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Original Article

Audio-Vestibular Findings in Young Regular and Non-Regular Personal Music System Users

Darshan Devananda[1], Vipin Ghosh[1], Nayana Benny[2], Mereena James[3]

[1]Department of Speech and Hearing, JSS Institute of Speech and Hearing, Karnataka, India
[2]Communicative Disorder Assistant, Kids Autism and Speech Clinic, Ontaria, Canada
[3]Ramaiah Memorial Hospital, Bangalore, Karnataka, India

ORCID iDs of the authors: D.D. 0000-0002-4909-4509, V.G. 0000-0003-4673-933X.

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BACKGROUND: Younger adults frequently utilize personal music systems (PMSs) for extended periods for leisure. It has been reported in the literature that hearing abilities are affected in such individuals. However, its effect on auditory processing abilities and the vestibular system remains unclear. Hence, the present study was carried out to investigate the audiological and vestibular functioning in young adults who use PMSs regularly.

METHODS: Forty participants between 18 and 25 years of age were divided into 2 groups. Group 1 included 20 regular PMSs users from 2 to 3 years, and group 2 comprised 20 participants who were non-regular PMSs users. Detailed audiological evaluations were carried out on 15 participants in each group, and vestibular evaluations were carried out on all the participants.

RESULTS: It was observed that the extended high-frequency hearing thresholds and otoacoustic emissions were affected in the regular PMSs users. The gap in noise test and vestibular evoked myogenic potential testing revealed that temporal resolution abilities and vestibular system functioning are also compromised among regular PMS users.

CONCLUSION: Thus, this study highlights the subtle vestibular and auditory impairments that PMS may produce in young adults, as well as the significance of a battery of tests to detect them.

KEYWORDS: Auditory and vestibular findings, leisure noise, personal music system users, recreational noise

INTRODUCTION

Personal music systems (PMSs) and personal listening devices (PLDs) are synonyms and terms that are interchangeably used in the literature to refer to portable devices that are used to play audio files. These devices include portable media players and mobile phones and are commonly used by younger adults for prolonged durations of recreation. It is reported that excessive exposure to recreational or occupational noise typically causes damage to the hair cells of the ear and leads to metabolic and mechanical changes in the organ of Corti, resulting in noise-induced hearing loss (NIHL). However, the extent of this damage remains uncertain.[12] Pure tone thresholds were normal in PLD users at conventional test frequencies (0.5-8 kHz), and their thresholds were worse for extended high-frequency (EHF) regions (8 kHz).[3] This could indicate an early stage of NIHL. The transient-evoked otoacoustic emission amplitude (TEOAE) and the distortion product otoacoustic emission (DPOAE) have been shown to decrease in regular PLD users relative to non-users. Important variations were also found between high frequencies (3-6 kHz) and EHFs (9-16 kHz) hearing thresholds among PMS users.[4] Among PMS users, elevated hearing thresholds were found, which were directly proportional to the volume and period of usage. There is a strong and reliable correlation with the audiometric notch in hearing threshold shift at 10, 11.2, 12.5, or 14 kHz, with EHF hearing threshold shift being even more frequent than the audiometric notch.[5] Since noise-exposed subjects with normal audiograms have decreased otoacoustic emissions (OAEs),[5,6] it has been believed that OAEs should be used before audiometric tests to detect noise-induced changes at early stages.[7] Thus, OAEs are reported to be a more sensitive early indicator of noise-related damage than the audiogram itself.[6-8] It is also reported that DPOAE amplitude reduction is an early warning of preclinical damage and increased susceptibility to hearing loss.[9]

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Along with hearing thresholds, temporal processing abilities are also reported to be affected because of prolonged exposure to noise.[10] However, another study reported that varying occupational noise exposure, like traffic noise exposure, does not have a marked impact on temporal processing skills as reflected by the gap detection test and temporal modulation transfer function.[11] Similarly, the effect of prolonged music exposure on the temporal envelope and fine structure perception abilities of young adults with normal hearing sensitivity was studied, and it was reported that the correlation between music exposure and temporal cues was non-significant.[12]

Individuals who are exposed to noise are also susceptible to vestibular system deficits due to their proximity to the cochlear structure and cochlear nerve. Animal studies demonstrate the resemblance between the functional impairments caused by high levels of noise on the vestibular system, particularly the otolith organs.[13] This finding can be described anatomically since the vestibular nerve, as well as the cochlear nerve, join and form the vestibulocochlear nerve after entering the internal acoustic meatus. Consequently, lesions in this area may produce symptoms in both components.

Vestibular-evoked myogenic potentials (VEMPs) are a common method used to investigate the vestibular system. This test assesses the functioning of the utricle and saccule as well as their neural pathways. Cervical vestibular-evoked myogenic potential (cVEMP) and ocular vestibular-evoked myogenic potentials (oVEMP) are increasingly being increasingly used for evaluating the integrity of the vestibular system. Abnormal VEMP recordings are reported in individuals with NIHL, which reflects the effect of noise on the sacculocollic pathway.[14] Similarly, a study has reported altered sacculocollic reflexes in regular PMS users.[15] Thus, it is a well-established fact that noise adversely affects hearing and that the vestibular system functioning is also at risk. However, there are equivocal findings on the effect of noise on auditory processing abilities. Hence, the present study was aimed at evaluating the peripheral hearing abilities, temporal processing skills, and integrity of the vestibular system in individuals who use PMS regularly.

METHODS

Participants

The current study used a standard group comparison design. A total of 40 participants were included in the current study. They were divided into 2 groups of 20 subjects each. All were within the age range of 18-25 years. The first group included participants who had been using PMS for at least 2 years for at least 2-5 hours daily with a loudness level of more than 4 on a scale of 10. This group was considered regular PMS users. The participants who did not meet the criteria were classified as non-regular PMS users. All the participants were native Kannada speakers with bilaterally normal hearing sensitivity. Individuals with any reported history of middle ear pathology, psychological, neurological, systemic, visual, behavioral, or other related pathology were not included in the current study. Informed written consent was obtained from all the individual participants included in the study. Institutional Ethical Committee of JSS Institute of Speech and Hearing with reference number: Jssish/EC/2022-18, date: October 03, 2022.

MAIN POINTS

- Hearing and vestibular functions in younger adults.
- Comparison of hearing and vestibular functions in regular and non-regular personal music system users.
- Recreational noise has an impact on hearing and vestibular functioning in younger adults.

Procedure

A detailed case history was taken for each participant before testing. A dizziness questionnaire developed by the Maryland Hearing and Balance Centre (2004)[16] was administered to all the participants to analyze the balance difficulties, if any, experienced by the participants. A detailed audiological profiling including pure tone audiometry, EHF audiometry, otoacoustic emissions, and gap in noise (GIN) test was carried out on 30 participants (15 from each group). Meanwhile, all the 40 participants underwent cVEMP and oVEMP testing. The procedures used to administer these tests are described below.

Pure Tone Audiometry and Extended High-Frequency Audiometry

A calibrated double-channel diagnostic audiometer, Inventis Piano with Telephonics Dynamic Headphones (TDH) 39 headphones, and radio ear B71 bone vibrator were used to carry out the pure tone audiometry testing. Audiometric hearing thresholds were measured for the octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 to 4000 Hz for bone conduction using the modified Hughson-Westlake procedure.[17] The pure-tone average was calculated by averaging thresholds obtained at 4-octave frequencies, i.e., 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz as recommended by the World Health Organization's hearing-impairment grading system.[18] Extended high-frequency audiometry was carried out using the same audiometer coupled with Sennheiser High Definition Audio (HDA) 206 headphones. Immittance testing was carried out to rule out middle ear pathologies in all the participants.

Otoacoustic Emission

Distortion product otoacoustic emission was recorded using neuro audio screen equipment in a sound-treated room with ambient noise levels meeting American National Standards Institute (ANSI) (1999) specifications. Signal-to-noise ratio (SNR) and amplitude of the OAE were measured at different probe tone frequencies.

Gap in Noise Test

A wideband noise signal with a duration of 500 milliseconds was used as the stimulus. The test was carried out using a staircase procedure, which was adopted in MATLAB (The Math Works, Inc, R2010a). The stimulus was presented using an HP (Intel Core i5 processor) laptop equipped with calibrated Sennheiser HD 206 headphones. The intensity of the stimulus was maintained at the participant's most comfortable level of loudness. Stimuli during the entire testing were presented binaurally for all the participants. A total of 30 trials were presented to each participant. A 3 Alternate Force Choice method was used where, in each trial, 3 stimuli were presented, 1 of which had a temporal gap (variable stimulus) while the other 2 did not (standard stimulus). The duration of the temporal gap increases or decreases adaptively, based on the response to the previous trial. The responses were recorded in the psychoacoustic toolbox for further analysis. The smallest gap in the varied stimulus that the individual was able to identify was defined as the GIN threshold.

Cervical Vestibular-Evoked Myogenic Potential and Ocular Vestibular-Evoked Myogenic Potential

Intelligent Hearing systems (IHS)version 4.3.02 (Miami, Florida, USA) were used for recording air-conducted tone burst evoked cVEMP and oVEMP. Gold-plated disc electrodes and a calibrated Eartone 3–A insert earphone were used to deliver the stimuli. Recording protocols for cVEMP and oVEMP are given in Table 1. The recorded cVEMP and oVEMP responses were analyzed, and peaks (cVEMP: P13, N23; oVEMP: n1, p1) were identified for all the participants in both groups. The absolute latencies, amplitudes, and amplitude asymmetry ratio were estimated for both cVEMP and oVEMP recordings. The amplitude asymmetry ratio for the P13-N23 complex was estimated using the following formula

Amplitude asymmetry ratio = amplitude of P13 – N23 complex in the right ear – amplitude of P13 – N23 complex in the left ear/amplitude of P13 – N23 complex in the right ear – amplitude of P13 – N23 complex in the left ear × 100 (1)

Similarly, the amplitude asymmetry ratio of the n1–p1 amplitude complex was estimated using the following formula:

Amplitude asymmetry ratio = amplitude of nl – pl complex in the right ear – amplitude of nl – pl complex in the left ear/amplitude of nl – pl complex in the right ear + amplitude of nl – pl complex in the left ear × 100 (2)

Further, the obtained raw data were subjected to suitable statistical analysis.

RESULTS

Shapiro–Wilk test was done to establish whether the data obtained were normally distributed. The findings suggested that the data were not normally distributed. Hence, non-parametric tests were performed for further analysis.

Pure Tone Average and High-Frequency Audiometry

Mann–Whitney *U* test was used to compare pure tone average and high-frequency audiometry thresholds across the groups. The results revealed that there was no significant difference between the groups in pure tone average (U = 1752.5, P > .05). However, a significant difference was observed between the groups for EHF thresholds at 10 kHz (U = 1398, P = .032) and 11.2 kHz (U = 1338.5, P = .014). The mean pure tone average and EHF thresholds obtained in both the groups are depicted in Figure 1.

Oto Acoustic Emission Amplitude and Signal-to-Noise Ratio

The Mann–Whitney *U* test revealed a significant difference between the groups in OAE amplitude at 4.2 kHz (U = 1396, P = .034) and OAE SNR at 6.5 kHz (U = 1410, P = .041). The mean and SD of OAE amplitude and SNR obtained in both the groups are shown in Figure 2.

Temporal Processing Abilities

Mean GIN thresholds obtained from both groups were also compared using the Mann–Whitney *U* test. This analysis revealed that there was a significant difference between the groups in GIN scores (U = 246, P = .003). The mean GIN thresholds obtained in both the groups are depicted in Figure 3. In addition, Spearman's rank correlation test was used to check for any potential correlation between GIN thresholds and variables such as pure tone thresholds, EHF thresholds, OAE amplitudes, and SNR in both groups. However, the results revealed that there is no significant correlation between GIN thresholds and any of these variables mentioned.

Cervical Vestibular-Evoked Myogenic Potential and Ocular Vestibular-Evoked Myogenic Potential

Latency and amplitude parameters of cVEMP and oVEMP were compared between the groups using the Mann-Whitney U test. The results showed that the latencies of P13 (U = 569.50, P = .027) and N23 (U = 567.50, P = .025) of cVEMP are significantly delayed in regular PMS users. However, there was no significant difference noted

Table 1. Recording Protocol of Cervical Vestibular-Evoked Myogenic Potential and Ocular Vestibular-Evoked Myogenic Potential for Participants in the Control and Experimental Group

Stimulus Parameters	cVEMP	oVEMP	Acquisition Parameters	cVEMP	oVEMP
Type of stimuli	Tone burst	Tone burst	Analysis time	70 ms including 10 ms pre-stimulus	70 ms, including 10 ms pre-stimulus
Stimulus frequency	500 Hz (black man window)	500 Hz (black man window)	Filter setting	High pass: 30 Hz Low pass: 1500 Hz	High pass: 30 Hz Low pass: 1500 Hz
Stimulus duration	2-0-2 cycle	2-0-2 cycle	Notch filter	Off	Off
Intensity	95 dBnHL	95 dBnHL	Amplification	5000	5000
Repetition rate	5.1/sec	5.1/sec	Number of channels	1	1
			Number of Recordings	2	2
Polarity	Rarefaction	Rarefaction	Transducer	Insert earphones (ER-3A)	Insert earphone (ER-3A)
Total number of stimuli	200	200	Electrode montage	Non-inverting electrode (+): midpoint of the sternocleidomastoid muscle of the side being stimulated. Inverting electrode (−): sternoclavicular junction. Ground electrode: Lower forehead	Inverting electrode (−): inferior to the lower eyelids Non-inverting electrode (+): immediately inferior to the inverting electrode Ground electrode: lower forehead

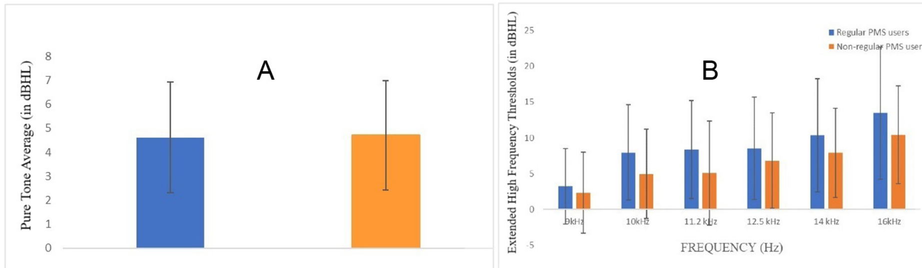

Figure 1. Mean and SD of (A) pure tone average and (B) extended high-frequency thresholds obtained in both groups.

in the latencies of n1 ($U=725.50$, $P=.47$) and p1 ($U=682.50$, $P=.25$) across the groups in oVEMP (Figure 4). Further, the amplitude of the P13-N23 complex was found to be significantly lower among regular PMS users when compared to non-regular PMS users ($U=348.00$, $P=.00$). On the contrary, the amplitude of the n1-p1 complex of oVEMP did not vary significantly between the groups ($U=624.00$, $P=.90$). The amplitude asymmetry ratio was also compared between the groups. The results revealed that the amplitude asymmetry ratio obtained using cVEMP responses ($U=62.00$, $P=.00$) and oVEMP responses ($U=127.00$, $P=.04$) were significantly higher in regular PMS users.

Spearman's rank correlation test was administered to check for any correlation between cVEMP and oVEMP responses and PMS usage. There was no significant correlation obtained between the hours of PMS usage per day and latencies of P13 ($\rho=-0.348$, $P > .05$) and N23 ($\rho=-0.014$, $P > .05$) in cVEMP. However, the correlation analysis between the hours of PMS usage per day and the cVEMP amplitude shows a very strong statistically significant negative correlation ($\rho=-0.837$, $P < .05$). Further, it was observed that there was a significant negative correlation between hours of PMS usage per day and the amplitude asymmetry ratio of cVEMP ($\rho=-0.577$, $P < .05$). Further, there is no significant correlation observed between hours of PMS usage per day and the latencies of n1 ($\rho=0.036$, $P > .05$) and p1 ($\rho=-0.114$, $P > .05$), amplitude of n1 p1 complex ($\rho=0.086$, $P > .05$), and amplitude asymmetry ratio of oVEMP ($\rho=0.077$, $P > .05$).

Similarly, analysis was carried out to check for a correlation between VEMP responses and the total number of years of PMS usage. It was revealed that there is no significant correlation between the total number of years of PMS usage and latency of the N13 peak obtained in cVEMP ($\rho=-0.084$, $P > .05$) and peaks obtained in oVEMP (n1: $\rho=-0.001$, $P > .05$; p1: $\rho=0.083$, $P > .05$). However, a significant correlation was noted between the number of years of PMS usage and latency of P23 in cVEMP ($\rho=-0.483$, $P=.031$). Further, there was no significant correlation observed between years of PMS usage and amplitude measures of cVEMP ($\rho=-0.43$, $P > .05$) and oVEMP ($\rho=0.038$, $P > .05$). Similarly, no significant correlation was observed between years of PMS usage and the amplitude asymmetry ratio of cVEMP ($\rho=-0.243$, $P > .05$) and oVEMP ($\rho=0.154$, $P > .05$).

The information gathered using the dizziness questionnaire was also analyzed. It was observed that 30% of regular PMS users who participated in the study reported symptoms of balance deficit. However, only 5% of participants among the non-regular PMS users reported balance-related problems.

DISCUSSION

Detailed audiological and vestibular evaluations were carried out on all the participants of the study. Results obtained in each of these evaluations were compared between regular and non-regular PMS users. These findings are discussed in this section.

Pure Tone Audiometry and High-Frequency Audiometry

Statistical analysis revealed that the mean pure tone average is not significantly different between the groups. Earlier researchers have reported that there is no significant correlation between hearing threshold and daily use of PMSs.[17-19] However, a few of the studies in the literature reported significant deviation in the pure tone threshold on PMS usage.[19-22] Earlier studies[19] reported that the pure tone thresholds are elevated in participants who used PMS for more than 5 years. Another study[20] also reported that the conventional audiometric findings were affected in prolonged PMS users. It is also reported that the higher frequency thresholds at 6 kHz and above are affected in people who use PMS for prolonged durations[21] while another study reported that the pure tone thresholds are affected in individuals who use earphones connected to the PMS.[22] The mean

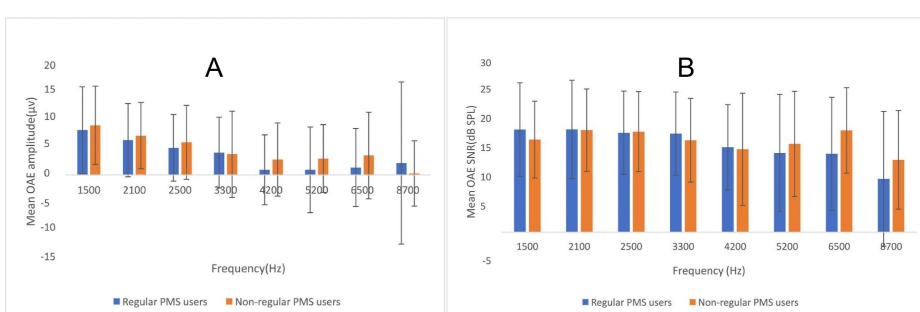

Figure 2. Mean and SD of (A) OAE amplitude and (B) SNR obtained in both groups.

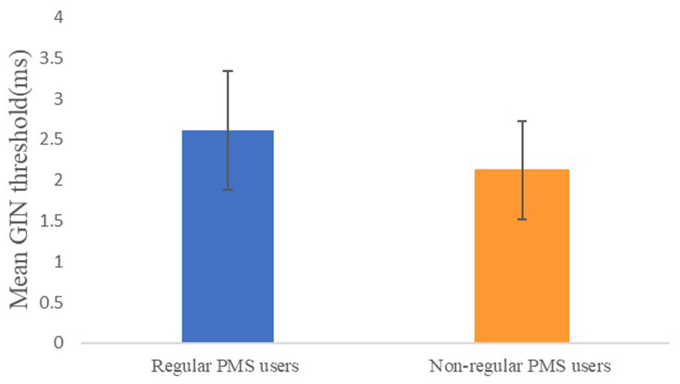

Figure 3. Mean and SD of gap in noise thresholds obtained in both the groups.

duration of usage of PMS among the regular PMS users in the current study was 3.25 years, which is comparatively lower than earlier studies. Also, some of the participants in the regular PMS group of the current study have been using headphones unlike earphones alone as reported in the earlier study. Thus, the variations observed between the findings of the current study and the earlier reports may be attributed to these methodological differences.

The EHF threshold was observed to be different between the groups at 10 kHz and 11.2 kHz. Similar findings are reported in some of the earlier studies conducted on PMS users. It is reported that the PLD users who had used the device for more than 5 years at high volume had considerably greater hearing thresholds at 3 kHz, 10 kHz, and 13 kHz. They concluded that EHF can be utilized to diagnose NIHL in PLD.[23] Thus, the earlier reports are in congruence with the present study findings and have demonstrated the effect of long-term regular usage of PMSs on EHF hearing thresholds.

Thus, from the current study findings, the hearing threshold, at least at the EHF range, can be used as a clinical tool to identify changes in hearing thresholds due to prolonged and intense exposure to recreational music.

Otoacoustic Emissions

The current study findings revealed that OAE amplitude and SNR are affected at the higher frequencies. It is reported in the earlier studies that when listening to levels more than 80 dB, the amplitudes of TEOAEs were considerably lower in PMS users.[24] Similarly, another study also reported that the TEOAE amplitude is reduced in subjects who used PMPs (personal music players) intensively compared to non-regular PMP users.[25] The longer PMP listening time was associated with worsened TEOAEs and DPOAEs, both in terms of years and hours per week. Thus, the OAEs, in general, are sensitive to the outer hair cell alterations due to PMS usage.

The Gap in Noise Test

Gap in noise thresholds were significantly reduced in the regular PMS users in comparison to non-regular PMS users. This finding suggests that temporal resolution abilities are affected in regular PMS users. It is reported that individuals who listen to PMSs at levels higher than 80 dB have impaired frequency discrimination and temporal modulation detection, as well as poor speech-in-noise perception.[26] A study on 118 train drivers also revealed that temporal processing skills are affected due to occupational noise exposure. They reported that this may even influence their speech recognition.[25] Thus, it may be inferred from the earlier findings that temporal processing skills are sensitive to noise exposure of different natures including recreational noise. The results of the current study complement these earlier findings. It was also observed that there is no significant correlation between GIN and any of the peripheral hearing measures. This indicates that the variations in temporal processing abilities observed in the study population cannot be attributed to deviations in hearing thresholds or OAE abnormalities.

Cervical Vestibular-Evoked Myogenic Potential and Ocular Vestibular-Evoked Myogenic Potential

In the current study, it was observed that all the latency and amplitude parameters of cVEMP were affected in regular PMS users. However, in oVEMP, only the amplitude asymmetry ratio was observed to be different across the groups. These findings are in congruence with some of the earlier reports.

Loud music from PMS is hypothesized to cause saccular overstimulation-like noise and damage these structures, which is indicated by abnormal or absent cVEMP responses.[15] Prolonged exposure to noise also has been shown to affect cVEMP responses. It is reported that 64.9% of 60 participants with NIHL had abnormal or missing cVEMP, with cVEMP being absent in 28.3%, latency being increased, and peak-to-peak amplitude being lowered in 36.6%.[25] These changes in the saccular macula or inferior vestibular nerve might produce asymmetry in the amplitude of the response or even the absence of response on the affected side.[27] Similarly, oVEMP abnormalities are also reported in earlier studies among individuals with NIHL. It is reported that 20% of participants with NIHL had no oVEMP responses, and the rest of the participants with NIHL had a typical response.[28]

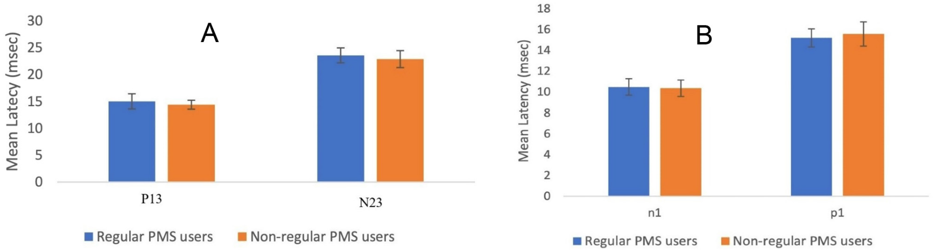

Figure 4. Mean and SD of (A) cervical vestibular-evoked myogenic potential latencies and (B) ocular vestibular-evoked myogenic potential latencies obtained in both the groups.

Correlational analysis between the duration of PMS usage per day and cVEMP responses revealed that the amplitude of the responses reduces, and the amplitude asymmetry ratio increases with an increase in the duration of usage. However, there was no significant correlation between oVEMP responses and the duration of PMS usage. This signifies that the daily dosage of PMS usage affects the vestibular system. However, there was no significant correlation between latency and amplitude measures of cVEMP and oVEMP and total number of years of PMS usage except for the latency of P13. One of the earlier studies also reported that there was no correlation between the duration of noise exposure with latency or amplitude measures of both cVEMP and oVEMP.[29]

Thus, the current study findings and their correlation with the existing literature reflect the impact of regular PMS on the vestibular system. In general, the cVEMP latency and amplitude measurements are found to be more affected in regular PMS users than oVEMP measurements. Earlier studies have also reported that the saccule and inferior vestibular nerve are found to be maximally affected due to overexposure to loud noise. The physical proximity of the saccule to the stapes footplate makes it the most vulnerable to noise-induced damage among the otolith organs.[30]

In addition, 30% of the regular PMS users reported vestibular symptoms. The most common symptom was a spinning sensation (66.6%), followed by light-headedness (33.4%). However, only 1 participant among the non-regular PMS users (5%) indicated light-headedness. An earlier study conducted on military band performers also reported that dizziness was the most common vestibular-related symptom experienced by their study participants.[31] Thus, subtle vestibular deficiencies are expressed as vestibular symptoms in some individuals who are exposed to recreational music.

CONCLUSION

It was observed in the current study that the test of peripheral hearing abilities, such as EHF thresholds and OAE amplitudes, and SNR were affected in the regular PMS users, while the conventional audiometry findings were unaffected. These findings suggest that OAEs and EHFs can be utilized as sensitive early indicators of PMS-induced hearing deficiencies. The current study also indicates the risk of auditory processing deficiencies in them as indicated in the GIN testing. Furthermore, the vestibular test findings imply that regular PMS usage has an impact on the vestibular system. In general, the cVEMP latency and amplitude measurements were shown to be more sensitive than oVEMP measurements. This finding is well linked with the higher prevalence of vestibular-related symptoms in them. Thus, this research emphasizes the subtle auditory and vestibular lesions that PMS may cause in young adults and the importance of test batteries to identify them.

Availability of Data and Materials: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Committee Approval: This study was approved by the Ethics Committee of JSS Institute of Speech and Hearing University (approval no.: Jssish/EC/2022-18; date: October 03, 2022).

Informed Consent: Written informed consent was obtained from the participants who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – D.D., V.G.; Design – D.D., V.G.; Supervision – D.D., V.G.; Resources –V.G., N.B., M.J.; Materials – N.B., M.J.; Data Collection and/or Processing – N.B., M.J.; Analysis and/or Interpretation – D.D., V.G., N.B.; Literature Search – D.D., V.G., N.B., M.J.; Writing – D.D., V.G.; Critical Review – D.D., V.G.

Declaration of Interests: The authors have no conflicts of interest to declare.

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