ISSN: 2083-389X
eISSN: 2084-3127

J Hear Sci, 2025; 15(2): 41–51
DOI: 10.17430/jhs/197358

Received:
April 25, 2024
Revision accepted:
December 13, 2024
Published online:
October 8, 2025

VARIABLE EARBUD OUTPUT ACROSS VARIOUS DEVICES

Bankole K. Fasanya[1A-F], **Efrem R. Reeves**[2BE], **Alexandra L. Francis**[3AF]

[1] Engineering and Industrial Professions, University of North Alabama, United States
[2] Warfighter Performance Group, Goldbelt Frontier, LLC, United States
[3] Speech, Language & Hearing Sciences, Purdue University West Lafayette, United States

Corresponding author: Bankole Fasanya, Engineering and Industrial Professions, University of North Alabama, 1 Harrison Plaza, 35632, Florence, United States; email: bfasanya@una.edu

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: Today, many people are in the habit of listening to music, watching movies, and playing games via headphones or earbuds connected to devices such as cellphones, computers, and iPads, when studying or doing other activities. This study investigated the LAeq output of four different devices connected with two different earbud types.

Material and methods: A GRAS 45CB Acoustic Test Fixture was used to measure the output of the earbuds. All devices were purchased in a regular store to mimic the natural process and usage of the products. Both earbuds have the same cable length and are of the same design.

Results: The findings indicated that one earbud brand produced varying output levels when connected to different devices, even when the same volume setting was used. Statistical analysis confirmed that the output differences across devices were significant, as reflected in the results: [$F(3) = 805.08$, $p < 0.001$], with a partial R^2 of 89.7% for the right ear, and [$F(3) = 805.08$, $p < 0.001$], with a partial R^2 of 89.7% for the left ear, based on measurements taken at five different volume levels. Likewise, the interactions were also found to be significant in both ears. Furthermore, the discrepancies between the left and right ear outputs for each earbud–device combination were found to be potentially unsafe, raising concerns about auditory risk. Notably, at the 60% volume setting, the sound output from both ears across all tested devices exceeded the exposure limits recommended by the U.S. Environmental Protection Agency (EPA).

Conclusions: Findings showed that one size does not fit all. Findings from this study could help government intervention in headphone/earbud manufacturing policy and standards and assist long-term users of earbuds to regulate the usage of earbuds.

Keywords: earbuds • cell phones • sound pressure • generation • hazard

ZMIANY POZIOMU DŹWIĘKU SŁUCHAWEK DOUSZNYCH W RÓŻNYCH URZĄDZENIACH

Streszczenie

Wprowadzenie: Obecnie wiele osób podczas nauki lub wykonywania innych czynności ma zwyczaj oglądania filmów, grania w gry i słuchania muzyki przez słuchawki lub wkładki douszne podłączone do takich urządzeń jak telefony komórkowe, komputery i iPady. W niniejszej pracy zbadano poziom LAeq czterech różnych urządzeń podłączonych do dwóch różnych typów słuchawek dousznych.

Materiał i metody: Do pomiaru mocy wyjściowej słuchawek wykorzystano urządzenie do testów akustycznych GRAS 45CB. W celu odwzorowania naturalnych procesów zakupu i użytkowania produktów wszystkie urządzenia zostały zakupione w zwykłym sklepie. Obie wkładki douszne mają taką samą długość kabla i są tej samej konstrukcji.

Wyniki: Wyniki wykazały, że jedna marka słuchawek dousznych wytwarzała różne poziomy wyjściowe po podłączeniu do różnych urządzeń, nawet przy tym samym ustawieniu głośności. Analiza statystyczna potwierdziła, że różnice wyjściowe między urządzeniami były znaczące, co znalazło odzwierciedlenie w wynikach: [$F(3) = 805,08$, $p < 0,001$], z częściowym R^2 wynoszącym 89,7% dla prawego ucha i [$F(3) = 805,08$, $p < 0,001$], z częściowym R^2 wynoszącym 89,7% dla lewego ucha, na podstawie pomiarów wykonanych dla pięciu różnych poziomów głośności. Podobnie interakcje także okazały się znaczące w obojgu uszach. Co więcej, rozbieżności między wyjściami lewego i prawego ucha dla każdej kombinacji słuchawek i urządzenia okazały się potencjalnie niebezpieczne, co świadczy o występującym ryzyku słuchowym. Warto zauważyć, że przy ustawieniu głośności na 60% całego zakresu poziom dźwięku w obojgu uszach we wszystkich testowanych urządzeniach przekroczył limity ekspozycji zalecane przez amerykańską Agencję Ochrony Środowiska (EPA).

Wnioski: Wyniki pokazały, że jedno rozwiązanie nie jest uniwersalne. Wyniki tego badania mogą pomóc instytucjom rządowym w interwencji w zakresie polityki i standardów produkcji słuchawek/ wkładek dousznych oraz pomóc osobom długofalowo korzystającym z słuchawek dousznych w uregulowaniu ich stosowania.

Słowa kluczowe: słuchawki douszne • telefony komórkowe • ciśnienie akustyczne • generacja • zagrożenie

Key to abbreviations	
ASA	Acoustical Society of America
ATF	acoustic test fixture
CDC	Center for Disease Control and Prevention
EPA	(U.S.) Environmental Protection Agency
IRB	institution review board
LAeq	average sound level
Leq	average exposure level
NIDCD	National Institute on Deafness and Other Communication Disorders
NIHL	noise induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
USAARL	U.S. Army Aeromedical Research Laboratory
WHO	World Health Organization

Introduction

The effects of hearing loss are not only local to the affected person, but also have global impacts. For example, the cost of lost productivity, special education, and medical treatment may exceed $30 billion per year for disorders of hearing, speech, and language [1]. According to Johns Hopkins Cochlear Center for Hearing and Public Health, as of 2019, approximately 38.2 million Americans (14.3%) report some degree of hearing loss [2]. Hearing loss is also rising among adolescents and has increased more than 30% between 1988 and 2006 [3]. In the early 20th century, health care experts, audiologists, parents, and governments expressed concerns about noise sources causing hearing loss in adolescents and young adults [4]. Recently, the World Health Organization (WHO) said that approximately 1.1 billion young people are at risk of potentially life-altering hearing loss due to loud noise exposure. In 2005, the Hearing Alliance of America reported that levels of hearing loss in 15% of college graduates are now equal to or greater than those of their parents and concluded that the significant cause is listening to loud music [5]. Various findings concluded that increasing numbers of adolescents and young adults now experience symptoms indicative of poor hearing, such as distortion, tinnitus, hyperacusis, or threshold shifts for reasons not yet affirmed [6–9].

Research has confirmed that today many youths are losing their hearing at alarming rates, presumably due to excessive noise exposure [10]. One possible explanation may be suggested by the results of Fasanya [11], who found that, of the total number of college students who participated in an audiometric experiment, 10% had their hearing thresholds shifted to such a degree that they were excluded from the study. The degree of potential hearing damage in young adults, like unselective exposure to places where there is a high level of noise, could bring irreversible damage to the auditory system and impact hearing performance. The use of earbuds has been attributed to hearing loss and hearing performance degradation. However, many have argued that various factors contribute to hearing loss and degradation associated with the daily use of earbuds. These factors include the design of the earbuds (in-ear, on-ear, or over-ear), the fit of the earbuds, their impedance, sensitivity, personal hearing sensitivity, audio processing and equalization settings, cable length, as well as the age and condition of the earphones.

Practically, the effect of these factors is relative. It depends on the connection. For example, one earbud connected with three different devices will not demonstrate any effect due to the design type, cable length, age, condition, impedance, and personal hearing sensitivity because only one type of earbud is used in the process. The electric circuitry of earbuds plays a major role in the voltage inputs. Therefore, one earbud type connected to different devices should produce the same output no matter what. Hence, if different earbuds are connected with the same devices, the possibility of producing different outputs is high due to the electric circuitry. Public understanding of earbuds is that one earbud should work perfectly in the same manner on any device. Contrary to this public opinion, the preliminary study by Fasanya et al. [12] proved otherwise. Therefore, to ensure safety and to protect users from overexposure, as well as educating users on how earbud works, it is imperative to understand how typical behavior such as earbud use may affect hearing.

Currently, the use of earbuds is rising all over the world, especially among the younger generation. In 2014, Ansari et al. [13] revealed that earbud usage is common among college students and 84% of all respondents in the preliminary survey conducted by Fasanya & Strong [14] used earbuds on a daily basis. Likewise, Świerczek et al. [15] revealed that the biggest threat causing hearing loss in children and adolescents is recreational noise, such as music on earbuds, concerts, discos, and toys. However, as useful as earbud devices may be in terms of allowing the user to listen uninterrupted, it does pose some safety risks [6,16]. The exponential increase in earbud usage began in the early 20th century and the targeted population is the younger generation [14]. Since the target population for earbuds are Generations Y and Z, these are the individuals who will be most impacted by any hazards associated with this device. In addition, many individuals within this demographic

Figure 1. Pictures of all headphone brands used for data collection

are or will be attending college, where they are even more likely to use earbuds regularly [14]. Certainly, they will often need to study or do homework, and some believe that earbuds will allow them to eliminate many of the distractions they will encounter. Findings from Vogel et al. revealed that frequent users were 4 times more likely to listen to high-volume music than were infrequent users, and adolescents in practical prevocational schools were more than twice as likely to listen to high-volume music as were those attending pre-university education [17].

It is important to note that the absolute volume, duration of exposure to loud sound, sound character, and individual susceptibility are the ultimate risk factors for hearing loss [15]. However, it is possible that usage such as volume settings differ between listeners depending on the manner in which the earbuds function: over the ear, in the ear, and on the ear [18], and the type of device to which the earbuds are connected (laptop, phone, tablet). Users may set their different devices to "the same" level setting, but this may result in delivering different absolute sound pressure levels to their ears. For example, in preliminary work Fasanya et al. [12] found that setting the volume to 40% of the maximum level on an iPhone delivered a different decibel level when compared with the 40% volume level of an Android phone with the same earbud type and brand. Therefore, effects on users may depend on the type of device the earbud is being connected to. Research has concluded that earbuds should not be considered as one size fits all [12], but currently there is no adequate empirical study to support this statement. In 2020, Fasanya et al. [12] also found that young adults mostly use one earbud type on different devices.

As much as the connection between sound level and hearing damage is well-known, and the connection between earbud usage and distraction is likewise easy to understand, it is not clear whether typical earbud use rises to hearing damaging levels or is susceptible to hearing acuity degradation. The differences in the outputs of the earbuds connected with different devices could be a hearing hazard for consumers who frequently use one earbud type on different devices. Therefore, it is imperative to conduct an empirical study to investigate the output of one earbud type connected with different devices. The hypotheses for this study were:

H1: The dB outputs from the two earbuds will vary significantly with the same device, even when set to the same volume level.
H2: The devices will produce different dB outputs using the same earbud in the same ear at the same volume setting.
H3: There will be an interaction effect between the earbuds and the devices when used at the same volume setting and in the same ear.

This study investigated the average sound level (LAeq) output in dBA of two different earbud types connected with four different devices produced in two different scenarios.

Material and methods

Four different devices were utilized for data collection in this study: the Blackberry Android model KEYone BBB100-1, the Android Google Pixel 3 model G013A, the iPhone 6x model A1586, and the Samsung Android Galaxy S8 model SM-G950U. Additionally, two types of earbuds were employed: the Panasonic earbud model RP-HJE120-R and the Samsung earbud model EO-EG920LW. Both earbuds have the same cable length and are of the same design. Both were bought on the same day to ensure the same age and condition. We chose the in-ear earbuds because research have shown that majority of the young adult use in-ear earbuds on a daily basis [19,20]. All devices and earbuds were purchased from retail stores to mimic the natural sources, where users normally purchase their products for use. The study experiment was conducted at U.S. Army Aeromedical Research Laboratory (USAARL) in Fort Rucker, now known as Fort Novosel, Alabama.

The following methods were formulated to achieve the primary goal of the study: (1) submit protocol to the institution review board (IRB); (2) purchase devices for data collection; (3) calibrate equipment (GRAS 45CB ATF, software, computer, cell phones and earbuds) for data collection; (4) connect earbud with devices and collect data.

The study protocol was approved by the principal investigator's university IRB before being taken to the site where data was collected. The university is located in the northwest of Indiana, United States. Sound pressure level delivery by the earbuds (**Figure 1**) was measured with the

Figure 2. GRAS 45CB acoustic test fixture (ATF) and testing lab setting during data collection

GRAS 45CB acoustic test fixture (ATF) connected to a Dell desktop computer. Prior to the experiment, the GRAS 45CB was calibrated with the Nelson Acoustic Trident software for data recording on the attached desktop computer. A WAV noise file was generated using REATpro software. Thereafter, the volume adjustment on all devices was calibrated. The number of clicks for each volume adjustment on the cellphones was determined through the transposition method before the start of the experiment.

The five different volume levels (20, 40, 60, 80, and 100%) used in the study were determined from past studies. The levels were selected to mimic different volume levels reported in research findings, as the commonly used volume by typical earbud users [14].

The sensitivities for both right and left ears were normalized to 14.35 mV/Pa and 15.92 mV/Pa, with a reference microphone at 49.8 mV/Pa. The calibrated offset in dB for the right, left, and the reference mic were –1.2, –2.1, and –0.9 dB, respectively. **Figure 2** represents the GRAS 45CB (ATF) for the study and the setup when one of the cellphones was connected for data collection. **Figure 3** is a screen print of the Nelson Acoustic software used for data acquisition. Data from the left and right ears were collected independently in one-third octave bands, in accordance with the findings presented in the 2019 Honeycutt report [21].

A two-factor factorial design repeated measure was employed in this study to evaluate the variations in earbud output across different devices and ear sides. This design was appropriate because the earbud's output, measured in decibels, was the only continuous variable in the experiment and served as the primary dependent variable. The independent variables were the playback device (Blackberry Android, Android Google Pixel, iPhone, and Samsung Android Galaxy) and the ear side (left or right), each having multiple levels. Data collection was carried out using the GRAS 45CB ATF, a standardized and calibrated system designed for accurate and repeatable earbud measurements. For each combination of device, volume level, and ear side, measurements were taken only once due to the controlled and repeatable nature of the ATF system.

We employed two-way ANOVA to analyze the data. This statistical method was selected to determine whether there were significant differences in earbud outputs, any significant differences within device types using a single earbud brand, or any interaction effects between the earbud and the device. The method allowed for a comprehensive assessment of both main effects. We used both descriptive and inferential statistical methods for the analysis. In the descriptive statistics, we determined the means and standard deviations, as well as differences between the output of the earbuds at each ear and at each volume. These were used to summarize the data and assess the practical significance of any observed differences in output. The inferential statistics were used to determine whether the observed differences in average output levels across devices and between earbuds were statistically significant. This dual approach provided both a practical interpretation of the data and a rigorous test of statistical significance. We hypothesized that there would be a significant difference in the mean values of the dependent variable (dB outputs) across the various levels of each independent factor, which was device type. Likewise, the interaction between the devices and the earbud was expected to be statistically significant.

Results

Data acquisition

At the end of each run/test, all 1/3-octave band frequencies from 31.5 to 16.000 Hz for all volumes on the two devices were exported from the software onto an Excel spreadsheet. All frequencies were tested on each ear for

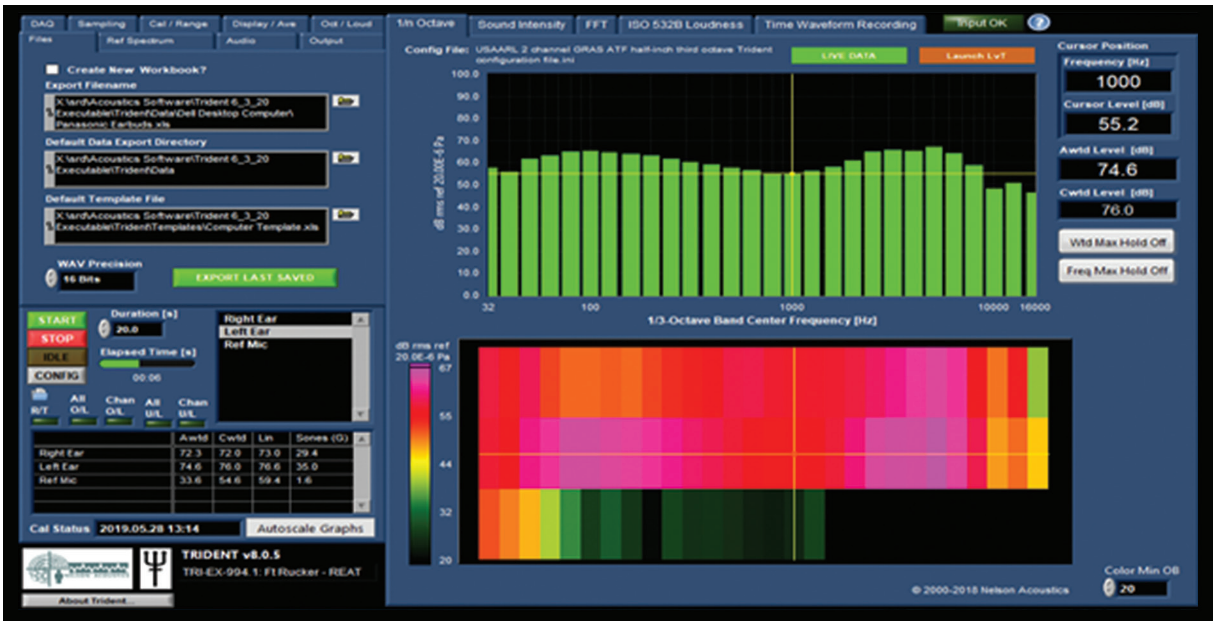

Figure 3. Nelson Acoustic Trident software that measures the third octave band center frequency sound is used for the recording. All parameters at each click and both right and left ears with the start and stop button for the software processing are included on the display box shown in the ScreenPrint

each earbud connected with the four devices at each volume level tested. The data from the report were compared with GRAS 45CB ATF manual data to ensure consistency of data recording.

After data from the Nelson Acoustic Trident software was exported to a spreadsheet, data processing and analysis were completed using MS Excel version 2020 (Microsoft, Redmond, WA, USA). Corresponding sound pressure levels with each earbud measured at each frequency and at each volume level were recorded. **Figure 4** and **Figure 5** plot outputs for the right and left ears across various volume levels, ranging from 20% to 100%, while using two different earbuds connected to four distinct devices. It is evident from both figures that different earbuds generate varying outputs in dBA when used with the same devices at identical volume levels.

Descriptive statistics

Our primary focus was to report the mean and standard deviation of the earbud output levels, and to assess their practical significance, rather than relying solely on statistical significance. To achieve this, we compared the variations in earbud output levels across different devices against the National Institute for Occupational Safety and Health (NIOSH) recommended noise exposure exchange rate (trade-off) of 3 dB. This benchmark was used as a critical threshold to assess whether the observed differences in output levels across devices could have meaningful implications for user hearing health and safety. We analyzed the differences in measured sound level output for each device–ear combination, and then calculated the range of these differences across all tested devices. Additionally, we quantified the percentage of output differences that fell below, equal to, or above the 3 dB exchange rate threshold. This comparison allowed us to determine not only the magnitude but also the potential real-world impact of using different devices with the same earbuds. The results of this comparison, including the range of output differences and the distribution of values relative to the 3 dB threshold, are summarized in **Table 1**. This table provides a clear representation of how frequently the variations in earbud output may exceed levels considered critical by occupational health standards, thereby helping to contextualize the findings in terms of practical auditory risk.

In order to facilitate a clearer understanding of the recorded measurements, we plotted the data captured from both the left and right ears, thereby enabling a pictorial representation of the observed variations. As illustrated in **Figure 4**, there are noticeable differences in the audio output levels between the left and right ears across several devices, despite using the same Samsung earbud and maintaining a consistent volume setting. This disparity suggests potential asymmetries in either the earbud design, device audio processing, or ear canal acoustics.

Table 2 presents the mean values and standard deviations of the sound output, measured in dBA, for all connected devices across the full range of volume levels tested in this study. These statistical summaries are provided separately for both the Panasonic and Samsung earbuds, and are distinguished by measurements taken at the left and right ears. This allows for a comparative analysis of the earbuds' performance in terms of consistency and output level variation across different devices and volume settings.

Figure 5 demonstrates that, for certain devices, the output at the left ear differs from that at the right ear when using the Panasonic earbud at a consistent volume level.

Inferential statistics

To further explore the differences in earbud output levels, we employed inferential statistical analysis by performing

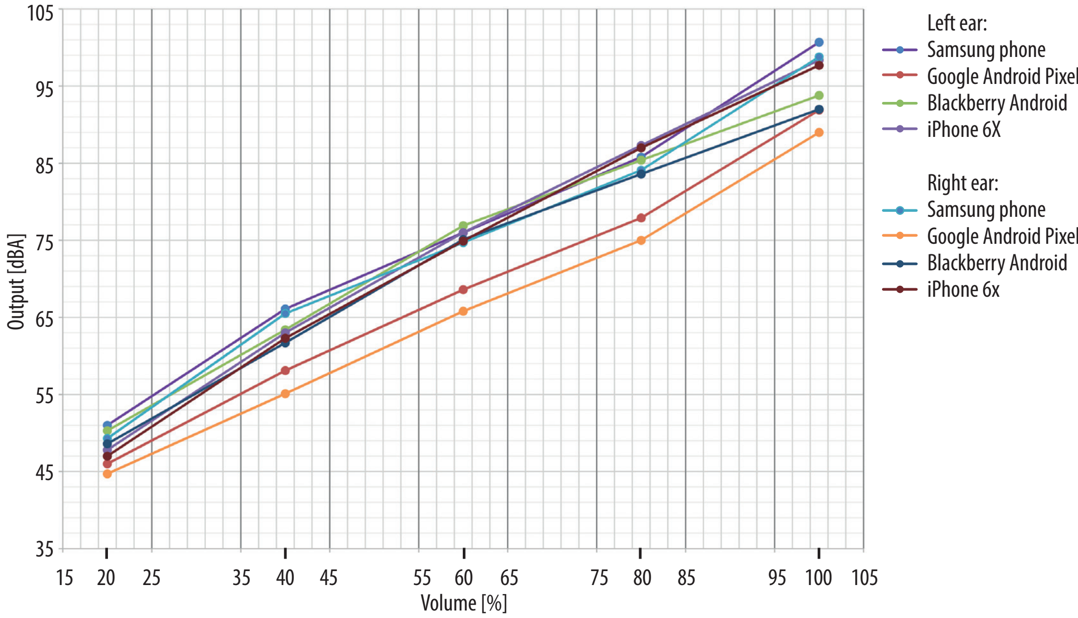

Figure 4. Output in dBA comparison of right and left ears for all four devices using Samsung headphone at the same % volume

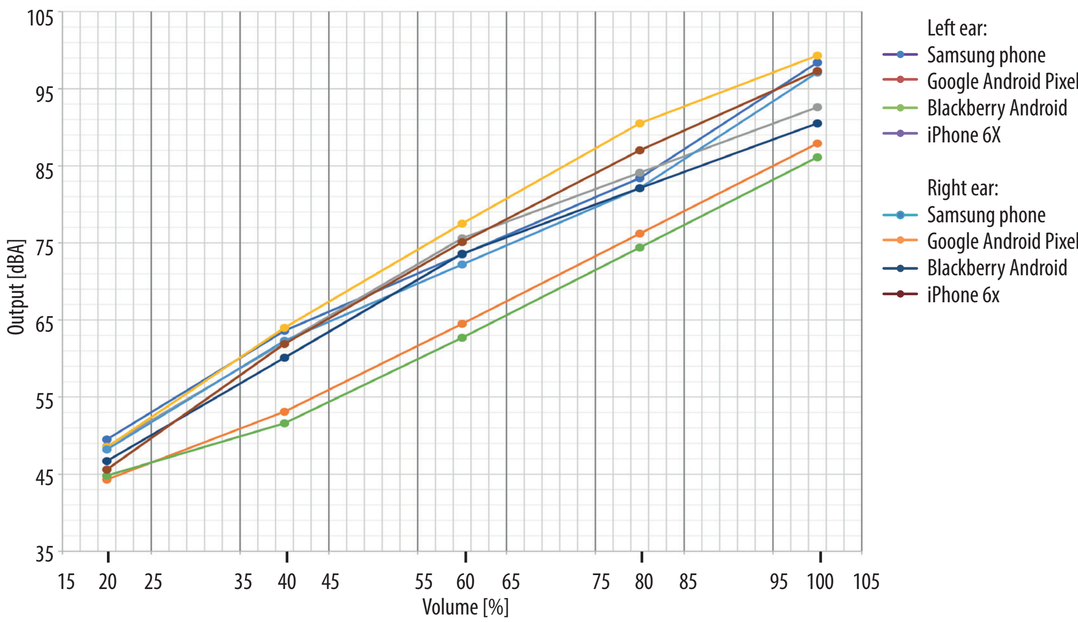

Figure 5. Output in dBA comparison of right and left ears for all four devices using Panasonic headphone at the same % volume

a two-way analysis of variance (ANOVA). This analysis was conducted on output data measured from both ear sides (left and right) across the various connected devices, with a significance level set at $\alpha = 0.05$. The primary objective was to determine whether the differences observed and summarized in **Table 3** were statistically significant. Before conducting inferential statistical tests, we assessed the assumption of normality for all datasets using the Jarque–Bera test, with a significance level of $\alpha = 0.05$. All p-values exceeded the alpha threshold, confirming that the data were normally distributed and met the assumptions required for ANOVA.

The results of the multivariate test using Wilks' lambda revealed a statistically significant effect of the device on dB output in the right ear. Specifically, the main effect of the device was significant, yielding [$F(3) = 539$, $p < 0.001$], with a partial R^2 of 85.4%. Likewise, a significant interaction effect was found between the device and the earbud, yielding [$F(3) = 18.276$, $p = < 0.001$], with a partial R^2 of 16.6%. The within-subjects effects on devices, assuming sphericity, were statistically significant [$F(3) = 346.373$, $p < 0.001$], with a partial R^2 of 55.5%. Additionally, the interaction between device and earbud was also significant [$F(3) = 377.784$, $p < 0.001$], with a partial R^2 of 10.8%.

Table 1. Output differences compared with NIOSH noise exchange rate of 3-dB

Devices	Range [dB]	% lower than 3-dB	% higher than 3-dB
Panasonic earbud			
BBA & AGP	1.9–11.1	10	90
BBA & IP	0.1–6.8	60	40
BBA & SAG	0.0–6.6	80	20
AGP & IP	1.7–14.3	10	90
AGP & SAG	3.4–11.0	0	100
IP & SAG	0.1–7.1	70	30
Samsung earbud			
BBA & AGP	1.9–9.3	10	90
BBA & IP	0.2–5.7	70	30
BBA & SAG	0.4–6.9	70	30
AGP & IP	1.8–11.7	20	80
AGP & SAG	4.6–10.4	0	100
IP & SAG	0.0–3.2	70	30

Note: BBA – Blackberry Android, AGP – Android Google Pixel, IP – iPhone, SAG – Samsung Android Galaxy

Table 2. Full data average values and standard deviation for both Panasonic and Samsung earbuds

Device type	Right ear										Left ear									
	20%		40%		60%		80%		100%		20%		40%		60%		80%		100%	
	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*	mean	*SD*
Panasonic earbud																				
BBA	46.70	5.87	60.10	5.24	73.60	5.18	82.10	5.20	90.50	5.21	48.60	6.17	62.10	5.71	75.60	5.66	84.10	5.67	92.60	5.68
AGP	44.80	8.00	51.60	6.26	62.70	5.45	74.40	5.41	86.10	5.43	44.30	7.11	53.10	5.39	64.50	4.61	76.20	4.51	87.90	4.51
IP	46.50	5.89	62.40	5.48	74.50	5.42	86.50	5.42	97.30	5.42	48.50	5.87	64.00	4.49	77.50	5.43	90.50	5.44	99.30	5.43
SAG	48.20	6.30	62.30	6.07	72.20	6.05	82.10	6.05	97.10	6.06	49.50	5.74	63.60	5.24	73.50	5.21	83.40	5.19	98.40	5.20
Samsung earbud																				
BBA	48.60	7.53	61.70	7.33	75.10	7.29	83.60	7.23	92.00	7.15	50.30	6.77	63.50	6.86	76.90	7.32	85.40	7.46	93.80	7.36
AGP	44.70	7.44	55.10	7.24	65.80	6.86	75.00	6.75	89.00	6.69	46.00	7.33	58.10	7.48	68.60	7.21	77.90	7.44	91.90	7.48
IP	47.50	5.89	62.50	5.48	75.30	5.42	86.70	5.42	97.70	5.44	47.80	5.87	63.00	5.49	76.00	5.43	87.30	5.44	98.40	5.43
SAG	49.30	6.17	65.50	9.09	74.70	8.46	84.10	7.98	98.80	7.57	51.00	6.07	66.10	7.25	76.00	7.20	85.80	7.12	100.70	7.14

Note: BBA – Blackberry Android, AGP – Android Google Pixel, IP – iPhone, SAG – Samsung Android Galaxy

The results revealed no statistically significant difference between the earbuds, yielding [$F(1) = 0.1100$, $p = 0.9150$]. The pairwise comparison results for the device types (Blackberry Android, Android Google Pixel, iPhone, and Samsung Android Galaxy) are presented in **Table 3**. All device outputs were significantly different from one another, except for the iPhone and Samsung Android Galaxy, which did not show a significant difference for the right ear.

Figure 6 illustrates the relationship between the devices' estimated marginal means and the earbuds. However, no significant difference was found between the effects of the two earbuds (Panasonic and Samsung) on dB outputs across devices.

A similar analysis was conducted on the left ear outputs. The main effect of the device was significant, yielding [$F(3) = 805.08$, $p < 0.001$], with a partial R^2 of 89.7%. Likewise, a significant interaction effect between the device and the earbud was found, yielding [$F(3) = 31.471$, $p < 0.001$], with a partial R^2 of 25.5%. The within-subjects effects on devices, assuming sphericity, were statistically significant [$F(3) = 148.373$, $p < 0.001$], with a partial R^2 of 34.9%. Additionally, the interaction between device and earbud was also significant [$F(3) = 22.569$, $p < 0.001$], with a partial R^2 of 7.5%. The results revealed no statistically significant difference between the earbuds, yielding [$F(1) = 2.691$, $p = 0.1020$]. The pairwise comparison results for the device types (Blackberry Android, Android Google

Table 3. Pairwise comparison results of devices on the right ear

Devices	Devices	Right ear		Left ear	
		mean difference	*P*-value	mean difference	*P*-value
BBA	AGP	6.3450	<.001	10.7410	<.001
	IP	−1.0470	0.0050	1.5670	0.2460
	SAG	−1.8260	<.001	1.3720	0.5860
AGP	BBA	−6.3450	<.001	−10.7410	<.001
	IP	−7.3920	<.001	−9.1730	<.001
	SAG	−8.1710	<.001	−9.3690	<.001
IP	BBA	1.0470	0.0050	−1.5670	0.2460
	AGP	7.3920	<.001	9.1730	<.001
	SAG	−0.7790	0.2220	−0.1950	1.0000
SAG	BBA	1.8260	<.001	−1.3720	0.5860
	AGP	8.1710	<.001	9.3690	<.001
	IP	0.7790	<.222	0.1950	1.0000

Note: BBA – Blackberry Android, AGP – Android Google Pixel, IP – iPhone, SAG – Samsung Android Galaxy

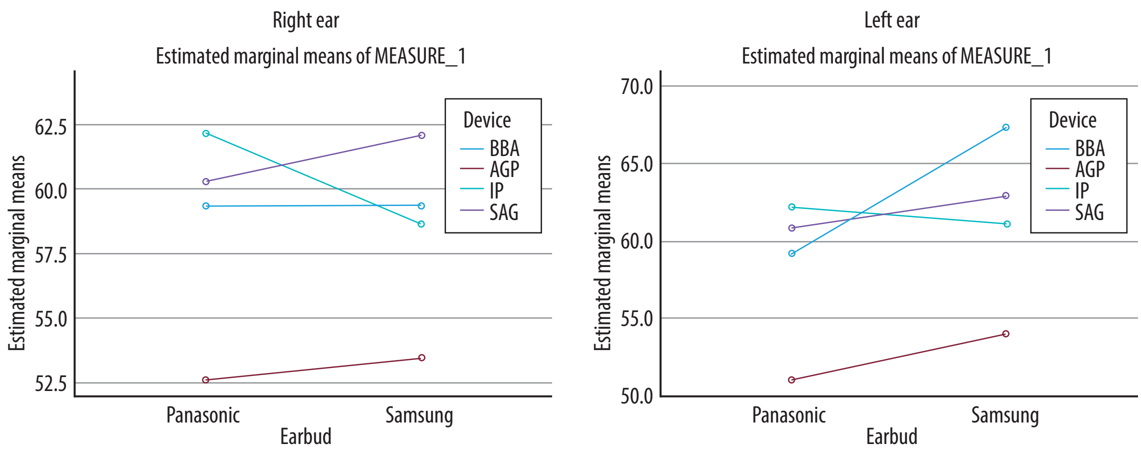

Figure 6. Relationship between the devices' estimated marginal means and the earbuds

Pixel, iPhone, and Samsung Android Galaxy) are shown in **Table 3**. All device outputs were significantly different when compared using Bonferroni, except for the following pairs: Blackberry Android and iPhone, Blackberry Android and Samsung Android Galaxy, and iPhone and Samsung Android Galaxy for the left ear. **Figure 6** (right) illustrates the relationship between the estimated marginal means and the earbuds. However, no significant difference was found between the effects of the two earbuds (Panasonic and Samsung) on dB outputs across devices.

To supplement the dBA analysis, we converted sound pressure level (dB values) into physical sound pressure units (pascals) and conducted a two-way ANOVA on the converted data. The results of the multivariate test using Wilks' lambda revealed statistically significant effects. Across all tested volume levels, the device effect was significant, yielding [$F(3) = 70.820$, $p < 0.0001$], with a partial R^2 of 43.5%. Likewise, a significant interaction effect between the device and the earbud was found, yielding [$F(3) = 13.182$, $p < 0.0001$], with a partial R^2 of 12.5% for the right ear. All devices were found to be statistically significantly different from one another when compared using the Bonferroni correction. Across all tested volume levels, the device effect was significant, yielding [$F(3) = 54.976$, $p < 0.0001$], with a partial R^2 of 37.4%. Likewise, a significant interaction effect between the device and the earbud was found, yielding [$F(3) = 26.602$, $p < 0.0001$], with a partial R^2 of 19.7% for the left ear. However, device comparisons using the Bonferroni correction revealed statistically significant differences between all devices, except between the Blackberry Android and the iPhone.

The findings further revealed noticeable variations in audio output between the left and right ears when using the same earbud across all tested devices. While some of these differences exceeded the thresholds established by the NIOSH noise exposure exchange rate guidelines, statistical analysis indicated that these differences were not significant at a 0.5 confidence level. However, from a practical standpoint, the observed discrepancies are considered meaningful, as they may have implications for user safety and listening experience, particularly during prolonged exposure. Additionally, our findings showed that the iPhone produced effects and outputs more similar to those of the BlackBerry Android than to any other type of phone tested in this study.

Discussion

Hearing loss among the younger generation is escalating and the reasons have not been well documented. Findings from this study focused on one aspect that might be one of the escalations. As reported by Fausti et al. [5], the Hearing Alliance of America reports that the levels of hearing loss among college graduates are now 15% greater than those of their parents, and a possible cause is listening to loud music. In fact, one study revealed that over 75% of its participants reported a variety of auditory symptoms after listening to music, including ear ringing, hearing loss, pain in the ears, limited concentration, and decreased tolerance to certain environmental sounds [19].

Not only listening to loud music but also the means of listening to music are important, with many young adults now using corded or Bluetooth earbuds daily. However, many believe that the earbuds help to cancel surrounding noise, neglecting the hazard associated with listening to music on the device. Findings from this research show that at a particular volume level, one earbud produced different outputs in dBA on different devices, and not only with different devices but also different outputs on right and left ears. The electric circuitry of an earbud could affect the voltage inputs when different earbuds are used on the same device, but not when one earbud type is used on different devices. Thus, the findings of this study reveal that earbud outputs are not standardized by manufacturers. We found that the outputs across different devices were found to be statistically significant.

The prevalence of hearing loss in the United States is increasing. In 2017, 25% of American adults, aged between 20 and 69, were documented to have noise induced hearing loss (NIHL) as reported by the Center for Disease Control and Prevention. The number of Americans with hearing loss increased from 13.2 million (6.3% of the US population) in 1971, to 20.3 million (8%) in 1991, and to 48 million (15.3%) in 2011 [22]. It is possible that nonoccupational noise exposure contributed to the increase in hearing loss, because the Occupational Health and Safety Administration OSHA regulations have reduced occupational hearing loss significantly. According to the findings of Gopal et al. [23], listening to music on an iPod Touch through earbuds at 100% volume for as little as 30 minutes can cause a temporary threshold shift and weaker otoacoustic emissions, posing a risk of auditory damage. Findings from this study revealed that both types of earbuds produced sound levels averaging above 98 dB across all devices at volume 100%.

The sudden jump in hearing loss among the younger generation in the world therefore needs critical assessment as well as serious investigation and intervention. The exponential increase in earbud usage began in the early 21st century, close to when there was an exponential increase in hearing degradation change the younger generation [14]. According to the National Institute on Deafness and Other Communication Disorders (NIDCD) [24] (p. 1), "Long or repeated exposure to sound at or above 85 decibels can cause hearing loss" (report of March 2014, updated March 2022). If this is the case at 80% volume, the output in dBA recorded from both earbuds tested in this study will not be appropriate for any users. Research has confirmed that earbud users increase the volume level of their devices to approximately 100% volume whenever there is background noise [25]. Our findings suggest that earbuds should be labeled with noise ratings, and that manuals should include volume levels along with corresponding dBA outputs for safe use.

According to CDC [26], the U.S. EPA recommended a 70 dBA exposure limit level for environmental noise to prevent hearing loss. The 85 dBA action level recommended by the OSHA has been recognized acceptable level for hearing loss prevention as well. However, 85 dBA is the standard level for occupational hearing loss and is not recommended for nonoccupational hearing loss. Hearing impairment due to voluntary use of earbuds is considered nonoccupational hearing loss. In 2007, Daniel [27] concluded that hearing impairment among children and teenagers has risen due mostly to voluntary exposure to loud noise, such as the use of earbuds on a daily basis. This could be one of the sources for nonoccupational hearing loss among the younger generations. Findings from this study have revealed that use of the two types of earbuds tested could expose users to sound levels above 85 dBA, the limit recommended by OSHA.

The 70 dBA level for hearing loss prevention recommended by the U.S. EPA is also documented. According to the EPA's 1974 report [28], the limit is for an equivalent continuous average exposure level (Leq) over 24 h. Likewise, the 70 dBA limit considers daytime and nighttime exposures to be equally hazardous to hearing. The EPA further expanded on the number of hours per day and the equivalent decibel level that might be high enough to cause hearing damage. The conclusion was that the 24 h limit is equivalent to a 75 dBA, 8 h workday exposure, with no noise exposure (i.e., noise < 70 dBA) during the remaining 16 h [29]. If this standard remains the case, both the tested earbuds will, based on the results from this study, not be appropriate for anyone to use at 60% volume level. On average, many young adults have confirmed using their earbuds at 60% and above volume level daily [14]. Our study showed that the average volume level, accepted to be comfortable for listening among earbud users as revealed in [14], will produce hazardous output with the tested earbuds.

According to Heinrich et al., long-term exposures to noise levels greater than 75 dBA, as recommended by the U.S. EPA in 1974, have the potential to cause metabolic changes in sensory hair cells, death of the cell, and decreased ability to perceive sound. Certainly, exposure to high-intensity noise for long durations can increase the risk of ear damage and cause permanent hearing damage (NIHL) [30]. The two earbuds tested in our study at 60% volume had their output greater or equivalent to 75 dBA when connected to any one of the four devices (Samsung, Google Android Pixel, Blackberry, and iPhone 6x). This is concerning, as these days many users use their earbuds for more than 8 hours daily and at a volume level equal to or above 60%.

We further found some variation between the right ear and left ear outputs of the same earbuds, which is also concerning. The differences were not statistically significant but practically meaningful, as they have implications for user safety and listening experience during prolonged exposure.

The NIDCD lists some activities that could put one at risk for NIHL: activities such as driving snowmobiles, target shooting and hunting, listening to music or watching movies at high volume through earbuds, and attending loud concerts either in an enclosed or open environment. Findings from our study revealed different outputs in dBA of the same type of earbud connected with the different devices at the same volume level. The majority of the differences in the outputs were found to be statistically significant. The results further indicate that one type of earbud does not fit all devices, as different outputs were recorded from various devices using the same earbud. Therefore, the variability in outputs produced by one type of earbud across different devices could result in users gradually developing NIHL without noticing.

Conclusions

The goal of this study was to investigate the average sound level (LAeq) output of two different earbud brands connected to four different phones (Samsung Android Galaxy, Google Android Pixel, Blackberry Android, and iPhone 6x). The same earbud designs were used for the study to ensure that different design types (in-ear, on-ear, or over-ear) did not contribute to output differences. Results showed that one size does not fit all, meaning that one type of earbud is not always safe to use on different devices at the same volume level. Standardization of a product should mean that it functions the same way at the same volume level on different devices. Thus, our study suggests that, for general usage, standardization should be done on earbuds and devices. The two earbuds tested produced different outputs in dBA in the right and left ear on the same device, which shows that the sensitivity of the tested earbuds was not consistent across the two ears.

Manufacturers continue to make more enticing devices, neglecting any associated risks. In most earbud brands, the associated risk of injury, aside from eliminating distraction and blocking out other sounds in the surroundings, is totally neglected. Music on the go is now one of the main factors that expands the usage of earbuds among young adults, children, and teenagers. Some of the potential risks associated with the use of earbuds include hearing threshold shifts, NIHL, and accidental injury. The findings from our study underline these risks. According to the 2021 report of the Acoustical Society of America (ASA), "auditory health risk is highest for people using personal audio systems for more than an hour a day at more than 50% volume over a five-year period" [31]. Findings from our study suggest that government intervention is necessary to regulate the manufacturing of earbuds, since many children and teenagers now use earbuds daily. The outputs in dBA for the two different earbud brands tested in our study, and connected with four different cell phone brands from different manufacturers, revealed that one earbud does not fit all. This suggests that users should check for device compatibility before buying an earbud.

To prevent an epidemic of NIHL among young adults, standards, public awareness, and education is necessary. The earbud brands tested in this study showed a significant difference between the outputs of the right and left ears under the same input volume level. More investigation is necessary to establish the extent of the problem among different earbud brands. Findings from this study could help promote awareness among frequent earbud users. They could also serve as a wake-up call for policymakers to enforce standards on earbud manufacturers. Finally, audiologists might use our findings to advise patients with hearing threshold shifts.

Acknowledgements

The authors acknowledge the contributions of Dr. W.A. Ahroon and Dr. H.G. Jones for their cooperation during data collection. Likewise, the efforts of Ms. Precious Fasanya during the initial stage of the exploration stage of this project and for contributions to headphone labeling is acknowledged. The authors also acknowledge Purdue University Northwest for the internal grant awarded for this study. The authors further declare no conflicts of interest.

Funding

This research and article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. National Institute on Deafness and Other Communication Disorders (NIDCD). 1990 Annual Report of the National Deafness and Other Communication Disorders Advisory Board. DHHS publication no. 1991; (NIH) 91-3189. Washington, D.C.: Government Printing Office. Available from: https://patents.google.com/patent/US6043221A/en [Accessed 23.06.2024].
2. Clason D. Hearing loss statistics at a glance. Available from: https://www.healthyhearing.com/report/52814-Hearing-loss-statistics-at-a-glance. [Accessed 1.06.2023].
3. Shargorodsky J, Curhan SG, Curhan GC, Eavey R. Change in prevalence of hearing loss in US adolescents. JAMA, 2010; 304(7): 772–8. https://doi.org/10.1001/jama.2010.1124
4. Rabinowitz PM, Slade MD, Galusha D, Dixon-Ernst C, Cullen MR. Trends in the prevalence of hearing loss among young adults entering an industrial workforce 1985 to 2004. Ear Hear, 2006; 27: 369–75. https://doi.org/10.1097/01.aud.0000224125.12338.9a

5. Fausti SA, Wilmington DJ, Helt PV, Helt WJ, Konrad-Martin D. Hearing health and care: the need for improved hearing loss prevention and hearing conservation practices. J Reh Res Dev, 2005; 42(4): 45–62. https://doi: 10.1682/jrrd.2005.02.0039
6. McNeill K, Keith SE, Feder K, Konkle AT, Michaud DS. MP3 player listening habits of 17 to 23-year-old university students. J Acoust Soc Am, 2010; 128(2): 646–53. https://doi.org/10.1121/1.3458853
7. Chung JH, Des Roches CM, Meunier J, Eavey RD. Evaluation of noise-induced hearing loss in young people using a web-based survey technique. Pediatrics, 2005; 115(4): 861–7. https://doi.org/10.1542/peds.2004-0173
8. Crandell C, Mills TL, Gauthier R. Knowledge, behaviors, and attitudes about hearing loss and hearing protection among racial/ethnically diverse young adults. J Natl Med Assoc, 2004; 96(2): 176–86.
9. Niskar AS, Kieszak SM, Holmes AE, Esteban E, Rubin C, Brody DJ. Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: The Third National Health and Nutrition Examination Survey, 1988–1994, United States. Pediatrics, 2001; 108(1): 40–3. https://doi.org/10.1542/peds.108.1.40
10. Schessel DA. Headphones & Earphones Can Cause Permanent Hearing Loss. Stony Brook, School of Medicine. Available from: https://medicine.stonybrookmedicine.edu/surgery/blog/headphones-and-earphones-can-cause-permanent-hearing-loss-what-you-need-to-know [Accessed 7.09.2023].
11. Fasanya BK. Quantitative Analyses of Acceptable Noise Level for Air Conduction Listening (Doctoral Dissertation). North Carolina Agricultural and Technical State University. Greensboro; 2013. Available from: https: //digital.library.ncat.edu/dissertations/118 [Accessed 4.06.2024].
12. Fasanya BK, Reeves E, Francis A. Correlations between headphones output in decibel and electronic devices volume (poster presentation). National Hearing Conservation Association Annual Conference (NHCA), February 18–22, 2020, Destin, FL, USA. Available from: https://static.sched.com/hosted_files/2020nhcaannualconference/9f/NHCA%20poster.pdf [Accessed 4.06.2024].
13. Ansari H, Mohammadpoorasl A, Rostami F, Maleki A, Sahebihagh, MH, Naieni KH. Pattern of use of earphone and music player devices among Iranian adolescents. Int J Prev Med, 2014; 5(6): 776–81.
14. Fasanya BK, Strong JD. Younger Generation Safety: Hearing Loss and Academic Performance Degradation Among College Student Headphone Users. In: Advances in Safety Management and Human Factors. Arezes P, Editor. Proceedings of the AHFE 2018 International Conference on Safety Management and Human Factors, July 21–25, 2018. Springer; 2018. Available from: https://doi.org/10.1007/978-3-319-94589-7_51 [Accessed 5.06.2024].
15. Świerczek PD, Sochań A, Kędziora-Kornatowska K. Noise-induced hearing loss in children and adolescents: a review. J Hear Sci, 2020; 10(2): 27–31. https://doi.org/10.17430/JHS.2020.10.2.3
16. Hoover A, Krishnamurti S. Survey of college students' MP3 listening: habits, safety issues, attitudes, and education. Am J Aud, 2010; 19(1): 73–83. https //doi.org/10.1044/1059-0889(2010/08-0036)
17. Vogel I, Verschuure H, van der Ploeg CP, Brug J, Raat H. Adolescents and MP3 players: too many risks, too few precautions. Pediatrics, 2009; 123(6): e953–e958. https://doi.org/10.1542/peds.2008-3179
18. Thompson D. How Headphones Changed the World. Available from: https://www.theatlantic.com/technology/archive/2012/05/how-headphones-changed-the-world/257830/ [Accessed 12.01.2024].
19. Osmanoğlu H, Dizdar HT, Koçyiğit AA. The effects of music listening time with headphones on hearing thresholds among the young population. Egypt J Otolaryngol, 2024; 40(1): 13. https://doi.org/10.1186/s43163-024-00574-9
20. Widen SE, Båsjö S, Möller C, Kähäri K. Headphone listening habits and hearing thresholds in Swedish adolescents. Noise Health, 2017; 19(88): 125–32. https://doi.org/10.4103/nah.NAH_65_16
21. Honeycutt R. Why most equalize in 1/3 octave bands? Available from: https://www.prosoundtraining.com/2019/07/26/why-equalize-in-1-3-octave-bands/ [Accessed 1.11.2023].
22. Lin FR, Niparko JK, Ferrucci L. Hearing loss prevalence in the United States. Arch Intern Med, 2011; 171(20): 1851–3. https://doi.org/10.1001/archinternmed.2011.506
23. Gopal KV, Mills LE, Phillips BS, Nandy R. Risk assessment of recreational noise-induced hearing loss from exposure through a personal audio system–iPod Touch. J Am Acad Audiol, 2019; 30(7): 619–33. https://doi.org/10.3766/jaaa.17140
24. National Institute on Deafness and Other Communication Disorders (NIDCD). Noise induced hearing loss. Available from: https://www.nidcd.nih.gov/health/noise-induced-hearing-loss [Accessed 24.04.2023].
25. Jiang W, Zhao F, Guderley N, Manchaiah V. Daily music exposure dose and hearing problems using personal listening devices in adolescents and young adults: a systematic review. Int J Audiol, 2016; 55(4): 197–205. https://doi.org/10.3109/14992027.2015.1122237
26. Center for Disease Control and Prevention (CDC). Public Health and Scientific Information. Recommendations and Guidelines: EPA: Exposure Limits. Available from: https://www.cdc.gov/nceh/hearing_loss/public_health_scientific_info.html [Accessed 4.05.2024].
27. Daniel E. Noise and hearing loss: a review. J Sch Health, 2007; 77(5): 225–31. https://doi.org/10.1111/j.1746-1561.2007.00197.x
28. U.S. Environmental Protection Agency (U.S. EPA). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. 1974. Available from: http://www.nonoise.org/library/levels74/levels74.htm [Accessed 16.04.2024].
29. Hammer MS, Swinburn TK, Neitzel RL. Environmental noise pollution in the United States: developing an effective public health response. Environ Health Perspect, 2014; 122(2): 115–19. https://doi.org/10.1289/ehp.1307272
30. South T. Managing Noise and Vibration at Work. London: Routledge; 2013.
31. Acoustical Society of America. Headphones and Earbuds Impact Younger Generations' Future Audio Health. Available from: https://neurosciencenews.com/auditory-health-headphones-18618/ [Accessed 16.04.2024].

Bankole K. Fasanya, email: bfasanya@una.edu • 0000-0001-5782-5810
Efrem R. Reeves, email: erreeves1@gmail.com • 0009-0005-7154-3744
Alexandra L. Francis, email: francisa@purdue.edu • 0000-0001-6159-8788