Sound-Level Monitoring Earphones With Smartphone Feedback as an Intervention to Promote Healthy Listening Behaviors in Young Adults

Megan Knoetze[1], Faheema Mahomed-Asmail[1], Vinaya Manchaiah[2,3] and De Wet Swanepoel[1,4,5]

[1]Department of Speech-Language Pathology and Audiology, University of Pretoria, Pretoria, South Africa. [2]Department of Speech and Hearing Sciences, Lamar University, Beaumont, Texas, United States of America. [3]Department of Speech and Hearing, School of Allied Health Sciences, Manipal University, Karnataka, India. [4]Ear Sciences Centre, School of Surgery, University of Western Australia, Nedlands, Australia. [5]Ear Sciences Institute Australia, Subiaco, Australia.

Financial disclosures/conflicts of interest: The last author (D.W.) is a scientific advisor to the hearX group. His relationship includes equity and consulting. The other authors report no conflict of interest.

All correspondence should be addressed to: De Wet Swanepoel, Department of Speech-Language Pathology and Audiology, University of Pretoria, Lynnwood Rd & Roper Street, Pretoria, South Africa. Email: dewet.swanepoel@up.ac.za

ABSTRACT

Objectives: More than a billion adolescents and youngsters are estimated to be at risk of acquiring recreational noise-induced hearing loss (RNIHL) due to the unsafe use of personal audio systems (PAS). RNIHL is preventable, therefore, the present study aimed to determine (i) the accuracy and reliability of dbTrack (Westone) sound-level monitoring earphones and (ii) the effect of sound-level monitoring earphones with smartphone feedback and hearing health information as an intervention to promote healthy listening behaviors in young adults.

Design: The study consisted of two phases, the first phase investigated the accuracy and reliability of dbTrack sound-level monitoring earphones. Accuracy was determined by comparing earphone measurements to sound level meter measurements. Intra-device reliability was determined by comparing earphone measurements during test-retest conditions. Nineteen participants were recruited through convenience sampling to determine within-subject reliability by comparing in-ear sound levels measured by the earphones during test-retest conditions. For the second phase of the study, a single-group pretest-posttest design was utilized. Forty participants, recruited through snowball sampling, utilized the sound-level monitoring earphones with the accompanying dbTrack smartphone application for 4 weeks. The application's smartphone feedback was disabled during the first 2 weeks (pretest condition) and enabled during the last 2 weeks (posttest condition). Average daily intensities, durations and sound dosages measured during pre- and posttest conditions were compared.

Results: Phase 1 dbTrack earphone measurements were within 1 dB when compared to sound level meter measurements. Earphones were also within 1 dB in repeated measures across earphones and across participants. Phase 2 posttest average daily intensity decreased by 8.7 dB (18.3 SD), duration decreased by 7.6 minutes (46.6 SD) and sound dose decreased by 4128.4% (24965.5% SD). Differences in intensity and sound dose were significantly lower with a small and medium effect size, respectively.

Conclusions: This study's preliminary data indicate that dbTrack (Westone) sound-level monitoring earphones with a calibrated in-ear microphone can reliably and accurately measure PAS sound exposure. Preliminary results also suggest that feedback on sound exposure using the accurate sound-level monitoring earphones with the accompanying dbTrack application can potentially promote safe listening behavior in young adults and reduce the risk of acquiring an RNIHL.

INTRODUCTION

Historically, the focus of noise-induced hearing loss (NIHL) has largely been related to occupational noise exposure and to hearing loss in the elderly arising from lifelong exposure to noise (Chung et al., 2005). However, with the increased use of personal audio systems (PAS), recreational noise-induced hearing loss (RNIHL) has become a major public health concern especially among adolescents and young adults (For reviews see: Jiang et al., 2016; You et al., 2020; Zhao et al., 2010). Several studies have shown that exposure to high levels of sound (noise, music etc.) can result in a temporary threshold shift (TTS) which recovers over time or in a permanent threshold shift (PTS) which does not recover to pre-exposure levels (Ryan et al., 2016). Moreover, excessive sound exposure can be associated with various auditory-related symptoms, such as tinnitus, hyperacusis, recruitment, abnormal speech perception and cochlear hypoxia (Groves, 2010; Harrison, 1998, 2008; Henry et al., 2019; Langguth et al., 2013; Liberman & Kujawa, 2017; Zhao et al., 2010). Although preventable, once occurred the RNIHL is irreversible and can have a severe negative impact on physical and mental health as well as academic or work performance (Seidman & Standring, 2010).

According to the World Health Organizations (WHO) estimates, more than a billion adolescents and young adults are at risk of acquiring RNIHL due to the unsafe use of PAS (World Health Organization, 2015). The WHO (2015) estimates that among the younger generation, aged 12-35 years, approximately 50% are exposed to dangerous sound levels due to their personal audio systems. A systematic review done by Jiang et al. (2016) showed that up to 58.2% of adolescents and young adults exceeded their 100% daily sound dose when listening to music through their PAS. These users also had significantly worse hearing thresholds, as well as poor otoacoustic emission results (Jiang et al., 2016). Similar findings were reported by the National Health and Nutrition Examination Survey (NHNES) in the United States indicating that the prevalence of hearing loss in teenagers, between 12 and 19 years of age, increased from 3.5% to 5.3% between 1994 and 2006 (Shargorodsky et al., 2010). Furthermore, a study by le Clercq et al. (2018) concluded that 1 in 7 children between the ages of 9 and 11 years either already had a high-frequency hearing loss and/or a high-frequency notch, which may be an early indication of RNIHL. Moreover, repeated exposure to short-duration loud sounds over a long period of time may contribute to the acceleration of age-related hearing loss later in life (Alvarado et al., 2019).

Educationally-based hearing conservation programs have been implemented in attempt to encourage hearing conservation among the youth and young adults (Khan et al., 2018).

Different types of education have been used, such as educating a group of individuals in a classroom setting or educating a large number of individuals through public health campaigns (Khan et al., 2018). However, both of these approaches have not been proven to be effective in changing listening behavior (Khan et al., 2018). The systematic review by Khan et al. (2018) showed that studies related to educational hearing conservation programs for the youth had multiple methodological limitations i.e. poor study designs and low-quality reporting of results. Furthermore, studies have clearly shown that conventional education is not significant in raising awareness and that raising awareness or knowledge does not, by itself, result in a change in listening behavior (Zhao et al., 2011).

Effective interventions that change listening behavior and encourage safe listening habits, especially in the youth, is an important but elusive goal (Khan et al., 2018). Portnuff (2016) investigated several existing interventions aimed at reducing the risk of RNIHL caused by high PAS exposure and made recommendations for future interventions. Firstly, Portnuff (2016) recommended that hearing health interventions should be based on established health-behavior models. Secondly, interventions should educate PAS users on the severity of hearing loss (Portnuff, 2016). Since RNIHL may not present itself immediately, young adults and adolescents often have a low perceived susceptibility and, therefore, they should be made aware of the immediate and future risks of high PAS exposure (Zhao et al., 2010). Thirdly, underlying factors that could influence listening behavior should always be taken into consideration (Portnuff, 2016). For instance, the perceived barriers to preventative action could influence listening behavior (e.g., believing that one cannot enjoy music at lower intensities) (Diviani et al., 2019). Lastly, the two most direct recommendations were the use of noise-cancelling earphones and self-monitoring of listening levels (Portnuff, 2016). Self-monitoring of listening levels can be used to guide PAS users to change their listening behavior and to maintain a safe listening standard (Portnuff, 2016).

Self-monitoring is a key component of behavior change interventions (Payne et al., 2015). Studies related to various types of health behavior, such as weight management, physical activity, medication usage, addiction and diabetes showed that self-monitoring through mobile applications (apps) can result in positive behavior change leading to improved health (Bond et al., 2014; Bricker et al., 2014; Kirwan et al., 2013; Mira et al., 2014). The increased use of mobile devices among the youth highlights the opportunity to impact health behavior through mobile apps. A literature review by Zhao et al. (2016) found that 17 out of 23 studies reported significant effects of mobile apps on targeted behavior change. In 12 out of the 23 studies, authors found that self-monitoring was the most popular behavioral change method (Zhao et al., 2016). Furthermore, features such as detailed information, regular feedback on performance and personalised messages, the involvement of health professionals, user-friendly designs and less time consumption improved the effectiveness of health-related apps to result in behavioral changes (Zhao et al., 2016).

Kaplan-Neeman et al. (2017) conducted a study to assess the feasibility of real-time monitoring of listening behavior by using a smartphone app. The researchers loaned smartphones to the participants and it was required of them to follow their usual listening habits by using these smartphones only (Kaplan-Neeman et al., 2017). Although this was an observational study, the study findings confirmed the feasibility of monitoring listening behavior with a smartphone app without interfering with the listeners' listening routine (Kaplan-Neeman et al., 2017). However, since the participants had to use loaner smartphones, rather than their own devices, it might have elevated their consciousness leading to more cautious listening habits. New technologies, such as dbTrack earphones (Westone), allow monitoring of personal sound exposure on their own devices using sound-level monitoring earphones and an accompanying smartphone app (dbTrack, 2018).

The use of technology is a promising development in hearing health intervention. Technology-based interventions offer the opportunity to reach larger audiences in cost-effective ways (Khan et al., 2018). However, the ideal intervention would consist of a combination of different intervention strategies, which may provide a better chance of changing listening behavior (Portnuff, 2016). This present study, therefore, evaluated a hearing conservation intervention based on the Capability, Opportunity, Motivation and Behavior model (COM-B model) to promote healthy listening behaviors in young adults. The study was conducted in two phases. Phase 1 of the study investigated the reliability and accuracy of dbTrack (Westone) sound-level monitoring earphones sound-level monitoring earphones. Phase 2 of the study evaluated the effect of sound-level monitoring earphones with smartphone feedback and hearing health information as an intervention to promote healthy listening behaviors in young adults.

MATERIALS AND METHODS

This study received institutional ethical approval from the Faculty of Humanities Research Ethics Committee, University of Pretoria before data collection for phase 1 (GW20170823HS) and phase 2 (HUM014/1219).

Phase 1: Accuracy and Reliability of Sound-Level Monitoring Earphones

Materials and Apparatus

All measurements were conducted in a sound-treated laboratory. Transducers used in both experiments were dbTrack sound-level monitoring earphones (Westone laboratories, Colorado Springs, USA) and its accompanying dbTrack smartphone app (hearX group, Pretoria, South Africa) downloaded and installed on a Samsung A320 device. A MPEG Audio Layer III (MP3) music playlist was created on the smartphone consisting of 8 songs (28.46 minutes in total). The following songs were included in the playlist: Hymn for the Weekend by Coldplay, Pompeii by Bastille, Stressed Out by Twenty One Pilots, We Belong by Pat Benatar, Feel It Still by Portugal. The Man, Stay With Me by Black English, There Will Be Time by Mumford & Sons as well as Born To Be Yours by Kygo and Imagine Dragons. This MP3 music playlist was pre-selected on the smartphone to be used throughout all of the measurements. The sound-level monitoring earphones were calibrated using the accompanying dbTrack calibrator, USB cable and power source. For experiment 1, an Occluded Ear Simulator coupler based on International Electrotechnical Commission (IEC) standard 60318-4 (GRAS: RA0045-S1) was also used for the measurements with a Rion NL-52 Sound Level Meter (SLM) which complies with the following standards: IEC 61672-1: 2002 Class 1, American National Standard Institute (ANSI) S1.4-1983 Type 1, ANSI S1.4A-1985 Type 1, ANSI S1.43-1997 Type 1, JISC 1509-1: 2005 Class 1.

Procedures

Before the sound level measurements were conducted for both of the experiments, the in-ear microphone of each pair of earphones was calibrated using a dbTrack calibrator. Each dbTrack calibrator generated a white noise at 60 A-weighted decibels (dBA) which was measured and digitally recorded across 1/3 octave bands on the SLM. Every calibrator is marked with a unique quick response (QR) code linking its reference intensities across 1/3 octave bands. When calibrating dbTrack earphones, the QR code was scanned by the app using the camera of the smartphone to recall this profile. The earphones were connected to the smartphone and a green silicone earphone tip was attached to the right earphone (containing the microphone). The calibrator was connected to a power source using a USB cable. The right earphone, which includes the in-ear microphone, was then placed in the calibrator to record the intensity levels across 1/3-octave bands through the dbTrack microphone on the accompanying app installed on the smartphone. The app subsequently adjusted the microphone sensitivity on the smartphone to match the calibration reference. See Figure 1 for the calibration setup using the dbTrack calibrator (Fig. 1).

Figure 1. Calibration setup for the calibration of the in-ear microphone of the dbTrack sound-level monitoring earphones

Experiment 1: Accuracy and Intra-Device Reliability of Sound-Level Monitoring Earphones

In order to determine the accuracy and intra-device reliability, repeated-measures were conducted using 7 pairs of sound-level monitoring earphones as well as an Occluded Ear Simulator coupler with an SLM. Each pair of earphones was individually connected to the smartphone with the right earphone connected to the Occluded Ear Simulator coupler and the SLM. The pre-selected MP3 music playlist on the smartphone was played through the earphones at a fixed volume of 80 dBA. The microphone of the right earphone measured the intensity of the sound and it was displayed on the dbTrack smartphone app's screen. At the same time, the SLM measured the intensity of the sound output of the earphones. Measurements were repeated with all 7 earphones.

Experiment 2: Within-Subject Reliability of Sound-Level Monitoring Earphones

Convenience sampling was used to recruit a sample of 19 participants in order to determine the within-subject reliability. A single pair of sound-level monitoring earphones was connected to the smartphone. Thereafter, the same procedure was followed for all of the participants. Silicone or foam earphone tips (depending on the fit) were selected for the participants. The participants were asked to listen to the pre-selected MP3 music playlist on the smartphone through the earphones, which was played at a fixed volume of 81 dBA. The earphones measured the participants' in-ear sound levels and it was displayed on the dbTrack smartphone app's screen. The participants were asked to remove the earphones and reinsert it for the measurements to be repeated.

Data Analysis

SLM as well as sound-level monitoring earphone measurements during test and retest conditions (across earphones and across participants) were coded in Microsoft Excel and transferred to Statistic Package Social Sciences (SPSS) version 26 for statistical analysis. Results were analyzed using descriptive statistical measures in terms of mean, standard deviation and range. The Shapiro-Wilk's test and visual inspection of normal Q-Q plots were used to test for normality. Paired-samples *t*-test was used examine statistical significance between test-retest conditions in experiment 1 and repeated measures in experiment 2. A *p*-value of < 0.05 was used to indicate the level of significance.

Phase 2: Effect of Sound-Level Monitoring Earphones with Smartphone Feedback and Hearing Health Information on Listening Behaviors in Young Adults

Participants

A non-probability snowball sampling method was used to recruit participants for the second phase of the study. SurveyMonkey was used to create an online recruitment survey which included questions regarding age, gender, listening habits, location and contact details. Potential participants were provided with a link to fill in the recruitment survey, which was used to select suitable participants for the study based on the inclusion and exclusion criteria. Participants were included if they resided in Pretoria (South Africa), if they made use of Android technology, if they listened to music/other media through their personal audio systems >5 days a week or at least >10 hours a week and if they listened to music or other media through their personal audio systems at a volume >75% most of the time. Participants were excluded if they were undergraduate or postgraduate audiology students to prevent bias. Forty participants (25 males and 15 females) within the age range of 18 to

35 years (Mean 22.73 and 3.49 SD) were selected and gave consent to take part in the study.

Study Design

The second phase of the study was conducted using a single-group pretest-posttest design. Participants completed an online survey regarding sound exposure through PAS. Thereafter, participants were required to use dbTrack sound-level monitoring earphones with the accompanying dbtrack app for 4 weeks. During the first 2 weeks, participants' in-ear sound levels were measured by the earphones and recorded in the app, with the app's smartphone feedback feature disabled (pretest condition). At the end of the first 2 weeks, a brief information guide on hearing health was provided electronically to the participants. During the last 2 weeks, the smartphone feedback was automatically enabled on the smartphone app, which allowed the participants to monitor their listening activity (posttest condition). Participants completed a second online survey with questions regarding feedback on the study.

Materials and Apparatus

The authors developed two online surveys on Google Forms. The first survey consisted of 11 questions regarding sound exposure through PAS to explore participants' self-reported listening behavior as well as motivation to change listening behavior at the beginning of the study. The second survey was created to provide participants with the opportunity to give feedback about the study after the study. It included 4 questions regarding the influence of the smartphone feedback and information on listening behaviors as well as the impact of the Coronavirus Disease of 2019 (COVID-19) and lockdown period on listening behaviors.

Listening behaviors of the participants were measured during the study using dbTrack sound-level monitoring earphones (Westone, laboratories, Colorado Springs, USA) with its accompanying dbTrack smartphone app (hearX group, Pretoria, South Africa). The earphones were connected to the participants' Android devices using its 3.5 mm jack and were calibrated using the dbTrack calibrator, USB cable and a MacBook Air laptop as a power source. The earphones are balanced armature, full-range, noise-cancelling earphones with built-in microphones to measure in-ear sound exposure in real-time (dbTrack, 2018). The dbTrack app was designed to record listening activity measured by the earphones (listening duration and listening intensity) and calculates an accurate sound dose on a daily and weekly basis (dbTrack, 2018). However, a customized version of the app was created by a technical specialist at hearX group which was used for the study. Therefore, the app was in "research mode" for the first 2 weeks. The app's smartphone feedback feature was disabled for 2 weeks, where after the app automatically enabled the smartphone feedback. The sound exposure limits of the dbTrack app are based on the WHO & International Telecommunication Union (ITU) standard for safe listening devices and systems (World Health Organization & International Telecommunication Union, 2019). The WHO-ITU standard recommends that adults expose themselves to sounds of 80 dBA through their PAS for only 40 hours per week (which in turn is derived from 8 hours per day for 5 days a week), with an exchange rate of 3 dB (World Health Organization & International Telecommunication Union, 2019). The app monitored all audio output from the device via the earphones, including music, videos and games. The dbTrack app synced the recorded listening behaviors to the participants' profiles on the secure dbTrack cloud-based portal. This tool was used by the authors to monitor each participants' listening activity and to identify possible syncing problems. An information leaflet with frequently asked questions

(FAQ) regarding possible technical difficulties and their solutions was provided to the participants to ensure accurate and reliable sound measurements (See PDF of FAQ, Supplemental Digital Content 1).

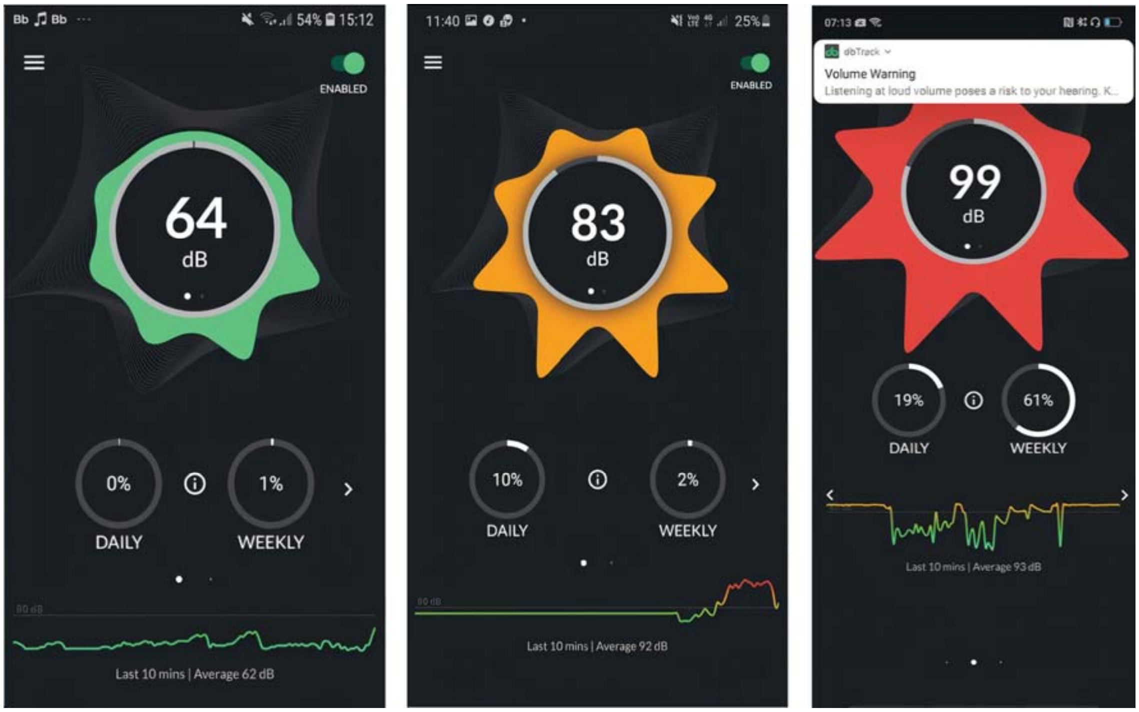
Procedures

Data were collected from 14 February 2020 until 11 August 2020. Participants were asked to complete the first online survey. Thereafter, the first author arranged individual meetings with the participants at a suitable time and place. At the meeting, participants downloaded and installed the customized version of the dbTrack smartphone app onto their Android devices through an Android Package Kit (APK) file. Each participant was provided with a pair of dbTrack sound-level monitoring earphones and a pair of custom-fit silicone earphone tips. The first author calibrated the in-ear microphone of each pair of earphones with the participants' devices by using the calibrator provided with each set of dbTrack earphones following the same calibration procedure as explained in phase 1. Participants were provided with the FAQ document, which was also explained to them verbally. Participants were asked to utilize their devices as they normally would on a daily basis and utilize the earphones provided to them for 4 weeks. The intervention was not discussed with the participants, to avoid influencing their listening behavior during the intervention period. However, it was mentioned that the app will change over time.

After the first 2 weeks (pretest condition), the hearing health information was provided electronically before the smartphone feedback was enabled on the dbTrack app for the posttest condition. The 2-page information guide included information on the following aspects; RNIHL and its effects on one's life, an explanation of safe listening, examples of how the permissible time decreases for safe listening as sound levels increase, safe listening tips and a noise thermometer (See PDF of hearing health information, Supplemental Digital Content 2). The participants were also informed by the first author that the app's feedback feature will be enabled the following day.

During the last 2 weeks (posttest condition), the smartphone feedback was automatically enabled on the dbTrack app, allowing participants to monitor their listening activity. The app provided real-time feedback based on listening behaviors (i.e. notifications of intensity levels, volume warnings, remaining safe listening time, daily and weekly sound dosages, and sound dose warnings). The feedback was colour-coded to convey the level of risk with green indicating low risk or safe listening, orange indicating moderate risk and red indicating high risk. The app also provided detailed historical information to track listening habits, guided participants on safe listening and raised awareness on damaging sound levels. See Figure 2A-C for an example of the green dbTrack application screen indicating safe listening (A), orange dbTrack application screen indicating moderate risk (B) and red dbTrack application screen indicating high risk with a volume warning (C) (Fig. 2).

After the four weeks, participants were provided with a link to complete the second online survey. After completing the study, participants returned the earphones and they received a $10 online shopping voucher as a reward for their participation.



Volume Warning

Listening at loud volume poses a risk to your hearing. K...

Figure 2. Green dbTrack application screen indicating safe listening (A), orange dbTrack application screen indicating moderate risk (B) and red dbTrack application screen indicating high risk with a volume warning (C).

Data Analysis

Responses from the two online surveys were exported to Microsoft Excel for statistical analysis. Results were analyzed using descriptive statistical measures in terms of frequency and percentage. Listening behaviors (average daily intensities, durations and sound dosages) measured during pretest and posttest conditions were retrieved from the dbTrack portal, coded in Microsoft Excel and transferred to SPSS version 26 for statistical analysis. Descriptive statistics were obtained through SPSS. The data was analyzed for outliers using the cut-off practice of values that fall outside of three standard deviations from the mean. The Shapiro-Wilk's test and visual inspection of normal Q-Q plots were used to test for normality. Paired-samples *t*-tests were used to determine whether there were statistically significant mean differences in intensity and duration measured during pre- and posttest conditions. The Wilcoxon signed-rank test was used to determine whether there were statistically significant median differences in sound dose measured during pre- and posttest conditions. A p-value of < 0.05 was used to indicate the level of significance using the paired-sample t-tests and the Wilcoxon signed-rank test. In addition, effect sizes were determined to gain a sense of the magnitude of change. Cohen's d formula was used to calculate effect sizes for intensity and duration as the data was normally distributed. According to Cohen (1988), effect sizes for d can be interpreted as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$). The r-value ($Z/\sqrt{N}$) was used to calculate the effect size for sound dose since the data was not normally distributed (Rosenthal, 1994). According to (Cohen, 1988, 1992), effect sizes for r can be interpreted as small ($r = 0.1$), medium ($r = 0.3$), and large ($r = 0.5$).

RESULTS

Phase 1: Accuracy and Reliability of Sound-Level Monitoring Earphones

Experiment 1: Accuracy and Intra-Device Reliability of Sound-Level Monitoring Earphones

The maximum Leq difference between the earphones and SLM was less than 1 Z-weighted decibels (dBZ) for both the test and retest conditions (Table 1). The maximum Leq difference between repeated measures across earphones (n = 7) was also less than 1 dBZ (Table 1). Differences between earphone and SLM measurements during test and retest conditions were normally distributed ($p > 0.05$), therefore, paired-samples t-tests were used to analyze data. Paired samples t-test showed no significant difference between earphone and SLM measurements during test (95%CI, -0.6 to 0.2, $t(6) = -1.283$, $p = 0.247$) and retest conditions (95%CI, -0.9 to 0.2, $t(6) = -1.555$, $p = 0.171$). Paired samples t-test showed no significant difference between repeated measures across earphones (95%CI, -0.1 to 0.5, *t*(6) = 2.109, *p* = 0.080).

Table 1. Comparison of sound-level monitoring earphone measurements (n=7 earphone pairs) and sound level meter measurements (Leq) during test and retest conditions (mean, SD and range) using a simulator coupler

	Equivalent continuous sound level (Leq) (dBZ)						
	Earphone test	**Earphone retest**	**SLM test**	**SLM retest**	**Earphone test-retest diff***	**Earphone and SLM test diff***	**Earphone and SLM retest diff***
Mean	79.6	79.4	79.8	79.7	0.3	-0.2	-0.3
SD	0.8	0.7	0.5	0.3	0.3	0.4	0.6
Min	78.5	78.4	79	79.3	-0.1	-0.6	-1
Max	80.7	80.5	80.5	80.1	0.8	0.6	0.7

*Falls within the American National Standard Institute (ANSI) SI.25-1991 standard for personal noise dosimeters of ±2 dB

Experiment 2: Within-Subject Reliability of Sound-Level Monitoring Earphones

Nineteen young adults participated in experiment 2 of phase 1 of the study (10 females and 9 males) between 20-35 years of age. The mean Leq difference between repeated measures across participants was less than 0.6 dBA and the maximum difference was less than 1.4 dBA (Table 2). Differences in in-ear sound levels between repeated measures across participants were normally distributed ($p > 0.05$), therefore, paired-samples *t*-tests were used to analyze data. Paired samples *t*-test showed a significant difference in in-ear sound levels between repeated measures across participants (95%CI, -0.9 to -0.1, *t*(18) = -2.382, *p* = 0.028), although the differences were within the ±2 dB margin as recommended by the ANSI standard for personal dosimeters.

Table 2. Comparison of in-ear sound levels (Leq) measured with sound level monitoring earphones during test and retest conditions (n = 19 participants)

	Equivalent continuous sound level (Leq) (dBA)		
	Test	**Retest**	**Within-subjects test-retest diff**[*]
Mean	81.2	81.6	-0.5
SD	1.7	1.5	0.9
Min	78.8	79.1	-1.9
Max	84.6	84.7	1.3

[*] Falls within the American National Standard Institute (ANSI) SI.25-1991 standard for personal noise dosimeters of ±2 dB

Phase 2: Effect of Sound-Level Monitoring Earphones with Smartphone Feedback and Hearing Health Information on Listening Behaviors in Young Adults

In the first online survey, more than half of the participants (55%) reported using their PAS every day of the week. Participants had to rate their motivation to develop safe listening habits on a 5-point Likert scale. Two-thirds of participants (67.5%) reported being motivated or very motivated to develop safe listening behaviors in this sample (See PDF of pretest survey responses on sound exposure through personal audio systems, Supplemental Digital Content 3).

Two outliers were identified in sound dose, one in pretest condition and one in posttest condition. However, the outliers were not excluded from the data since the outcomes and statistical significance remains unchanged with the outliers excluded. Differences in average daily intensity and duration were normally distributed ($p > 0.05$), therefore, the paired-samples *t*-tests were used to analyze data. Differences in average daily sound dose were not normally distributed ($p < 0.05$), therefore, Wilcoxon signed-rank test was used to analyze the data. Average daily intensity, duration and sound dose measured with the sound level monitoring earphones and its accompanying app during pre- and posttest conditions are compared in Table 3.

Table 3. Average daily intensity, duration and sound dose measured by the sound-level monitoring earphones during pretest and posttest conditions (n = 40)

	Pretest	**Posttest**	**Difference**	**Effect size**
Intensity ***Mean (SD)***	59.6 (18.6) dBA	51 (21.4) dBA	8.7 (18.3) dBA*	0.474^{a}
Duration ***Mean (SD)***	65.6 (52.4) minutes	58 (57.6) minutes	7.6 (46.6) minutes	0.163^{a}
Sound dose ***Mean (SD)***	5912.7 (24479.9)%	1784.3 (6845.9)%	4128.4 (24965.5)%**	-0.373^{b}

*Significant difference ($p < 0.05$; Paired-samples *t* test)
**Significant difference ($p < 0.05$; Wilcoxon signed-rank test)
^{a}Cohen's *d*
^{b}*r* value (Z/√N)

Average daily intensity ranged from 18.7 dBA to 97.1 dBA during pretest condition and from 9.7 dBA to 96.6 dBA during posttest condition. Paired samples *t*-test showed a statistically significant decrease in the mean intensity between pre- and posttest conditions with a small effect size (95% CI, 2.8 to 14.5, $t(39) = 2.998$, $p = 0.005$, $d = 0.474$). Average daily duration ranged from 7.9 minutes to 208.9 minutes during pretest condition and from 2 minutes to 246.9 minutes during posttest condition. Paired samples *t*-test showed no significant decrease in the mean duration between pre- and posttest conditions with a small effect size (95%CI, -7.3 to 22.5, $t(39) = 1.033$, $p = 0.308$, $d = 0.163$). Average daily sound dose, calculated by the dbTrack app, ranged from 0.3% to 148517.3% during pretest condition and from 0.1% to 40959.5% during posttest condition. Wilcoxon signed-rank test showed a statistically significant median decrease (median= 44) in average daily sound dose during posttest condition (median= 19) when compared to pretest condition with a medium effect size (median=89.6, $z = -3.342$, $p = 0.001$, $r = -0.373$). See Figure 3 for box-and-whisker plots of average daily (A) intensity (B) duration and (C) sound dose measured during pre- and posttest conditions (Fig. 3A-C).

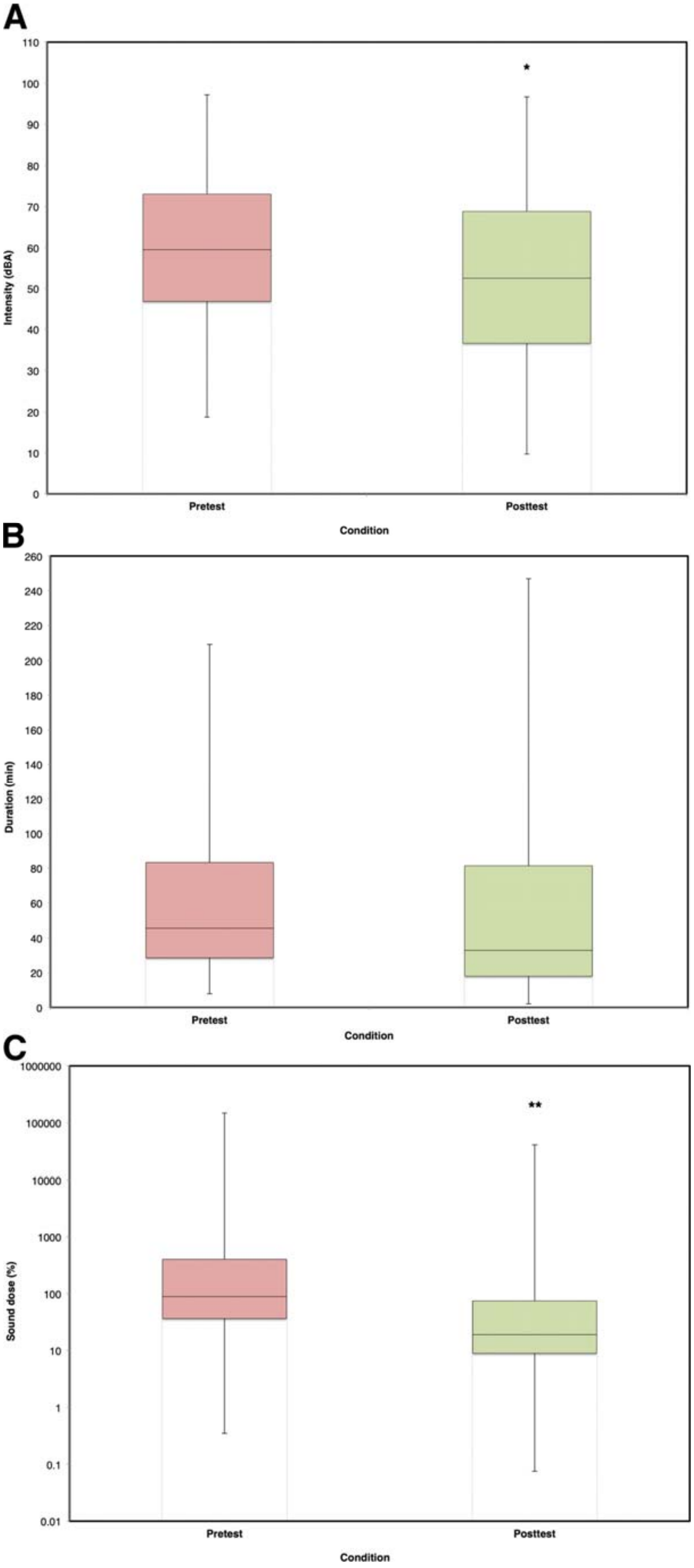

A
110
100
90
80
70
60
50
40
30
20
10
0
Intensity (dBA)
*
Pretest
Posttest
Condition
B
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Duration (min)
Pretest
Posttest
Condition
C
1000000
100000
10000
1000
100
10
1
0.1
0.01
Sound dose (%)
**
Pretest
Posttest
Condition

Figure 3. Box-and-whisker plots (boxes represent interquartile range and whiskers represent range) of average daily (A) intensity (B) duration and (C) sound dose measured during pre- and posttest conditions (n=40). ***Significant difference ($p < 0.05$; Paired-samples t test); **Significant difference ($p < 0.05$; Wilcoxon signed-rank test).***

The post-study survey revealed that smartphone feedback and hearing health information motivated 95% of the participants to change their listening behavior. Most of them (90%) reported that smartphone feedback contributed the most. Thirty participants participated in the study during the COVID-19 pandemic or lockdown period. Nearly all of them (83.3%) indicated that the COVID-19 pandemic or lockdown period influenced their normal listening behavior, 46.7% reported that they used their PAS more and 36.7% reported that they used their PAS less.

DISCUSSION

Evaluating the risk of NIHL requires a reliable method to measure and monitor noise or sound exposure. A number of studies have been done on the use of in-ear monitoring of noise exposure in occupational settings (Bonnet et al., 2015, 2019; Bonnet et al., 2020; Nadon, et al., 2020; Nogarolli et al., 2019), however, limited research is available pertaining to in-ear monitoring of sound exposure in recreational settings. To our knowledge, only two studies have monitored listening behaviors using dosimetry measurements (Kaplan-Neeman et al., 2017; Portnuff et al., 2013). Neither of these studies made use of in-ear monitoring specifically, Portnuff et al. (2013) used an external dosimeter and Kaplan-Neeman et al. (2017) used a smartphone app. This present study evaluated a novel hearing conservation intervention for young adults to address RNIHL using dbTrack sound-level monitoring earphones with smartphone feedback. The following highlights the main findings and implications.

Phase 1: Accuracy and Reliability of Sound-Level Monitoring Earphones

Phase 1 of the current study investigated the accuracy and reliability of dbTrack (Westone) sound-level monitoring earphones designed to measure sound levels inside the ear canal. The mean Leq difference was within 1 dBZ between the earphones and SLM as well as between repeated measures across earphones (n = 7). Differences between earphone and SLM measurements as well as differences between repeated measures across earphones were not statistically significant (using $p < 0.05$). Phase 1 (experiment 2) showed that the mean Leq difference across participants (n = 19) was also within 1 dBA even though differences in in-ear sound levels between repeated measures across participants were statistically significant (using $p < 0.05$). The sound-level monitoring earphones were therefore well within the recommended ANSI SI.25-1991 standard for personal noise dosimeters of ±2 dB when compared to a reference measurement and when compared to each other (ANSI S1.25-1991, 2007). Therefore, dbTrack (Westone) sound-level monitoring earphones can measure PAS exposure accurately and reliably.

Phase 2: Effect of Sound-Level Monitoring Earphones with Smartphone Feedback and Hearing Health Information on Listening Behaviors in Young Adults

The first online survey revealed that most participants (87.5%) have been using PAS for more than 5 years. Earphones (62.5%), as opposed to headphones (10%), were the most commonly used by participants. Individuals using earphones as opposed to headphones have higher preferred listening levels (Hodgetts et al., 2007). Kim et al. (2009) found significantly elevated hearing thresholds in individuals who had been using PAS for over 5 years and in those who had used earphones specifically. Nearly half of the participants (45%) reported that they use their PAS for 10-11 hours per week and most participants (70%) indicated that they listen at a volume of 75% most of the time. These results were expected since participants had to meet the inclusion criteria. However, listening behavior measured by the sound-level monitoring earphones during the pretest condition showed that a large portion of the participants (72.5%) did not meet the minimum criteria of using their PAS for 10 hours per week. Furthermore, only 7.5% of participants' average daily intensity reached 75% of the maximum output during the pretest condition since the maximum volume outputs of PAS can reach over 125 dBA (Breinbauer et al., 2012). Previous studies have also found inconsistencies between self-reported listening behavior and logged listening behavior (Hodgetts et al., 2009; Kaplan-Neeman et al., 2017; Portnuff et al., 2013).

Phase 2 of the study implemented an intervention protocol based on the COM-B model. The COM-B model has successfully been used in studies in the field of audiology as a theoretical basis for behavior change (Barker et al., 2016; Maidment et al., 2019). We hypothesized that by addressing the capabilities and opportunities, it would drive the participants' motivation to change their listening behavior. To address the participants' psychological capability (i.e. knowledge), the intervention included hearing health information. Furthermore, to address the participants' physical capability (i.e. skills), real-time smartphone feedback was provided via the dbTrack app. The invitation to take part in this study provided the participants with the social opportunity to take part in a research experiment with other young adults who self-reported similar listening habits. A physical opportunity was provided to the participants during the study by giving them physical access to the dbTrack (Westone) sound-level monitoring earphones and its accompanying dbTrack app to monitor their listening behavior. Differences in the average daily intensity and sound dose between pre- and posttest conditions were statistically significant with a small and medium effect size respectively, however, differences in the average daily duration were not statistically significant (using $p < 0.05$). This finding supports previous research, which has shown that young adults are more inclined to engage in the intentional behavior of lowering the intensity of their PAS rather than decreasing their listening time (Gopal et al., 2019). The post-study survey revealed that 95% of participants were motivated by the smartphone feedback and hearing health information to change their listening behavior. It is important to highlight that 90% of participants indicated that smartphone feedback played the biggest role in motivating them to change their listening behavior.

Bond et al. (2014) demonstrated that a smartphone-based intervention can significantly reduce excessive sedentary time in obese individuals. Similar to our findings, 90% of the participants indicated that the real-time smartphone feedback motivated them to change their behavior. Kebede & Pischke (2019) showed that using a diabetes smartphone application for self-management can improve self-care in individuals with type 1 and type 2 diabetes. Furthermore, a study done by Steinberg et al. (2015) demonstrated that measuring weight on a daily basis could help obese individuals to reduce or maintain weight. Similarly, the dbTrack earphones and app might help PAS users to reduce their daily sound dosages by measuring their in-ear sound levels and providing real-time feedback. It is noteworthy that the interventions that were designed to reduce RNIHL related to PAS specifically are scarce in the peer-reviewed literature (Portnuff, 2016). The Cheers for Ears program, consisting of a multimodal classroom presentation, was successful in changing self-reported listening behavior in children (Taljaard et al., 2013). However, studies have shown inconsistencies between self-reported listening behavior and logged listening behavior (Hodgetts et al., 2009; Kaplan-Neeman et al., 2017; Portnuff et al., 2013). As mentioned before, these discrepancies could be seen in this study as well. This highlights the significance of digital technologies, such as the sound-level monitoring earphones with its accompanying app used in this study, which calculates exact sound dosages and allows individuals to accurately monitor their sound exposure to prevent them from acquiring an RNIHL.

It is important to note that, unlike most other studies done within this field, the sound exposure limits used in this study were based on the WHO-ITU standard for safe listening devices and systems (World Health Organization & International Telecommunication Union, 2019). Prior to the WHO-ITU standard, there were no established standards specifically for the use of PAS. With only general guidelines available for PAS exposure, most studies have used standards and recommendations established for noise exposure in occupational settings (Jiang et al., 2016). The WHO-ITU standard is more conservative in terms of sound allowance when compared to many other standards developed for occupational noise exposure, for example, the widely used National Institute for Occupational Safety and Health (NIOSH) standard (National Institute for Occupational Safety and Health, 1998). Therefore, participants were more likely to exceed their daily sound dose limits when compared to other studies using less conservative standards. This may explain the high sound dose percentages recorded in this study in some participants.

This study’s main limitations were the small sample size and high variability in results. Other limitations include possible sampling bias since non-probability sampling was used which can lead to bias with some members of the population more likely to be included than others. Real-ear measurements could have been conducted in phase 1 to assess the participants' in-ear sound levels in addition to the real-ear coupler measurements. Furthermore, most of the data collection for phase 2 of this study took place during the COVID-19 pandemic and lockdown period. This affected participants' daily routines including their listening behaviors. The post-study survey revealed that 83.3% of participants felt that the COVID-19 pandemic and lockdown period had influenced their normal listening behaviors (n = 30). Moreover, the study was terminated earlier due to the pandemic allowing a smaller sample than initially anticipated. This may explain small effect sizes or marginal significance levels in some instances due to a smaller sample. Since the sound dose calculations were based on the conservative WHO-ITU standard, participants with high sound dose percentages received multiple notifications from the app during the posttest condition which they might have become accustomed to over time. This can be seen as a study limitation since it might have been counterproductive and lessened the effect of the app's feedback on their listening behavior. In addition, the wide range of sound dosages can also be seen as a study limitation since high variability is expected to decrease the power to detect a difference between pre- and posttest conditions. Only Android technology was used in this study, which does not allow for the devices' internal compressors to be switched off. Although the audio route with the least processing was used, this might have contributed to the high variability of results between participants. A number of other factors may also have influenced the participants' listening behaviors throughout the 4-week study period. These included exams, work, family events and religious events.

Therefore, this research should be expanded using a larger sample over a longer period of time. As sample size increases, variability is expected to decrease and the power to detect a difference between pre- and posttest conditions is expected to increase. A larger sample might also lessen the impact of internal and external factors on listening behaviors. A longer study period can be used to determine whether the effects of the intervention are sustained and including samples of different ages, especially teenagers, could inform preventative strategies in this group.

CONCLUSIONS

This study's preliminary data indicate that dbTrack (Westone) sound-level monitoring earphones with a calibrated in-ear microphone can reliably and accurately measure PAS sound exposure. Smartphone feedback on sound exposure measured by dbTrack earphones with hearing health information demonstrated a significant decrease in intensity and sound dose with a small and medium effect, respectively. Preliminary results suggest that smartphone feedback on sound exposure using the accurate sound-level monitoring earphones with the accompanying dbTrack app can potentially promote safe listening behavior in young adults and reduce the risk of acquiring an RNIHL.

REFERENCES

Alvarado, J. C., Fuentes-Santamaría, V., Gabaldón-Ull, M. C., & Juiz, J. M. (2019). Age-related hearing loss is accelerated by repeated short-duration loud sound stimulation. *Frontiers in Neuroscience*, *13*(77), 1–14. https://doi.org/10.3389/fnins.2019.00077

American National Standards Institute S1.25-1991. (2007). Specifications for Personal Noise

Dosimeters. https://law.resource.org/pub/us/cfr/ibr/002/ansi.s1.25.1991.pdf

Barker, F., Atkins, L., & de Lusignan, S. (2016). Applying the COM-B behaviour model and behaviour change wheel to develop an intervention to improve hearing-aid use in adult auditory rehabilitation. *International Journal of Audiology*, *55*(sup3), S90–S98. https://doi.org/10.3109/14992027.2015.1120894

Bond, D. S., Thomas, J. G., Raynor, H. A., Moon, J., Sieling, J., Trautvetter, J., Leblond, T., & Wing, R. R. (2014). B-MOBILE - A smartphone-based intervention to reduce sedentary time in overweight/obese individuals: A within-subjects experimental trial. *PLoS ONE*, *9*(6),e100821. https://doi.org/10.1371/journal.pone.0100821

Bonnet, F., Nélisse, H., Nogarolli, M. A. C., & Voix, J. (2019). In-ear noise dosimetry under earplug: Method to exclude wearer-induced disturbances. *International Journal of Industrial Ergonomics*, *74,* 102862. https://doi.org/10.1016/j.ergon.2019.102862

Bonnet, F., Voix, J., & Nélisse, H. (2015). The opportunities and challenges of in-ear noise dosimetry. *Canadian Acoustics - Acoustique Canadienne*, *43*(3), 80–81.

Bonnet, F., Nélisse, H., Nogarolli, M. A. C., & Voix, J. (2020). Individual in situ calibration of in-ear noise dosimeters. *Applied Acoustics*, *157*, 107015. https://doi.org/10.1016/j.apacoust.2019.107015

Breinbauer, H. A., Anabalõn, J. L., Gutierrez, D., Cárcamo, R., Olivares, C., & Caro, J. (2012). Output capabilities of personal music players and assessment of preferred listening levels of test subjects: Outlining recommendations for preventing music-induced hearing loss. *Laryngoscope*, *122*(11), 2549–2556. https://doi.org/10.1002/lary.23596

Bricker, J. B., Mull, K. E., Kientz, J. A., Vilardaga, R., Mercer, L. D., Akioka, K. J., & Heffner, J. L. (2014). Randomized, controlled pilot trial of a smartphone app for smoking cessation using acceptance and commitment therapy. *Drug and Alcohol Dependance*, *143*, 87–94. https://doi.org/https://doi.org/10.1016/j.drugalcdep.2014.07.006

Chung, J. H., Roches, C. M. Des, Meunier, J., & Eavey, R. D. (2005). *Evaluation of Noise-Induced Hearing Loss in Young People Using a Web-Based Survey Technique*. *Paediatrics*, *115*(4), 861–867. https://doi.org/10.1542/peds.2004-0173

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J. : L. Erlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

dBTrack. (2018). *dBTrack*. https://www.dbtrack.com/

Diviani, N., Zanini, C., Amann, J., Chadha, S., Cieza, A., & Rubinelli, S. (2019). Awareness, attitudes, and beliefs about music-induced hearing loss: Towards the development of a health communication strategy to promote safe listening. *Patient Education and Counseling*, *102*(8), 1506–1512. https://doi.org/10.1016/j.pec.2019.03.013

Gopal, K. V., Champlin, S., & Phillips, B. (2019). Assessment of safe listening intentional behavior toward personal listening devices in young adults. *International Journal of Environmental Research and Public Health*, *16*(17), 3180. https://doi.org/10.3390/ijerph16173180

Groves, A. (2010). The Challenge of Hair Cell Regeneration. *Experimental Biology and*

Medicine, *235*(4), 434–466. https://doi.org/https://dx.doi.org/10.1258%2Febm.2009.009281

Harrison, R. V. (1998). An Animal Model of Auditory Neuropathy. *Ear and Hearing*, *19*(5), 355–361. https://doi.org/10.1097/00003446-199810000-00002

Harrison, R. V. (2008). Noise-induced hearing loss in children: A “less than silent” environmental danger. *Paediatrics and Child Health*, *13*(5), 377–382. https://doi.org/10.1093/pch/13.5.377

Henry, K. S., Sayles, M., Hickox, A. E., & Heinz, M. G. (2019). Divergent Auditory Nerve Encoding Deficits Between Two Common Etiologies of Sensorineural Hearing Loss. *The Journal of Neuroscience*, *39*(35), 6879–6887. https://doi.org/10.1523/JNEUROSCI.0038-19.2019

Hodgetts, W. E., Rieger, J. M., & Szarko, R. A. (2007). The effects of listening environment and earphone style on preferred listening levels of normal hearing adults using an MP3 player. *Ear and Hearing*, *28*(3), 290–297. https://doi.org/10.1097/aud.0b013e3180479399

Hodgetts, W. E., Rieger, J. M., & Szarko, R. A. (2009). What is the influence of background noise and exercise on the listening levels of iPod users? *International Journal of Audiology*, *48*(12), 825–832. https://doi.org/10.3109/14992020903082104

Jiang, W., Zhao, F., Guderley, N., & Manchaiah, V. (2016). Daily music exposure dose and hearing problems using personal listening devices in adolescents and young adults: A systematic review. *International Journal of Audiology*, *55*(4), 197–205. https://doi.org/10.3109/14992027.2015.1122237

Kaplan-Neeman, R., Muchnik, C., & Amir, N. (2017). Listening to music with personal listening devices: monitoring the noise dose using a smartphone application. *International Journal of Audiology*, *56*(6), 400–407. https://doi.org/10.1080/14992027.2017.1297541

Kebede, M. M., & Pischke, C. R. (2019). Popular Diabetes Apps and the Impact of Diabetes App Use on Self-Care Behaviour: A Survey Among the Digital Community of Persons With Diabetes on Social Media. *Frontiers in endocrinology*, *10*, 135. https://doi.org/10.3389/fendo.2019.00135

Khan, K. M., Bielko, S. L., & McCullagh, M. C. (2018). Efficacy of hearing conservation education programs for youth and young adults: A systematic review. *BMC Public Health*, *18*(1). https://doi.org/10.1186/s12889-018-6198-7

Kim, M. G., Hong, S. M., Shim, H. J., Kim, Y. D., Cha, N. I., & Yeo, S. G. (2009). Hearing threshold of Korean adolescents associated with the use of personal music players. *Yonsei Medical Journal*, *50*(6), 771–776. https://doi.org/10.3349/ymj.2009.50.6.771

Kirwan, M., Vandelanotte, C., Fenning, A., & Duncan, M. J. (2013). Diabetes Self-Management Smartphone Application for Adults With Type 1 Diabetes: Randomized Controlled Trial. *Journal of Medical Internet Research*, *15*(11), e235. https://doi.org/10.2196/jmir.2588

Langguth, B., Kreuzer, P., Kleinjung, T., & De Ridder, D. (2013). Tinnitus: causes and clinical management. *The Lancet. Neurology.*, *12*(9), 920–930. https://doi.org/10.1016/S1474-4422(13)70160-1

le Clercq, C. M. P., Goedegebure, A., Jaddoe, V. W. V., Raat, H., Baatenburg de Jong, R. J., &

van der Schroeff, M. P. (2018). Association Between Portable Music Player Use and Hearing Loss Among Children of School Age in the Netherlands. *JAMA Otolaryngology–Head & Neck Surgery*, *144*(8), 1–8. https://doi.org/10.1001/jamaoto.2018.0646

Liberman, M. C., & Kujawa, S. G. (2017). Cochlear synaptopathy in acquired sensorineural hearing loss: Manifestations and mechanisms. *Hearing Research*, *349*, 138–147. https://doi.org/10.1016/j.heares.2017.01.003

Maidment, D. W., Ali, Y. H. ., & Ferguson, M. A. (2019). Applying the COM-B model to assess the usability of smartphone-connected listening devices in adults with hearing loss. *Journal of the American Academy of Audiology*, *30*(5), 417–430. https://doi.org/https://doi.org/10.3766/jaaa.18061

Mira, J. J., Navarro, I., Botella, F., Borrás, F., Nuño-Solinís, R., Orozco, D., Iglesias-Alonso, F., Pérez-Pérez, P., Lorenzo, S., & Toro, N. (2014). A Spanish Pillbox App for Elderly Patients Taking Multiple Medications: Randomized Controlled Trial. *Journal of Medical Internet Research*, *16*(4), e99. https://doi.org/10.2196/jmir.3269

Nadon, V., Bonnet, F., Bouserhal, R. ., Bernier, A., & Voix, J. (2020). Method for protected noise exposure level assessment under an in-ear hearing protection device: a pilot study. *International Journal of Audiology*, 1–10. https://doi.org/https://doi.org/10.1080/14992027.2020.1799082

National Institute for Occupational Safety and Health. (1998). *Occupational Noise Exposure: Revised Criteria 1998*. https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf

Nogarolli, M. A. C., Bonnet, F., Nélisse, H., & Voix, J. (2019). *Design and laboratory validation of an in-ear noise dosimetry device*. [Conference paper]. Proceedings of the 26th

International Congress on Sound and Vibration, 2019, Montreal, Canada.

Payne, H. E., Lister, C., West, J. H., & Bernhardt, J. M. (2015). Behavioral Functionality of Mobile Apps in Health Interventions: A Systematic Review of the Literature. *JMIR MHealth and UHealth*, *3*(1), e20. https://doi.org/10.2196/mhealth.3335

Portnuff, C. D. F. (2016). Reducing the risk of music-induced hearing loss from overuse of portable listening devices: understanding the problems and establishing strategies for improving awareness in adolescents. *Adolescent Health, Medicine and Therapeutics*, *7*, 27–35. https://doi.org/10.2147/AHMT.S74103

Portnuff, C. D. F., Fligor, B. J., & Arehart, K. H. (2013). Self-report and long-term field measures of MP3 player use: How accurate is self-report? *International Journal of Audiology*, *52 Suppl 1*, S33–S40. https://doi.org/10.3109/14992027.2012.745649

Rosenthal, R. (1994). Parametric measures of effect size. In *The handbook of research synthesis* (pp. 231–244). Russell Sage Foundation.

Ryan, A. F., Kujawa, S. G., Hammill, T., Le Prell, C., & Kil, J. (2016). Temporary and Permanent Noise-induced Threshold Shifts: A Review of Basic and Clinical Observations. *Otology and Neurotology*, *37*(8), e271–e275. https://doi.org/10.1097/MAO.0000000000001071

Seidman, M. D., & Standring, R. T. (2010). Noise and Quality of Life. *International Journal of Environmental Research and Public Health*, *7*(10), 3730–3738. https://doi.org/10.3390/ijerph7103730

Shargorodsky, J., Curhan, S., Curhan, G., & Eavey, R. (2010). Change in prevalence of hearing loss in US adolescents. *JAMA*, *304*(7), 772-778.

https://doi.org/10.1001/jama.2010.1124

Steinberg, D. M., Bennett, G. G., Askew, S., & Tate, D. F. (2015). Weighing every day matters: daily weighing improves weight loss and adoption of weight control behaviors. *Journal of the Academy of Nutrition and Dietetics, 115*(4), 511–518. https://doi.org/https://doi.org/10.1016/j.jand.2014.12.011

Taljaard, D. S., Leishman, N. F., & Eikelboom, R. H. (2013). Personal listening devices and the prevention of noise induced hearing loss in children: The cheers for ears pilot program. *Noise and Health*, *15*(65), 261–268. https://doi.org/10.4103/1463-1741.113523

World Health Organization. (2015). *1.1 billion people at risk of hearing loss*. World Health Organization. http://www.who.int/mediacentre/news/releases/2015/ear-care/en/

World Health Organization and International Telecommunication Union. (2019). *Safe Listening Devices and Systems*: *a WHO-ITU standard.* https://apps.who.int/iris/bitstream/handle/10665/280085/9789241515276-eng.pdf

You, S., Kong, T. H., & Han, W. (2020). The effects of short-term and long-term hearing changes on music exposure: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *17*(6), 2091. https://doi.org/10.3390/ijerph17062091

You, S., & Kwak, C. (2020). Use of Personal Listening Devices and Knowledge / Attitude for Greater Hearing Conservation in College Students : Data Analysis and Regression Model Based on 1009 Respondents. *International Journal of Environmental Research and Public Health, 17*(18), 2934. https://doi.org/10.3390/ijerph17082934

Zhao, F., French, D., Manchaiah, V. K. C., Liang, M., & Price, S. M. (2011). Music exposure and hearing health education: A review of knowledge, attitude, and behaviour in adolescents and young adults. *Health Education Journal*, *71*(6), 709–724. https://doi.org/https://doi.org/10.1177%2F0017896911422780

Zhao, F., Manchaiah, V. K. C., French, D., & Price, S. M. (2010). Music exposure and hearing disorders: An overview. *International Journal of Audiology*, *49*(1), 54–64. https://doi.org/64. https://doi.org/10.3109/14992020903202520

Zhao, J., Freeman, B., & Li, M. (2016). Can Mobile Phone Apps Influence People's Health Behavior Change? An Evidence Review. *Journal of Medical Internet Research*, *18*(11), e287. https://doi.org/10.2196/jmir.5692