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Comparative Evaluation of Nerve Conduction Velocity and Pure Tone Audiometric Findings in Users and Non-Users of Personal Listening Devices

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Abstract:

Background: Chronic use of personal listening devices could result in chronic acoustic stress in young adults, and potential peripheral nerve-conduction effects are unknown.

Objective: To compare nerve conduction parameters and pure tone audiometric findings in habitual users and low-exposure non-users.

Methods: 140 healthy adults (18-30 years) were included in the study, 70 of whom were habitual users (exposing to music for at least 2 hours/day for at least 2 years) and 70 who were not (exposing to music less than 30 minutes/day). Duration of exposure, type of device, estimated volume setting, symptoms and occupational or recreational noise were documented. Conducted nerve studies of the median, ulnar, peroneal, tibial and sural nerves, and bilateral pure tone audiometry from 0.25 to 8 kHz.

Results: Users reported 3.1±1.2 hours/day of listening for 4.6±2.1 years. There were no significant differences between groups in nerve conduction velocities, distal latencies, or response amplitude (sural velocity 48.7±4.4 m/s, 49.3±4.2 m/s, respectively; p=0.41). In contrast, users had higher thresholds at 4 kHz (16.8±7.5 versus 12.9±5.9 dB HL; p=0.001), 6 kHz (20.9±9.1 versus 14.1±6.6 dB HL; p<0.001), and 8 kHz (21.7±9.5 versus 15.0±7.0 dB HL; p<0.001). A bilateral 4-6 kHz notch occurred in 18.6% of users and 4.3% of non-users (p=0.008), while tinnitus was reported by 27.1% and 8.6%, respectively (p=0.004). The cumulative exposure was correlated with the 6-kHz threshold (r=0.43; p<0.001).

Conclusion: Early high-frequency auditory changes and tinnitus were associated with the use of the device, but not with peripheral nerve-conduction abnormalities in general. It is recommended that listening-dose reduction and hearing-conservation education be warranted.

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Introduction

The use of headphones and earphones has become a daily habit for studying, traveling, exercising and enjoying leisure time with the help of a smartphone and portable media players. The acoustic dose to the ear will vary with sound level, duration of listening, fit of the transducers, ambient noise level, and individual behavior. Young listeners may turn up the volume when they are in noisy places and may not realize that they are exposed to sound over a period of time if it is not uncomfortable in a single incident. Observational studies have revealed potentially dangerous listening habits of personal listening device users, such as extended listening time per day and listening intensities that exceed recommended limits [1].

Cochlear injury occurs when mechanical and metabolic stress is greater than the ability of the hair cells, supporting cells, synapses and auditory neurons to recover. Initial normal pure tone audiometry may be followed by subtle changes at speech frequencies or at extended high frequencies of 4-8 kHz. A study of young adults revealed that duration of exposure was as important as volume and was related to less favorable hearing thresholds [2]. Evidence from systematic review also indicates a relationship between daily music dose and auditory symptoms and threshold change, but exposure measurement is frequently imprecise [3].

Early detection is important because permanent disability can be preceded by a temporary threshold shift and/or tinnitus. In adolescents, threshold changes, symptoms and diminished auditory reserve have been described in response to apparently normal communication ability from recreational noise studies [4]. Extended high frequency audiometry may detect differences prior to conventional audiometry, and OAE may detect outer-hair-cell dysfunction. The risk of these devices, however, is not consistent across studies due to inconsistent device output, earphone coupling, participant recall, and definitions of unsafe use.

There is no evidence of personal listening exposure as an outcome of peripheral nerve conduction. Acoustic energy is delivered locally to the auditory system; generalized peripheral neuropathy at normal listening levels is not expected. However, certain device users sit in extended positions, develop repetitive compression of the upper limbs and have lifestyle exposures that may affect nerve measurements. Incorporating nerve conduction into a comparative protocol thus offers a physiological negative-control domain: an exposure with an auditory-specific effect should result in audiometric differences but not in a systematic generalized difference in median, ulnar, sural, peroneal or tibial function.

The present study compared the peripheral

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nerve conduction studies and standardized pure tone audiometry of habitual users with low exposure non-users. The main hypothesis was that users would have higher hearing thresholds for the 4-8 kHz range and a higher prevalence of tinnitus and/or audiometric notches. The secondary hypothesis was that the conventional peripheral nerve conduction parameters would not be different when adjusted for age, sex, height, body mass index and physical activity.

1. Materials and Methods

A comparative cross-sectional study was carried out in a university physiology laboratory in conjunction with audiology and neurology. Healthy adults 18-30 years old were recruited from students, interns, and community volunteers. The personal listening device use of at least 2 hours/day for 5 or more days per week for 2 or more years was required for habitual users. The non-users reported less than 30 minutes/day and no previous period of regular use. Seventy participants were included in each group, frequency-matched by age and sex.

Diabetes, thyroid disease, renal disease, vitamin B12 deficiency, neurologic illness, previous injury to upper or lower limb nerves, otitis media, tympanic membrane disease, congenital hearing impairment, occupational noise, regular firearm use, night club employment, recent acoustic trauma, and ototoxic medication were all excluded. Those who had conductive hearing loss, abnormal tympanometry or an air-bone gap > 10 dB were excluded. Concerts and loud recreational activities were recorded and added as a covariate.

Listening-exposure assessment

The questionnaire was structured and recorded the type of device, earphone style, years of use, duration of use per day, the percentage of usual volume, exposure to noise, breaks, and symptoms such as tinnitus, ear fullness, reduced clarity, and transient muffling. Participants performed as they normally would on their own instrument on a familiar song. Output was estimated using a standardised coupler for a sub-sample of 60 users, and the percentage shown was moderately related to measured A-weighted output. An ordinal volume factor and years multiplied by hours/day were used to create a cumulative listening index.

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Nerve conduction studies

Surface electrodes were used for standard distances and median, ulnar sensory studies, sural sensory studies, common peroneal and tibial motor studies were conducted. Prespecified temperature thresholds were maintained for the temperature of the limbs. Distal latency, conduction velocity, sensory nerve action potential amplitude, compound muscle action potential amplitude and selected F-wave latencies were recorded. Test was conducted by a trained physiologist who was not aware of the audiometric result. Documentation of height, dominant hand, BMI, and recent strenuous exercise was recorded as these factors may affect measurements.

Audiological assessment

Audiometry was preceded by otoscopy and tympanometry. Air-conduction thresholds were obtained bilaterally at 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz using calibrated equipment in a sound-treated booth. When indicated, bone conduction was tested at 0.5, 1, 2 and 4 kHz. Audiologist had no information about nerve-conduction results. The threshold at 4 or 6 kHz was defined as 4 or 6 kHz at least 10 dB poorer than the 2 kHz threshold and 8 kHz threshold or adjacent recovery pattern; bilateral notches were analyzed separately. Low frequency and high frequency averages were computed.

Statistical analysis

With alpha of 0.05, a sample size of 70 per group was used to achieve 80% power to detect a 4-dB difference in the 6-kHz threshold. Independent t tests, Mann-Whitney tests, chi-square tests, or Fisher exact tests were used for group comparisons. Mixed-effects models with participant as a random intercept were used for analysis of ear-specific thresholds. Audiometric outcomes were adjusted for age, sex, recreational noise and family history of early hearing loss using multivariable regression. Nerve-conduction models also were adjusted for height, BMI, and limb temperature. Spearman correlation coefficients were used to correlate cumulative listening index with high frequency thresholds. Exploratory frequency-by-frequency comparisons were performed and corrected for false discovery rate, with $p<0.05$ being significant for primary outcomes.

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2. Results

The mean participant age was 23.6±3.1 years among users and 23.2±3.0 years among non-users (p=0.43), and each group included 36 men. Body mass index, height, exercise habits, blood pressure, and recent concert attendance were comparable. Users listened for 3.1±1.2 hours/day over 4.6±2.1 years; 64.3% commonly used in-ear devices, 51.4% reported usual volume above 70% of maximum, and 57.1% frequently listened in noisy surroundings. Tinnitus and transient muffling were more frequent among users (Table 1).

Table 1. Participant characteristics and listening exposure

Variable	PLD users (n=70)	Non-users (n=70)	p-value
Age, years	23.6±3.1	23.2±3.0	0.43
Male sex, n (%)	36 (51.4)	36 (51.4)	1.00
BMI, kg/m²	23.1±2.7	22.8±2.6	0.51
Listening duration, h/day	3.1±1.2	0.2±0.1	<0.001
Years of regular use	4.6±2.1	0.4±0.3	<0.001
Usual volume >70%, n (%)	36 (51.4)	2 (2.9)	<0.001
Use in noisy surroundings, n (%)	40 (57.1)	7 (10.0)	<0.001
Tinnitus, n (%)	19 (27.1)	6 (8.6)	0.004
Transient muffling, n (%)	16 (22.9)	4 (5.7)	0.004
Recent concert/noisy event, n (%)	17 (24.3)	14 (20.0)	0.54

Peripheral nerve conduction parameters were within laboratory reference ranges in both groups. No significant differences were found in median or ulnar sensory latency, sensory velocity, sural velocity or amplitude, median or ulnar motor velocity, or lower-limb motor velocity. Adjustment for height, body mass index, and limb temperature did not materially change the estimates. Four users and three non-users had an isolated borderline parameter, without a consistent anatomical pattern or clinical symptoms (Table 2).

Table 2. Comparison of peripheral nerve conduction parameters

Parameter	PLD users	Non-users	p-value
Median sensory latency, ms	3.18±0.29	3.15±0.28	0.54
Median sensory velocity, m/s	53.6±4.0	54.0±4.1	0.56
Median SNAP amplitude, µV	32.1±9.3	33.0±9.0	0.56
Ulnar sensory velocity, m/s	54.7±3.8	55.1±3.9	0.54
Sural sensory velocity, m/s	48.7±4.4	49.3±4.2	0.41
Sural SNAP amplitude, µV	15.5±4.3	16.0±4.5	0.50
Median motor velocity, m/s	56.0±3.6	56.4±3.7	0.52
Peroneal motor velocity, m/s	48.1±3.5	48.5±3.7	0.51
Tibial motor velocity, m/s	46.9±3.4	47.2±3.5	0.61
Any borderline parameter, n (%)	4 (5.7)	3 (4.3)	>0.99

Audiometric thresholds were similar at 0.25-2 kHz but diverged at 4, 6, and 8 kHz. The largest adjusted difference occurred at 6 kHz (6.5 dB; 95% CI 3.8-9.2; p<0.001). A bilateral 4-6 kHz notch was present in 13 users and 3 non-users. Although most participants retained a speech-frequency pure tone average of 25 dB HL or better, 22 users versus 8 non-users had a high-frequency average above 20 dB HL (p=0.006) (Table 3).

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Table 3. Bilateral mean pure tone thresholds and notch prevalence

Outcome	PLD users	Non-users	p-value
0.5 kHz, dB HL	9.8±4.3	9.5±4.1	0.67
1 kHz, dB HL	9.5±4.2	9.2±4.0	0.67
2 kHz, dB HL	10.6±4.8	9.9±4.5	0.37
4 kHz, dB HL	16.8±7.5	12.9±5.9	0.001
6 kHz, dB HL	20.9±9.1	14.1±6.6	<0.001
8 kHz, dB HL	21.7±9.5	15.0±7.0	<0.001
Speech-frequency PTA, dB HL	10.0±3.6	9.5±3.4	0.40
High-frequency average, dB HL	19.8±7.8	14.0±5.8	<0.001
Bilateral 4-6 kHz notch, n (%)	13 (18.6)	3 (4.3)	0.008
HF average >20 dB, n (%)	22 (31.4)	8 (11.4)	0.006

The cumulative listening index correlated with thresholds at 4 kHz (r=0.31; p=0.009), 6 kHz (r=0.43; p<0.001), and 8 kHz (r=0.38; p=0.001) among users. Daily duration and use in noisy surroundings remained associated with the 6-kHz threshold in a multivariable model, whereas displayed volume percentage was less consistent after adjustment. Tinnitus was associated with a higher high-frequency average (21.9±8.1 versus 17.1±7.4 dB HL; p=0.01) but not with any nerve-conduction parameter.

3. Discussion

Low-exposure non-users had lower thresholds at 4-8 kHz and more often bilaterally had notches and tinnitus and experienced transient muffling than did habitual personal listening device users. Conversely, peripheral nerve conduction was similar in generalized areas. This combination facilitates an exposure-specific auditory effect, instead of a widespread neurophysiological defect. Previous studies on young listeners have also found hazardous listening behaviors and early signs of hearing risk despite the fact that the majority of listeners have fairly normal hearing at the speech frequencies [5].

The greatest group difference was found in the 6-kHz area. Noise-related notches are generally found in the middle of the band (between 3 and 6 kHz) due to the resonance of the ear canal, middle-ear transfer characteristics, and cochlear mechanics. Personal listening devices bring sound close to the tympanic membrane, and in-ear coupling can result in significant amount of sound at seemingly normal displayed volume settings. In studies of leisure-noise exposure, young listeners have been found to have auditory changes prior to functional difficulty [6]. It is biologically and behaviorally plausible that cumulative exposure and daily duration would be related to high-frequency thresholds.

The listening duration and listening in noise

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were stronger predictors than displayed volume percentage. The percentage settings are not common between phones, applications, tracks, and earphones; the same percentage may be equal to different sound-pressure levels. Users also tend to raise their level in buses, gyms or streets to compensate for ambient sound. Studies with adolescents have shown that context of use is a factor in risk and may account for the fact that duration alone is not sufficient to define dose [7]. Dose-monitoring functions that can show real-time output over time can be more helpful than general warnings.

The lack of nerve-conduction differences is not a mere afterthought, but a significant finding. The auditory system is a target of acoustic exposure, and it is not likely that exposure to ordinary devices would cause diffuse median, ulnar, sural, tibial, or peroneal injury. The latter also minimizes the risk of the audiometric differences being due to an undiagnosed generalized neuropathy. The isolated borderline conduction values were also distributed equally and randomly, as would be expected in healthy populations in the presence of biological and technical variation.

The thresholds observed were mostly within the normal range but high elevations at low frequency may suggest low reserve. All noise-injury is not detected by pure tone detection. Suprathreshold coding or speech understanding in noise can be affected by cochlear synaptopathy without affecting routine thresholds. Personal music-player users have been found to have early cochlear or neural indicators in studies using otoacoustic emissions and electrophysiological measures [8]. An effective prevention program should therefore not be delayed until a hearing loss is clinically apparent.

The percentage of users with tinnitus was clinically significant. Tinnitus may be temporary following exposure to high levels of noise, but if it persists it may indicate repeated cochlear stress. The 60/60 concept should be used only as a simple starting message in counseling, not as a universal scientific threshold: Users should turn down the volume, take quiet breaks, use well-fitting noise-isolating or active-noise-cancelling devices in noisy places, listen to the device dose warnings, and not listen to continuous high-level audio while sleeping. It is estimated that there are a large number of young people who are affected by unsafe recreational listening, and that education and device level protection are scalable [9].

The strengths of the study are the matched groups, standardized audiometry, explicit criteria for exposure, assessment of symptoms, adjustment for recreational noise, and inclusion of a physiologically distinct nerve-conduction domain. The study has limitations such as cross-sectional design,

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self-reported historical dose, incomplete dosimetry for all subjects, and the absence of prolonged high-frequency audiometry, OAE, or speech-in-noise testing. Selection bias is a possibility because there may have been a greater response rate from symptomatic users. Notch definition is helpful, but not specific for device exposure, 4-6 kHz. Individual susceptibility and reversibility should be determined in prospective studies with repeated objective auditory measures and dose recorded by the smartphone.

Experimental and behavioural studies support the biological plausibility of early PLD-related auditory change. Exposure of the device at its maximum output level may cause temporary threshold shifts and decrease in the amplitude of the OAE [10]. Prevention thus needs messages that make the acoustic risk real in terms of real behaviours, such as reducing volume, listening breaks, and listening to warning signs [11]. Long-term PLD use has been linked to hearing loss in the conventional and extended high frequencies [12] and combined audiometry and otoacoustic-emission testing has been shown to detect early changes in the cochlea before conventional thresholds are clearly abnormal [13].

Adolescent studies suggest that the impact of cumulative recreational-noise exposure on hearing trajectories may be observed [14]. There are still pilot studies that support the use of extended high frequency audiometry as a sensitive measure in young PLD users [15]. High-duration listening is also well documented across the nation from samples taken from universities [16]. Recent reviews suggest that prolonged high-frequency testing is warranted for early detection of possible damage from PLD [17] and newer experimental studies have shown that music listening in the recreational setting can temporarily impact auditory performance even in young adults with normal baseline audiograms [18].

4. Conclusion

HFT was also found to be related to mild but consistent HFT, increased tinnitus prevalence and increased frequency of audiometric notches in young adults who were regular users of personal listening devices. Physiological differences were limited to auditory exposure and peripheral nerve conduction was similar. Preventing progression may be achieved by reducing cumulative listening dose, limiting volume escalation in noise and adding periodic hearing assessment.

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