 inch) pressure microphone (model 4144). Before testing each participant, biological calibration of the audiometer was carried out using the routine procedure employed in the audiology clinic at the All India Institute of Speech and Hearing, Mysore. Pure tone hearing thresholds in a conventional audiometric range (0.25–8 kHz) were assessed using TDH-39 headphones, while the thresholds in an extended audiometric range (9–16 kHz) were assessed using HDA 200 headphones. Pure tone thresholds were estimated using a modified version of the Hughson and Westlake procedure.[13]

Syllable identification in noise. The stimuli for this task consisted of 16 syllables (/ba, cha, da, dha, dza, ga, ka, la, ma, na, pa, ra, sa, sha, ta, tha/). These syllables were recorded from a female native speaker of Kannada. Stimuli were recorded using a Microbook II audio interface (MOTU, Cambridge, Massachusetts, USA) connected to a personal computer using Adobe Audition software (version 3; Adobe Systems, San Jose, California, USA). The microphone was kept at a distance of 15 cm from the speaker's mouth. A sampling rate of 44 100 Hz was used. The recorded stimuli were edited to remove intervals of silence before and after the stimulus. All the stimuli were root-mean-square normalised using Adobe Audition software. Speech noise was added to the normalised stimuli to generate stimuli with 0 dB and −5 dB signal-to-noise ratios, using a custom written code implemented in Matlab® software.

Participants were seated comfortably in a quiet room in front of a computer monitor at a distance of 1.5 m. Stimuli were presented monaurally to participants at their most comfortable levels using Sennheiser™ HD449 circumaural headphones. The participants were instructed to click on the corresponding consonant-vowel syllable on the computer screen after hearing the stimuli. Each syllable was presented five times in each signal-to-noise ratio condition. This resulted in a total of 160 presentations ($5 \times 16 \times 2 = 160$). The order of presentation of stimuli was randomised for each participant. Presentation of the stimuli and acquisition of the responses were controlled using Paradigm experiment builder software (version 2.4; Perception Research Systems, Lawrence, Kansas, USA).

Psychophysical tests. Psychophysical testing included assessment of basic auditory skills. Specifically, frequency processing, intensity processing and temporal processing were evaluated by measuring frequency discrimination, intensity discrimination and temporal modulation transfer function respectively.

These basic auditory skills were evaluated with a two-up, one-down staircase procedure using a psychoacoustic toolbox implemented in Matlab.[14] Stimuli were generated at a 44 100 Hz sampling rate. A three-interval, alternate forced-choice method was employed to track an 80 per cent correct response criterion. During each trial, a stimulus was presented in each of three intervals: two intervals contained a reference stimulus and the other interval contained a variable stimulus (described below). The participants were instructed to indicate the interval containing the variable stimulus. The stimuli for all the tests were presented at 70 dB SPL through Sennheiser HD449 circumaural headphones connected to a MacBook Air®.

The minimum intensity difference that was necessary to perceive the two otherwise identical stimuli was measured. The standard stimulus was a 250 ms long pure tone at 1000 Hz with a 10 ms ramp. The variable stimulus was similar to the standard stimulus except that its intensity was varied depending on each participant's responses. In the three-interval, alternate forced-choice procedure, the participants' task was to indicate which interval contained the louder signal.

Frequency discrimination was measured for the 250 ms long pure tones at 1000 Hz with a 10 ms ramp.

In the three-interval, alternate forced-choice task, participants were required to identify the interval with a higher pitch. The frequency of the variable tone was adapted according to each participant's responses.

Temporal modulation refers to a reoccurring change (in frequency or amplitude) in a signal over time. A 500 ms Gaussian noise was sinusoidally amplitude-modulated at modulation frequencies of 8, 16, 32, 64 and 128 Hz. The noise stimuli had two 10 ms raised cosine ramps at onset and offset. In order to assess temporal modulation transfer function, the participants had to detect the modulation and determine which interval had the modulated noise. Modulated and unmodulated stimuli were equated for total root-mean-square power. Depth of the modulated signal varied according to each participant's response, up to an 80 per cent criterion level. The modulation detection thresholds were expressed in decibels using the following equation: modulation detection thresholds in decibels = 20 $\log_{10}$ m, where m = modulation detection threshold in percentage.

Transient evoked otoacoustic emissions. The TEOAEs were recorded using a commercially available computer-based otoacoustic emissions analyser (ILO-V6; Otodynamics, Hatfield, UK). Participants sat in a comfortable chair and the OAE probe was adequately sealed in the external ear canal. An intrinsic real ear intensity calibration was used to determine the quality of the OAE probe seal before measurement commenced. The TEOAEs were measured for 65 dB SPL linear clicks of 80 µs duration. The average response from a total of 260 clicks was used for the analysis. A recording was rejected if the stimulus stability was less than 95 per cent. The global TEOAE amplitude and amplitudes at 1000, 1414, 2000, 2828 and 4000 Hz frequency bands were noted and used for analysis.

Results

Phase I results

The overall in situ output sound pressure levels (LAeq values) obtained at participants' preferred volume control settings using the Kemar are shown in Figure 2. The figure shows that preferred listening levels varied considerably among participants (range, 51–98 dB).

The mean LAeq levels, with one standard deviation, measured across frequencies, are plotted in Figure 3. From Figure 3, it can be inferred that songs listened to using personal music systems had more energy in the 0.4–4 kHz frequency region.

Figure 4 shows the equivalent diffuse field sound pressure levels (LAeq) for individual participants. This shows that a small proportion of the participants were listening to music at levels higher than the safety limit set by the Indian Ministry of Environment and Forests, which is 90 dBA for 8 hours with a 5 dB exchange rule.[4] This safety limit is less stringent when compared with the standards on hazardous levels of noise exposure set by international committees or organisations. For example, the International Organization for Standardization defines a time-weighted average of 85 dBA for an 8-hour period per day as a maximum permissible exposure limit.[15] This standard uses a 3 dB exchange rule. The limit of 85 dB is not completely harmless, as some individuals may still incur permanent hearing loss if exposed to it. Noise regulations at workplaces in the UK limit the daily exposure level to 80 dBA.[16]

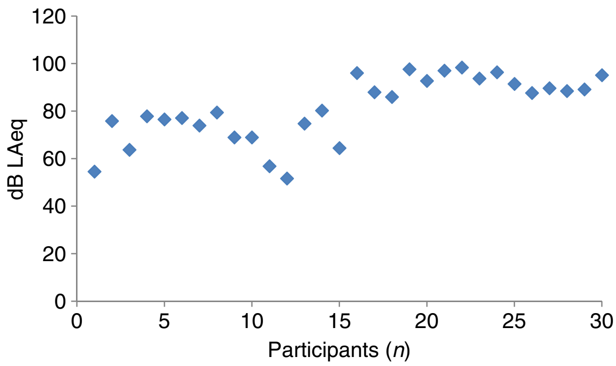

FIG. 2
A-weighted equivalent continuous sound level (dB LAeq) values of individual participants.

In order to further understand the impact of noise levels on hearing, the study participants were divided into two groups based on diffuse field LAeq levels. The first group consisted of individuals who used personal music systems at levels higher than 80 dB LAeq and the second group comprised individuals who listened to music at levels lower than 80 dB LAeq. All behavioural and physiological measures of hearing acuity were determined for both of these groups separately. There were 15 participants in each group.

Phase II results

Pure tone audiometry. The pure tone thresholds of all participants were well within normal limits (less than 15 dB HL) for frequencies between 0.25 and 8 kHz in both ears. Figure 5 shows the mean pure tone thresholds (in dB HL) of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) for frequencies between 0.25 and 8 kHz.

As shown in Figure 5, the mean pure tone thresholds of personal music system users listening at levels higher than 80 dB LAeq are slightly poorer when compared to the other two groups, especially at high frequencies. To test whether these differences were statistically significant, separate multivariate analyses of variance were carried out for each ear. The results revealed a significant main effect of group in both right ears ($F(16, 102) = 1.8$, $p < 0.05$) and left ears ($F(16, 102) = 1.7$, $p < 0.05$). Pairwise comparisons

https://doi.org/10.1017/S0022215116001031 Published online by Cambridge University Press

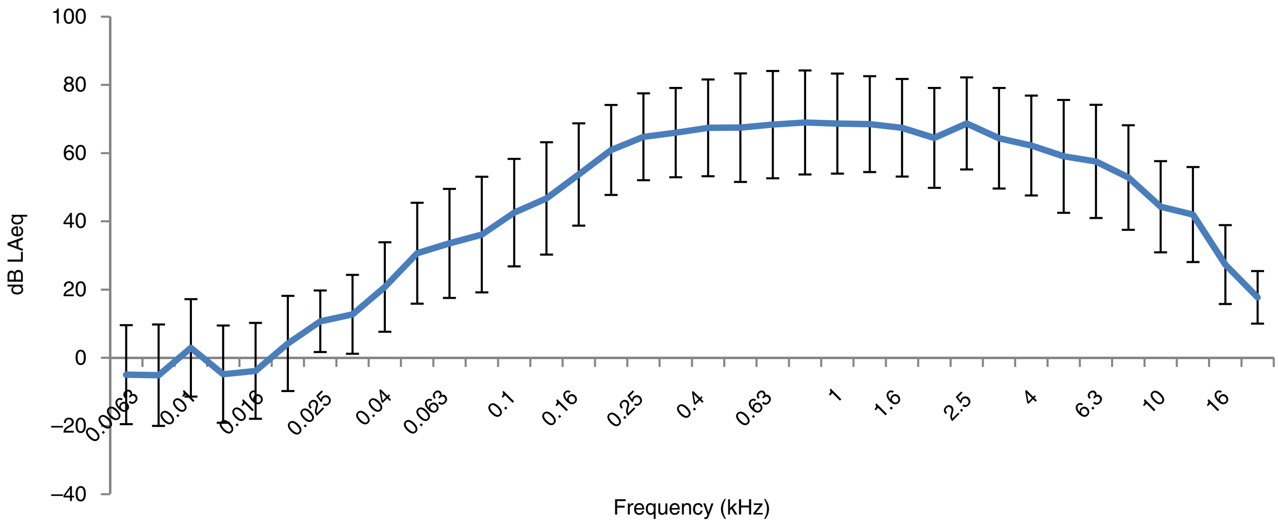

FIG. 3
Mean A-weighted equivalent continuous sound level (dB LAeq) values of all participants as a function of frequency. Error bars indicate one standard deviation.

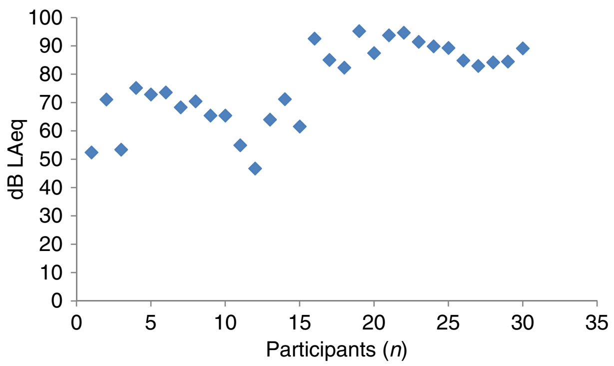

FIG. 4
Equivalent diffuse field A-weighted equivalent continuous sound level (dB LAeq) values for individual participants.

with Bonferroni correction showed that pure tone hearing thresholds were significantly worse in the personal music system user group listening at levels higher than 80 dB LAeq at 0.5 kHz in the right ear, and at 0.5, 2, 3, 4, 6 and 8 kHz in the left ear, in comparison with the other two groups. There was no statistically significant difference between non-users and users of personal music systems listening at levels lower than 80 dB LAeq at any of the frequencies in either ear.

Extended high frequency audiometry. Figure 6 shows the mean extended high frequency pure tone thresholds (in dB SPL), with one standard deviation, for the three groups.

The figure shows that the mean extended high frequency thresholds of the personal music system user group listening at levels higher than 80 dB LAeq is poorer than that of the other two groups for most of the frequencies. Multivariate analysis of variance revealed a significant main effect of group in both right ears ($F(12, 106) = 3.5$, $p < 0.05$) and left ears ($F(12, 106) = 2.3$, $p < 0.05$). Pairwise comparison with Bonferroni correction showed that personal music system users listening at levels higher than 80 dB LAeq had significantly worse pure tone thresholds in both ears at all frequencies except 9 kHz and 10 kHz in the right ear when compared to the other two groups. There was no statistically significant difference between the mean pure tone hearing thresholds of non-users and users of personal music systems listening at levels lower than 80 dB LAeq at any of the frequencies in either ear.

Syllable identification in noise. The mean numbers of syllables identified by the participants at 0 dB and −5 dB signal-to-noise ratio are shown in Figure 7.

A one-way analysis of variance was performed for each signal-to-noise ratio separately to determine the statistical significance of differences in mean syllable identification scores among the three groups. The results showed no significant main effect of group at 0 dB signal-to-noise ratio ($F(2, 57) = 2$, $p > 0.05$). However, there was a significant main effect of group at −5 dB signal-to-noise ratio ($F(2, 57) = 3.4$, $p < 0.01$). Bonferroni post hoc analyses showed that the personal music system user group listening at levels higher than 80 dB LAeq had significantly poorer syllable identification scores compared to personal music system non-users.

Psychophysical tests. Figure 8 shows the mean intensity discrimination thresholds for the three groups. The figure demonstrates that the personal music system users listening at levels higher than 80 dB LAeq had poorer intensity discrimination threshold values compared to the other two groups. However, one-way analyses of variance showed no significant main effect of group on intensity discrimination threshold ($F(2, 57) = 2.4$, $p > 0.05$).

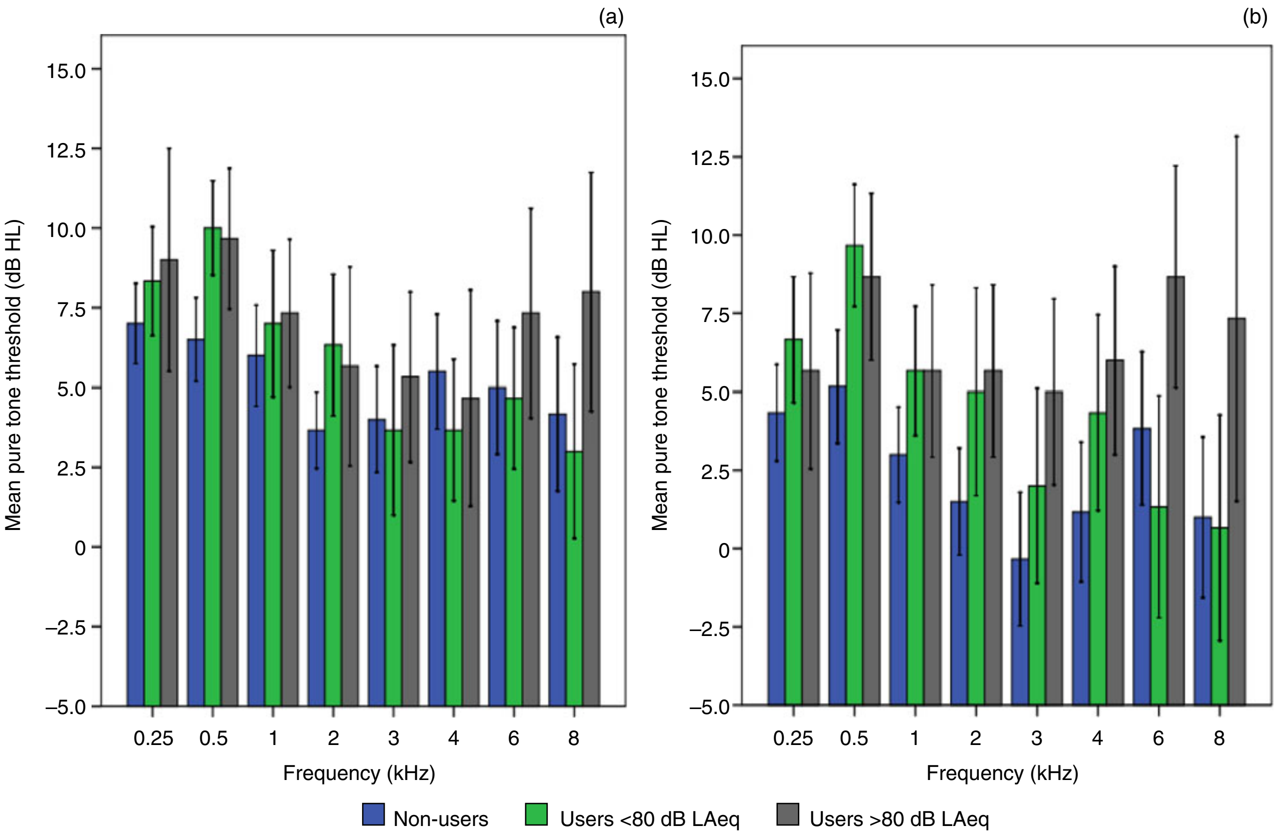

FIG. 5

Mean pure tone thresholds of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) for frequencies 0.25, 5, 1, 2, 3, 4, 6 and 8 kHz, in right (a) and left ears (b). Error bars represent standard deviations.

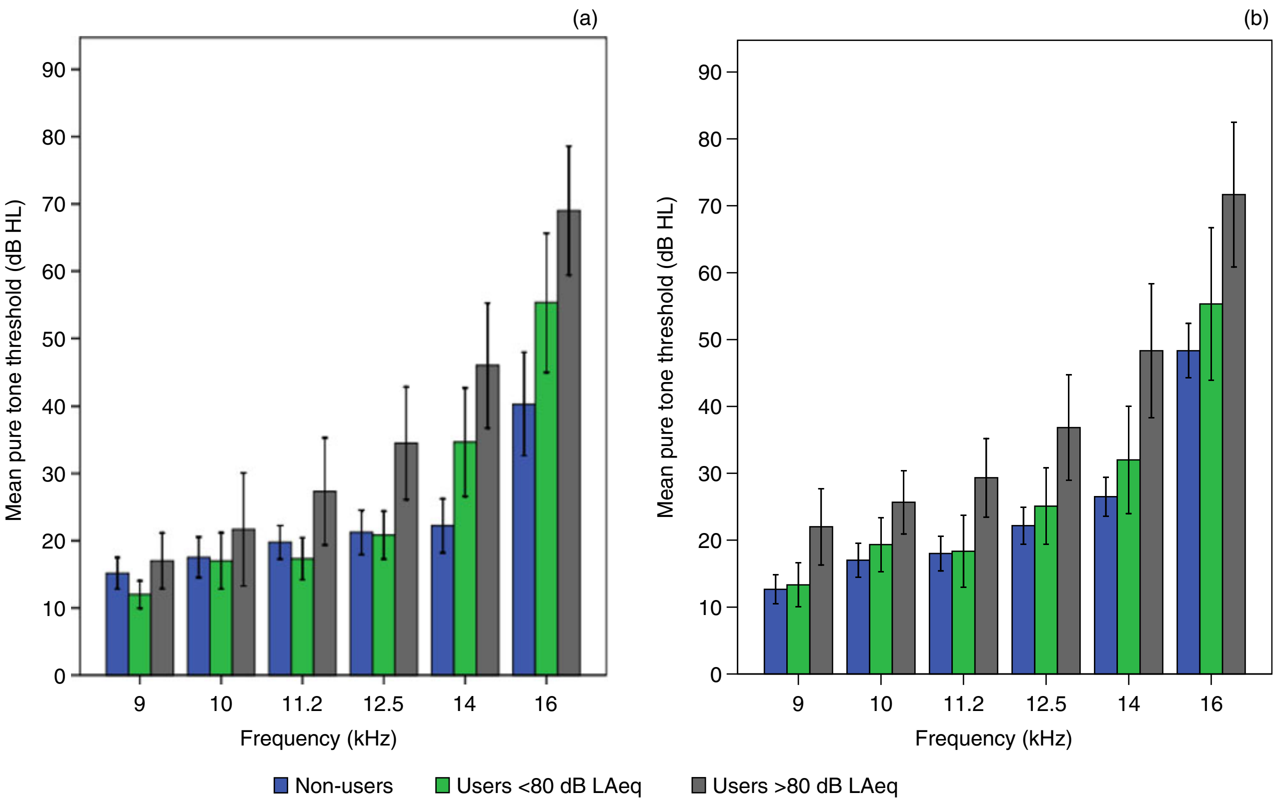

FIG. 6

Mean extended high frequency pure tone thresholds of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) for frequencies 9, 10, 11.2, 12.5, 14 and 16 kHz, in right (a) and left ears (b). Error bars represent standard deviations.

https://doi.org/10.1017/S0022215116001031 Published online by Cambridge University Press

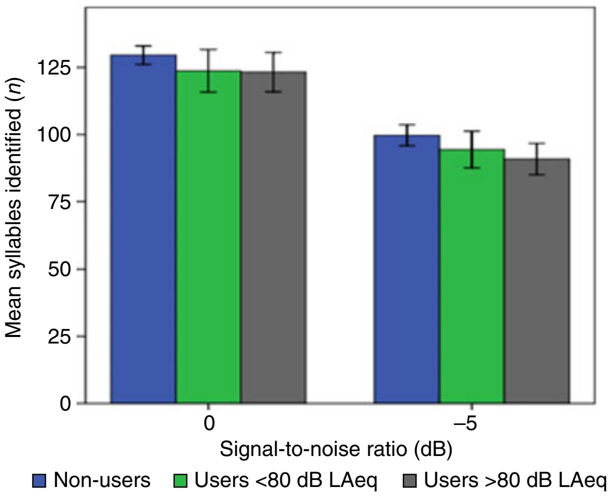

FIG. 7

Mean number of syllables identified by non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) in noise at 0 dB and −5 dB signal-to-noise ratios. Error bars represent one standard deviation.

Figure 9 shows the mean frequency discrimination thresholds, with one standard deviation, for the three groups. The figure shows that the personal music system user group listening at levels higher than 80 dB LAeq had poorer frequency discrimination thresholds compared to the other two groups. One-way analyses of variance showed a significant main effect of group on frequency discrimination thresholds (F(2, 57) = 6.4, $p < 0.05$). Bonferroni post hoc analyses revealed that personal music system users listening at levels higher than 80 dB LAeq had poorer frequency discrimination thresholds compared to the other two groups. There was no statistically significant difference between the frequency discrimination thresholds of non-users and users of personal music systems listening at levels lower than 80 dB LAeq.

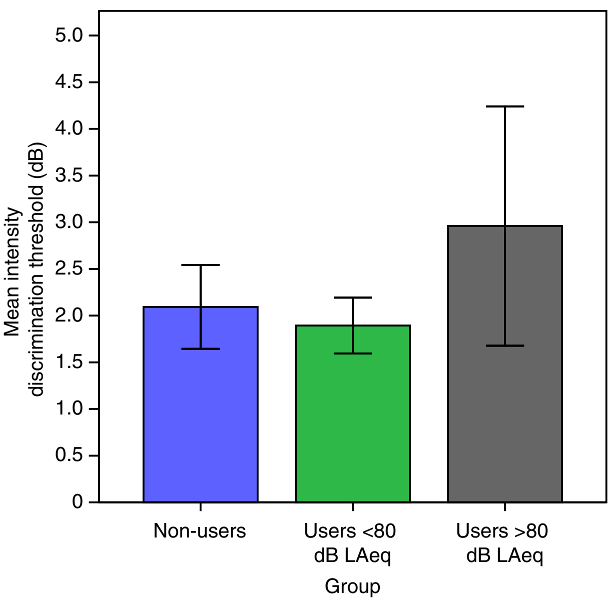

FIG. 8

Mean intensity discrimination thresholds of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq groups). Error bars represent standard deviations.

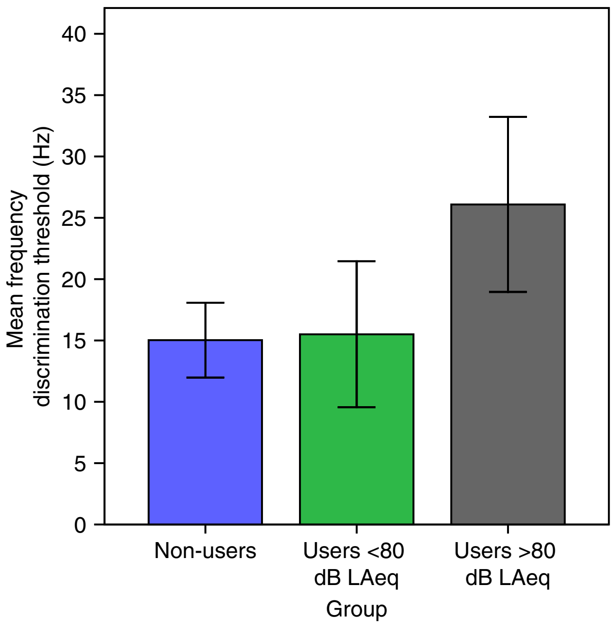

FIG. 9

Mean frequency discrimination thresholds of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq groups). Error bars represent standard deviations.

Temporal modulation transfer function. Mean modulation detection thresholds as a function of frequency, with one standard deviation, across the three groups, are depicted in Figure 10. The figure shows that mean modulation detection thresholds were poorer in the personal music system user group listening at levels higher than 80 dB LAeq compared to the other two groups.

The multivariate analysis of variance showed a significant main effect of group on mean modulation detection thresholds only at 32 Hz (F (2, 50) = 6.75, $p < 0.01$). At other modulation frequencies, although personal music system users listening at levels higher than 80 dB LAeq had lower mean modulation detection thresholds, the difference did not reach statistical significance (F(2, 57) = 1.2, $p > 0.05$, for 8 Hz; F(2, 57) = 1.164, $p > 0.05$, for 16 Hz; F(2, 57) = 2, $p > 0.05$, for 64 Hz; and F (2, 57) = 2.6, $p > 0.05$, for 128 Hz). Pairwise comparisons with Bonferroni corrections for multiple comparisons showed that the personal music system user group listening at levels higher than 80 dB LAeq had significantly poorer mean modulation detection thresholds compared to the other two groups.

Transient evoked otoacoustic emissions. The global transient evoked OAE (TEOAE) amplitudes were considered for analysis. The mean TEOAE amplitudes in

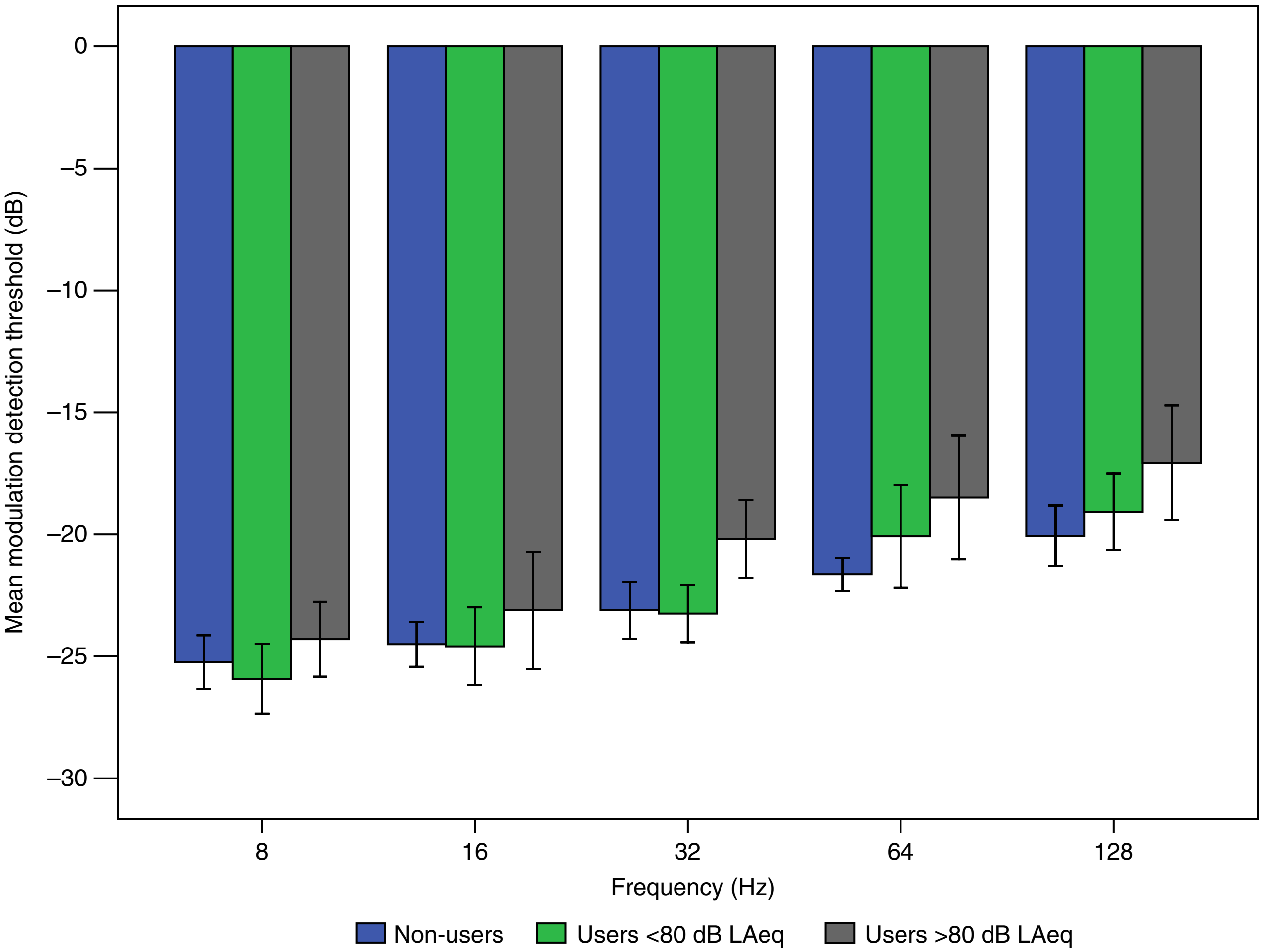

FIG. 10
Mean modulation detection thresholds of non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) at 8, 16, 32, 64 and 128 Hz. Error bars represent one standard deviation.

non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq) are shown in Figure 11.

The figure shows that mean TEOAE amplitude was lower in the personal music system user group listening at levels higher than 80 dB LAeq compared to the other two groups. The one-way analysis of variance revealed a significant main effect of group on global TEOAE amplitude in right ears (F(2, 57) = 9.5, $p < 0.01$) and left ears (F (2, 57) = 4.76, $p < 0.01$). Pairwise comparisons with Bonferroni corrections revealed that the personal music system user group listening at levels higher than 80 dB LAeq had significantly smaller TEOAE amplitudes compared to the other two groups, in both ears. There was no statistically significant difference between TEOAE amplitudes for non-users and users of personal music systems listening at levels lower than 80 dB LAeq.

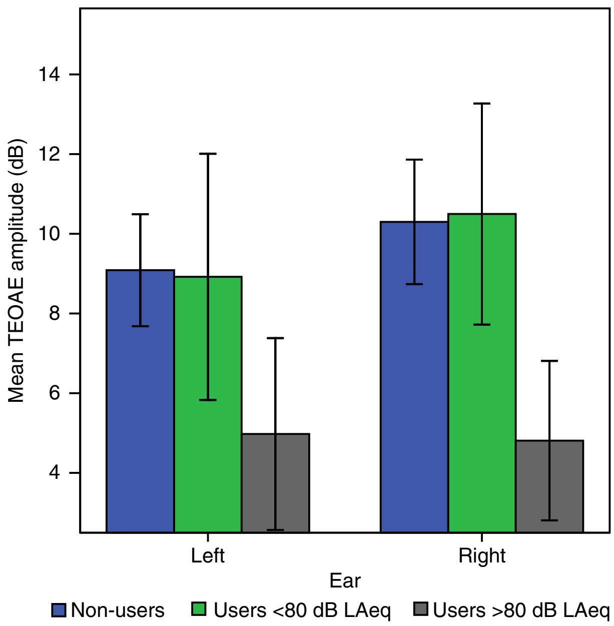

FIG. 11
Mean transient evoked otoacoustic emission (TEOAE) amplitudes in non-users and users of personal music systems (listening at levels lower than 80 dB LAeq or higher than 80 dB LAeq), for right and left ears. Error bars represent one standard deviation.

Output listening levels and auditory behaviour

Pearson's product-moment correlation analysis was conducted to assess the relationship between auditory behaviours and listening levels. Table I shows the correlation coefficients (r values) and levels of

https://doi.org/10.1017/S0022215116001031 Published online by Cambridge University Press

TABLE I
CORRELATION BETWEEN A-WEIGHTED EQUIVALENT CONTINUOUS SOUND LEVELS AND AUDITORY MEASURES

Parameter	r value
TEOAE	
– Right ear	−0.4*
– Left ear	−0.6*
PTA conventional	
– Right ear	−0.1
– Left ear	0
PTA extended high frequency	
– Right ear	0.5*
– Left ear	0.5*
Mean modulation detection threshold	
– 8 Hz	0.1
– 16 Hz	0.2
– 32 Hz	0.4
– 64 Hz	0.2
– 128 Hz	0.3
Intensity discrimination	0.2
Frequency discrimination	0.2
Syllable identification	
– At 0 dB SNR	0
– At −5 dB SNR	0.2

*$p < 0.05$. TEOAE = transient evoked otoacoustic emission; PTA = pure tone average; SNR = signal-to-noise ratio

significance (p values) for significant correlations, and Figure 12 shows scatter plots of the same. The table and figure show that the TEOAE amplitudes of both ears had significant negative correlations with LAeq sound pressure levels. This means that individuals who listened to personal music systems at higher levels had lower TEOAE amplitudes. Furthermore, there was a significant positive correlation between extended high frequency average pure tone thresholds and LAeq. This means that individuals who listened to personal music systems at higher LAeq levels had worse thresholds in the extended high frequency region. All other correlations between auditory measures and LAeq were not significant.

Summary

The results showed that an alarming proportion of young adults were using personal music systems at levels that could damage hearing. Although all personal music system users had clinically normal hearing thresholds and OAEs, those who used these devices at higher settings had lower OAE amplitudes and poorer pure tone hearing thresholds, especially at higher frequencies. These individuals also had poorer frequency and temporal processing. Furthermore, there was a significant relationship between TEOAE amplitudes, hearing thresholds at high frequencies and LAeq levels.

Discussion

The use of personal music systems is now very common among the young.[1,2] Technological advancements have made personal music systems more popular than ever. Improvements in digital technology have meant that personal music systems are now small and lightweight, with considerable storage capacity and improved sound quality. This has led to prolonged use of personal music systems at higher volume settings.[1]

Output sound pressure levels

The results revealed that output sound pressure levels at participants' preferred volume control settings ranged between 51 and 98 dB LAeq. Comparison of equivalent diffuse field LAeq values showed that about 33 per cent of participants reached the maximum allowable noise level if listening for 4 hours, and more than 20 per cent of the participants reached the maximum allowable noise level within 1 hour. These figures are alarming, as substantial proportions of young adults are using personal music systems at sufficiently loud levels to cause damage to hearing.

The output levels in the current study are comparable to those reported in the literature. Torre reported that maximum ear canal sound pressure levels of personal music systems exceeded 100 dB SPL.[8] Similar results were also reported by Kumar *et al.*[10] They stated that nearly 30 per cent of the participants in their study were using personal music systems at levels higher than permissible limits.

As noted earlier, given the improvements in signal processing and digital technology, music is no longer distorted at high volume settings. Hence, young adults are more likely to use personal music systems for longer periods, at higher volume settings. In addition, most modern day personal music systems are used with the ear bud or insert type of earphones, and previous research has shown that ear canal output sound pressure levels are higher with the insert type of earphones.[7,9,17,18]

Effects of personal music systems on hearing

Pure tone hearing thresholds. Pure tone hearing thresholds showed that in high frequencies and in extended high frequencies, the personal music system user group listening at levels higher than 80 dB LAeq had significantly poorer hearing thresholds compared to the other two groups. These findings suggest that the use of personal music systems at higher volume levels has a deleterious effect on hearing thresholds in the extended high frequency region. These effects were seen despite normal hearing in the conventional audiometric frequency region.

The insensitivity of measurements in the conventional frequency region in revealing subtle cochlear damage is well reported in the literature.[10,19,20] Extended high frequency hearing thresholds are reported to be more sensitive to noise-induced damage than conventional audiometric frequencies. Peng *et al.* reported that extended high frequencies may be affected by noise earlier when compared to conventional audiometric frequencies.[11] Sulaiman *et al.* reported that personal music system users for

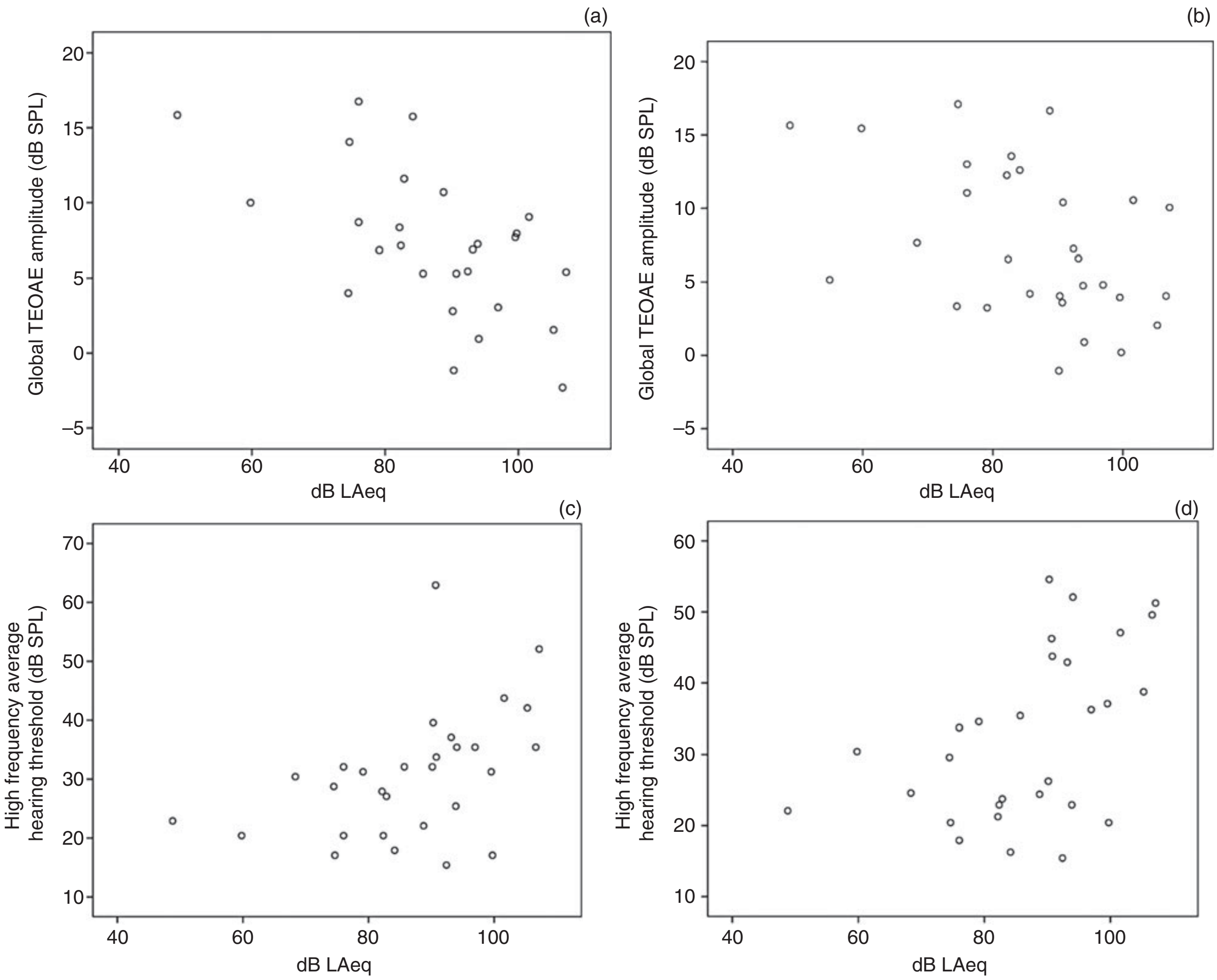

FIG. 12

Scatter plots of average A-weighted equivalent continuous noise level (dB LAeq) values and: global transient evoked otoacoustic emission (TEOAE) amplitudes in right ears (a) and left ears (b); extended high frequency average hearing thresholds in right ears (c) and left ears (d).

whom noise levels exceeded 85 dBA had poorer extended high frequency hearing thresholds and an increased incidence of tinnitus.[21] Furthermore, poorer extended high frequency thresholds were also exhibited in those users whose noise levels were 75 dBA or less but who had been using personal music systems for more than four years. Poorer thresholds in the extended high frequency region in combination with clinically normal hearing thresholds in the conventional audiometric range suggests that listening to music through personal music systems at higher intensities may cause subtle pre-clinical damage to the auditory system, and over the years such behaviour may be hazardous to hearing.

Transient evoked otoacoustic emissions. Global amplitudes of transient evoked OAEs (TEOAEs) were significantly poorer in the personal music system user group listening at levels higher than 80 dB LAeq compared to the other two groups. Previous reports have also indicated the deleterious effects of personal music system use on OAEs. LePage and Murray analysed the TEOAE amplitudes of 1724 participants.[22] Their results showed that TEOAE amplitudes were lower in personal music system users. Santaolalla Montoya *et al*. measured the TEOAE and distortion product OAE (DPOAE) amplitudes in young adults using MP3 players.[23] They evaluated incidence, amplitude and spectral content of both TEOAEs and DPOAEs. Their results indicated that the subjects who had used MP3 players for the most years and for a greater number of hours per week had a reduced incidence and lower amplitudes of both OAE types. The OAEs were affected in the high and low frequency regions. The authors concluded that OAEs can be used to detect subtle cochlear damage even before it is evident in conventional pure tone audiometry.[23]

Kumar *et al*. compared DPOAE amplitudes between normal hearing users and non-users of personal music systems.[10] Their results revealed that individuals who listened to music at higher output sound pressure levels had lower DPOAE amplitudes at 6 kHz. However, all individuals had clinically normal

https://doi.org/10.1017/S0022215116001031 Published online by Cambridge University Press

DPOAE amplitudes and signal-to-noise ratios. These results suggest that listening to music can cause slight pre-clinical damage to the auditory system, and such activity could over time adversely affect the hearing system.

Psychophysical and speech perception measures. The personal music system user group listening at levels higher than 80 dB LAeq showed significantly poorer intensity discrimination thresholds and modulation detection thresholds compared to the other two groups. Furthermore, the group listening to music at levels higher than 80 dB LAeq showed significantly poorer syllable identification in noise at −5 dB signal-to-noise ratio. At better signal-to-noise ratio (0 dB), there was no difference between the groups. This result indicates a difficulty in perceiving speech in adverse listening conditions for individuals who listened to music at higher noise levels. No such findings (poor performance) were observed for those individuals who used personal music systems at levels lower than 80 dB LAeq. Therefore, it seems that a safe level to listen to personal music systems is lower than 80 dB LAeq.

Poor performance on the psychophysical tasks could be due to subtle damage to cochlear functioning or an effect of prolonged exposure to loud music in the central auditory system. In the present study, reduced OAE amplitude, along with elevated extended high frequency thresholds, indicate compromised cochlear functioning. Cochlear damage is known to alter the sharpness and shapes of auditory filters, which in turn may have deleterious effects on supra threshold auditory processing, such as speech perception in noise.[24,25]

Observed poor performance on speech perception in noise, intensity discrimination and mean modulation detection thresholds could also be due to alterations in the central auditory pathway. Previous reports have indicated that any damage to the cochlear structure can eventually result in central auditory pathway alterations.[26] Kujala and Brattico, in their review of detrimental noise effects on speech perception, pointed out that noise has transient and sustained detrimental effects on central speech processing.[27] During noise, the well-known left hemisphere dominance in speech discrimination became right hemisphere preponderant. Long-term exposure to noise has a persistent effect on brain organisation and attention control. Kujawa and Liberman showed, in animal models, that the thresholds and damage to cochlear sensory cells due to acoustic overexposure is completely reversible.[28] However, acute loss of afferent nerve endings is persistent. Furthermore, overexposure also causes delayed degeneration of the cochlear nerve. The authors concluded that noise-induced damage to the ear has progressive consequences that are considerably more widespread and are not revealed by conventional audiometry.

Relationship between auditory measures and listening levels

The results indicated that exposure levels were significantly correlated with the extended high frequency thresholds and TEOAE amplitudes. This suggests that individuals who listen to personal music systems at higher volume levels tend to have poor extended high frequency thresholds and reduced TEOAE amplitudes, indicative of cochlear damage. However, all the participants in the current study had normal hearing in the conventional frequency region. As discussed earlier, extended high frequency audiometry and OAEs are more sensitive to subtle cochlear dysfunction compared to conventional testing.

- **Personal music system use is increasing**
- **Prolonged use may result in damage to hearing**
- **Use of personal music systems at higher volume levels caused elevated extended high frequency thresholds and reduced otoacoustic emissions**
- **It also caused poor speech-in-noise perception, and reduced frequency discrimination and temporal modulation detection**
- **There was a positive relationship between deleterious hearing effects and noise exposure levels**

Conclusion

Our results suggest that listening to music through personal music systems at higher volume levels (over 80 dB LAeq) may not result in clinically significant hearing loss, yet may cause subtle pre-clinical damage to the auditory system, and over the years such behaviour may be hazardous to hearing.

Acknowledgement

This work was supported by the Department of Science and Technology, Government of India (SB/FT//LS-179/2012).

References

1 Williams W. Noise exposure levels from personal stereo use. *Int J Audiol* 2005;**44**:231–6
2 Keppler H, Dhooge I, Vinck B. Hearing in young adults. Part I: the effects of attitudes and beliefs toward noise, hearing loss, and hearing protector devices. *Noise Health* 2015;**17**:237–44
3 National Institute for Occupational Safety and Health. Noise and Hearing Loss Prevention. In: http://www.cdc.gov/niosh/topics/noise/stats.html [8 March 2016]
4 Ministry of Environment and Forests. Noise Pollution (Regulation and Control) Rules, 2000. In: http://envfor.nic.in/downloads/public-information/noise-pollution-rules-en.pdf [8 March 2016]
5 Wood WS. Maximum available sound-pressure levels from stereo components. *J Acoust Soc Am* 1972;**52**:484
6 Katz AE, Gerstman HL, Sanderson RG, Buchanan R. Stereo earphones and hearing loss. *N Engl J Med* 1982;**307**:1460–1

7 Fligor BJ, Cox LC. Output levels of commercially available portable compact disc players and the potential risk to hearing. *Ear Hear* 2004;**25**:513–27
8 Torre P. Young adults' use and output level settings of personal music systems. *Ear Hear* 2008;**29**:791–9
9 Lee PC, Senders CW, Gantz BJ, Otto SR. Transient sensorineural hearing loss after overuse of portable headphone cassette radios. *Otolaryngol Head Neck Surg* 1985;**93**:622–5
10 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**:132–40
11 Peng J-H, Tao Z-Z, Huang Z-W. Risk of damage to hearing from personal listening devices in young adults. *J Otolaryngol* 2007; **36**:181–5
12 Margolis RH, Heller JW. Screening tympanometry: criteria for medical referral. *Audiology* 1987;**26**:197–208
13 Carhart R, Jerger JF. Preferred method for clinical determination of pure-tone thresholds. *J Speech Hear Disord* 1959;**24**:330–45
14 Grassi M, Soranzo A. MLP: a MATLAB toolbox for rapid and reliable auditory threshold estimation. *Behav Res Methods* 2009; **41**:20–8
15 ISO 1999:2013. Acoustics -- Estimation of noise induced hearing loss. In: http://www.iso.org/iso/catalogue_detail.htm?csnumber=45103 [8 March 2016]
16 Health and Safety. The Control of Noise at Work Regulations 2005. In: http://www.legislation.gov.uk/uksi/2005/1643/pdfs/uksi_20051643_en.pdf [8 March 2016]
17 Hodgetts WE, Rieger JM, Szarko RA. The effects of listening environment and earphone style on preferred listening levels of normal hearing adults using an MP3 player. *Ear Hear* 2007;**28**:290–7
18 Catalano PJ, Levin SM. Noise-induced hearing loss and portable radios with headphones. *Int J Pediatr Otorhinolaryngol* 1985;**9**: 59–67
19 Mehrparvar AH, Mirmohammadi SJ, Ghoreyshi A, Mollasadeghi A, Loukzadeh Z. High-frequency audiometry: a means for early diagnosis of noise-induced hearing loss. *Noise Health* 2011;**13**:402–6
20 Mehrparvar AH, Mirmohammadi SJ, Davari MH, Mostaghaci M, Mollasadeghi A, Bahaloo M *et al*. Conventional audiometry, extended high-frequency audiometry, and DPOAE for early diagnosis of NIHL. *Iran Red Crescent Med J* 2014;**16**:e9628
21 Sulaiman AH, Husain R, Seluakumaran K. Hearing risk among young personal listening device users: effects at high-frequency and extended high-frequency audiogram thresholds. *J Int Adv Otol* 2015;**11**:104–9
22 LePage EL, Murray NM. Latent cochlear damage in personal stereo users: a study based on click-evoked otoacoustic emissions. *Med J Aust* 1998;**169**:588–92
23 Santaolalla Montoya F, Ibarguen AM, Vences AR, del Rey AS, Fernandez JM. Evaluation of cochlear function in normal-hearing young adults exposed to MP3 player noise by analyzing transient evoked otoacoustic emissions and distortion products. *J Otolaryngol Head Neck Surg* 2008;**37**:718–24
24 Glasberg BR, Moore BC. Auditory filter shapes in subjects with unilateral and bilateral cochlear impairments. *J Acoust Soc Am* 1986;**79**:1020–33
25 Moore BC. *Cochlear Hearing Loss: Physiological, Psychological and Technical Issues*. Chichester: John Wiley & Sons, 2007
26 Harrison RV. The prevention of noise induced hearing loss in children. *Int J Pediatr* 2012;**2012**:473541
27 Kujala T, Brattico E. Detrimental noise effects on brain's speech functions. *Biol Psychol* 2009;**81**:135–43
28 Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *J Neurosci* 2009;**29**:14077–85

Address for correspondence:
Dr U Ajith Kumar,
Department of Audiology,
All India Institute of Speech and Hearing,
Manasagangothri,
Mysore-570006, India

E-mail: ajithkumar18@gmail.com

Dr U A Kumar takes responsibility for the integrity of the content of the paper
Competing interests: None declared