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Sound-Level monitoring earphones with smartphone feedback as an intervention to promote healthy listening behaviours in young adults

by

Megan Clarissa Knoetze

(16005725)

Dissertation submitted in fulfilment of the requirements for the degree MA (Audiology) in the Department of Speech-Language Pathology and Audiology, Faculty of Humanities, University of Pretoria.

Supervisors:

Prof De Wet Swanepoel

Dr Faheema Mahomed-Asmail

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Megan Clarissa Knoetze

Department of Speech-Language Pathology and Audiology

University of Pretoria

Email: meggieknoetze@gmail.com

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Full names of student: **Megan Clarissa Knoetze**

Student number: **16005725**

Date submitted: **26 November 2020**

Topic of work: **Sound-Level monitoring earphones with smartphone feedback as an intervention to promote healthy listening behaviours in young adults**

Signature: 

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ETHICS STATEMENT

The author, whose name appears on the title page of this dissertation, has obtained, for the research described in this work, the applicable research ethics approval.

The author declares that she has observed the ethical standards required in terms of the University of Pretoria’s Code of ethics for researcher’s and the Policy guidelines for responsible research.

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ABSTRACT

Background

More than a billion adolescents and young adults are at risk of acquiring recreational noise-induced hearing loss (RNIHL) due to the unsafe use of Personal Audio Systems (PAS). Although preventable, once occurred the RNIHL is irreversible and can have a severe negative impact on physical and mental health as well as on academic or work performance. Educational programs alone have not been effective in changing listening behaviour in PAS users.

Objectives

The present study, therefore, 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 behaviours 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 dbTrack (Westone) 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 dBA (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 small and medium effect size, respectively.

Conclusions

This study's 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 behaviour in young adults and reduce the risk of acquiring an RNIHL.

KEYWORDS

Hearing conservation; Hearing intervention; Noise-induced hearing loss; Music-induced hearing loss; Recreational noise-induced hearing loss; Sound-induced hearing loss; Personal audio systems; Listening behaviour; Young adults.

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LIST OF ABBREVIATIONS AND ACRONYMS

APA: American Psychological Association

APK: Android Package Kit

App: Application

COM-B model: Capability, Opportunity, Motivation and Behaviour model

COVID-19: Coronavirus Disease of 2019

dBA: A-weighted decibels

dBZ: Z-weighted decibels

ITU: International Telecommunication Union

NIHL: Noise-induced hearing loss

RNIHL: Recreational Noise-Induced Hearing Loss

SLM: Sound Level Meter

SPSS: Statistic Package Social Sciences

TTS: Temporary Threshold Shift

USB: Universal Serial Bus

PAS: Personal Audio System

PTS: Permanent Threshold Shift

WHO: World Health Organization

FORMATTING

American Psychological Association (APA) 7th edition referencing style was used in this dissertation.

CHAPTER 1: INTRODUCTION

According to the World Health Organization (WHO), more than 466 million individuals are suffering from a disabling hearing loss (World Health Organization, 2019). There are many risk factors related to hearing loss, including noise exposure in occupational and recreational settings (World Health Organization, 2018). A noise-induced hearing loss (NIHL) can be defined as a sensorineural hearing impairment in the higher frequencies, either caused by a single exposure to an intense sound or long term exposure to excessive sound with intensities greater than 75-85dB (Basner et al., 2014). Although preventable, once occurred the NIHL is irreversible and can have a severe negative impact on one's physical and mental health as well as academic or work performance (Seidman & Standring, 2010).

Excessive sound exposure can result in a temporary threshold shift (TTS), which can be described as a temporary loss of hearing sensitivity that recovers over time (Ryan et al., 2016). The recovery time of a TTS depends on the level and duration of sound exposure, the type of sound exposure and individual susceptibility (Ryan et al., 2016). Furthermore, excessive sound exposure can result in a permanent threshold shift (PTS), referring to the permanent loss of cochlear hair cells (Ryan et al., 2016). The micromechanical structure of the hair cell stereocilia, their connections and the ion channels of the membrane are frail structures easily damaged by auditory overstimulation (Harrison, 2008). There are also proven to be indirect effects such as cochlear hypoxia and local vascular damage (Harrison, 1998). This refers to the reduction of intra-cochlear oxygen levels and blood flow in the cochlea, which can lead to further damage to the hair cells (Harrison, 1998). The cochlear hair cells cannot regenerate and therefore it is important to prevent damage to the hair cells (Groves, 2010).

Additionally, acute or chronic exposure to high sound levels can result in tinnitus, defined as the perception of sound without the presence of an external sound source (Langguth et al., 2013). Tinnitus can have an adverse effect on quality of life, since it may cause depression, sleep disturbance and decreased sustained attention (Adrian & El Refaie, 2000). Moreover, excessive sound exposure can be associated with various other auditory-related symptoms, such as hyperacusis, recruitment and abnormal speech perception (Groves, 2010; Henry et al., 2019; Liberman & Kujawa, 2017; Zhao et al., 2010).

Recreational Noise-Induced Hearing Loss and Personal Audio Systems

Historically, the focus of noise-induced hearing loss 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 (Jiang et al., 2016; You et al., 2020; Zhao et al., 2010). According to the World Health Organization (WHO, 2015) estimates, more than a billion adolescents and young adults are at risk of acquiring RNIHL due to the unsafe use of PAS. 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, high sound exposure from an early age can increase the risk of acquiring age-related hearing loss later in life (Kujawa & Liberman, 2006).

Preventing RNIHL associated with PAS

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). A number of public health campaigns have been implemented to raise awareness about safe listening practices including Listen To Your Buds, Dangerous Decibels, It's a Noisy Planet, Don't Lose the Music, Cheers for Ears and NOISE (World Health Organization, 2015). However, these approaches have not been proven to be effective in changing listening behaviour (Khan et al., 2018). A 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 behaviour (Zhao et al., 2011).

Effective interventions that change listening behaviour 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-behaviour models e.g. the Capability, Opportunity, Motivation and Behaviour model (COM-B model)(Michie et al., 2014). 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 behaviour should always be taken into consideration (Portnuff, 2016). For instance, the perceived barriers to preventative action could influence listening behaviour (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 behaviour and to maintain a safe listening standard (Portnuff, 2016).

Self-monitoring is a key component of behaviour change interventions (Payne et al., 2015). Studies related to various types of health behaviour, such as weight management, physical activity, medication usage, addiction and diabetes showed that self-monitoring through mobile applications (apps) can result in positive behaviour change leading to improved health (Bond et al., 2014; Bricker et al., 2014; Kirwan et al., 2013; Mira et al., 2014; Steinberg et al., 2015). The increased use of mobile devices among the youth highlights the opportunity to impact health behaviour through mobile apps. A review by Zhao et al. (2016) found that 17 out of 23 studies reported significant effects of mobile apps on targeted behaviour change. In 12 out of the 23 studies, authors found that self-monitoring was the most popular behavioural 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 behavioural changes (Zhao et al., 2016).

Kaplan-Neeman et al. (2017) conducted a study to assess the feasibility of real-time monitoring of listening behaviour 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 behaviour 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).

Standards and recommendations for the use of PAS

Until recently, there were no established standards or recommendations specifically for recreational noise exposure including the use of PAS. With only general guidelines available for recreational noise exposure, most studies related to PAS exposure have used standards and recommendations established for noise exposure in occupational settings e.g. the NIOSH standard (Jiang et al., 2016). The NIOSH standard specifies that if a person is exposed to 85 A-weighted decibels (dBA) over an 8-hour work shift, he or she will reach 100% of their daily noise dose (National Institute for Occupational Safety and Health, 1998). As the intensity of the noise increases, the allowable exposure time to noise decreases to maintain an acceptable noise dose to prevent overexposure (National Institute for Occupational Safety and Health, 1998). Therefore, if the noise levels increase by 3 dB, the duration of the exposure will be cut in half (this is referred to exchange rates)(National Institute for Occupational Safety and Health, 1998).

Developed under the “Make Listening Safe” initiative, the World Health Organization in collaboration with the International Telecommunication Union (WHO-ITU) established the first global standard for safe listening devices and systems (World Health Organization & International Telecommunication Union, 2019). The WHO-ITU standard specifies that adults and sensitive users (e.g. children) can safely listen to 80 dBA and 75 dBA respectively for 8 hours a day, with a 3 dB exchange rate (World Health Organization & International Telecommunication Union, 2019). Furthermore, the WHO-ITU standard recommends that personal listening devices should include; software that measures the duration and level of sound exposure as a percentage used of a reference exposure, an individualized listening profile with cues for action, general information on safe listening and volume limiting options (World Health Organization & International Telecommunication Union, 2019).

Rationale for current study

New technologies such as dbTrack (www.dbtrack.com) sound-level monitoring earphones and accompanying application adhere to the global WHO-ITU standard for safe listening devices and systems. 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). Effective interventions require a combination of different intervention strategies, which may provide a better chance of influencing listening behaviour (Portnuff, 2016). The present study, therefore, evaluated a hearing conservation intervention based on the COM-B model to promote healthy listening behaviours in young adults with smartphone feedback on listening behaviour using sound-level monitoring earphones. The study was conducted in two phases. Phase 1 of the study investigated the reliability and accuracy of dbTrack (Westone) 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 behaviours in young adults.

CHAPTER 2: METHODOLOGY

2.1 Research aim(s)

This study aimed to determine 1) the accuracy and reliability of dbTrack (Westone) sound-level monitoring earphones and 2) the effect of sound-level monitoring earphones with smartphone feedback and hearing health information on listening behaviours in young adults.

2.2 Research design

An outline of the research design is presented in Figure 1, which is followed by a detailed description.

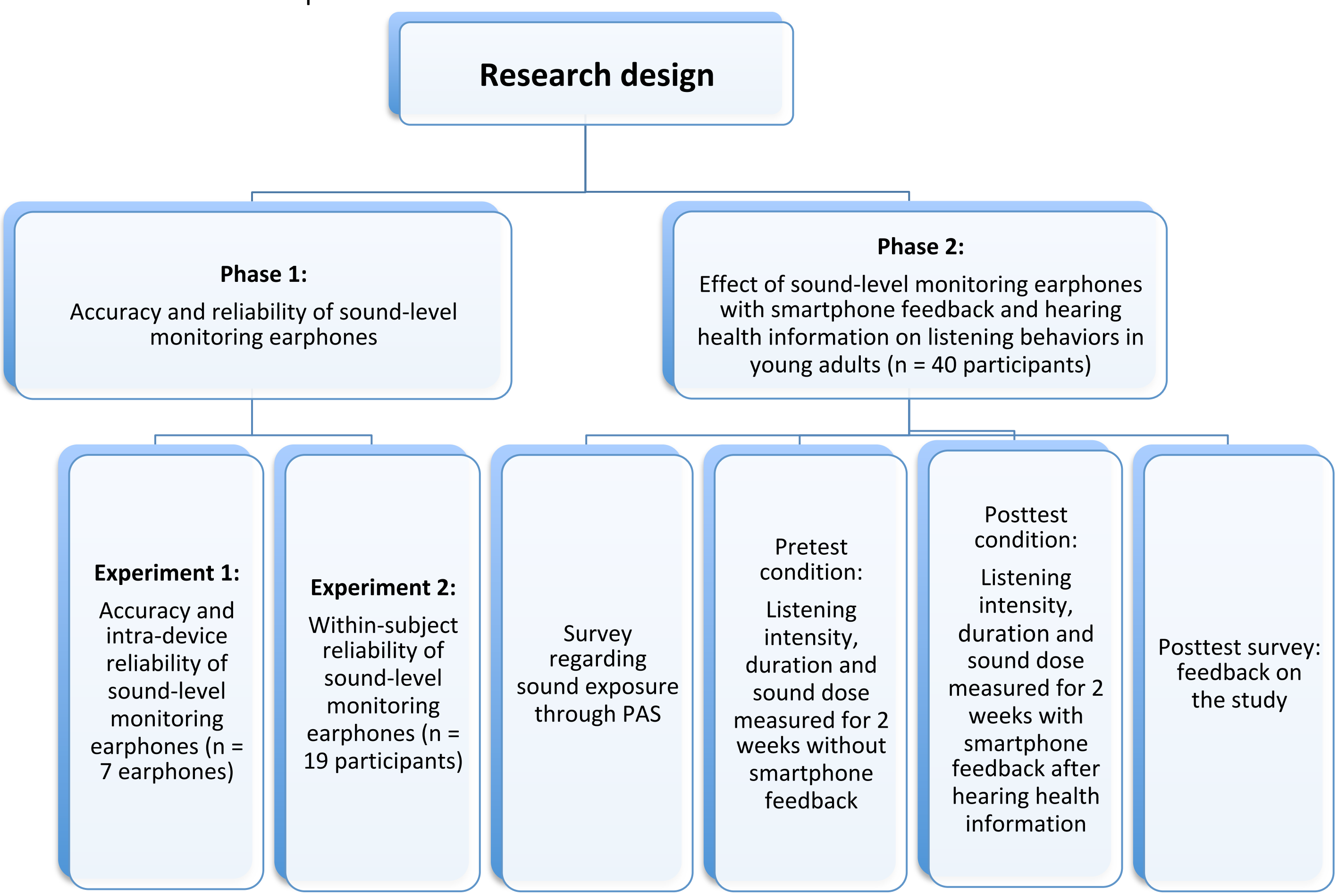

Figure 1. An outline of the research study design

The study was conducted in two phases. Phase 1 of the study included two experiments.

The first experiment was conducted to determine the accuracy and intra-device reliability of dbTrack (Westone) sound-level monitoring earphones. Accuracy was determined by comparing earphone measurements to Sound Level Meter (SLM) measurements. Intra-device reliability was determined by comparing earphone measurements during test-retest conditions. The second experiment was conducted to determine within-subject reliability of dbTrack (Westone) sound-level monitoring earphones. Nineteen participants were recruited through a non-probability convenience sampling method. Within-subject reliability was determined by comparing in-ear sound levels measured by the earphones during test-retest conditions.

Phase 2 of the study was conducted using a single-group pretest-posttest design. A non-probability snowball sampling method was used to recruit participants. Potential participants were provided with a link to fill in an online recruitment survey, which was used to select suitable participants for the study based on the inclusion and exclusion criteria. Forty young adults who reported high exposure to sound through their PAS (i.e., 10 hours weekly at a volume >75% most of the time) in the recruitment survey were selected and asked to participate in the study. Participants completed an online survey regarding sound exposure through PAS. Thereafter, participants were required to use dbTrack (Westone) sound-level monitoring earphones with an accompanying smartphone app for 4 weeks. During the first 2 weeks, the participants' in-ear sound levels were measured by the sound-level monitoring 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 application, which allowed the participants to monitor their listening activity (posttest condition). Participants completed a second online survey with questions regarding feedback on the study.

2.3 Ethical considerations

Ethical approval for this study was granted from the Research Ethics Committee of the Faculty of Humanities, University of Pretoria prior to data collection for phase 1 (Appendix A) and phase 2 (Appendix B).

Informed consent

Informed consent protects a participant's right to autonomy (Leedy & Ormrod, 2016). Before the commencement of the study, a verbal explanation of the research was given to the participants where after they received a written or electronic informed consent letter (Phase 1 Appendix D, Phase 2 Appendix E). The letters clearly described the nature of the study as well as the nature of participants' involvement in the study (Leedy & Ormrod, 2016). It included the procedures, risks and benefits of participation in the study. All participants were aware that their participation was voluntary, and that they could withdraw from the study at any time without any negative consequences.

Protection of harm

The ethical principle of non-maleficence requires high sensitivity from the researcher to protect participants against any potential harm, whether it is emotional, psychological, economic or social in nature (Mantzorou & Fouka, 2011). The risks of participating in a research study should not be greater than the risks involved in one's everyday living (Leedy & Ormrod, 2016). This study involved no risks and did not expose the participants to any form of physical or psychological harm.

Benefits

Participants who participated in phase 1 of the study received a lunch voucher and stood a chance to win a prize at the end of the study. Participants who participated in phase 2 of the study received an R150 takealot voucher after they have completed the 4-week study period as a reward for participation in the study. According to Grant & Sugarman (2004), the use of incentives to recruit and retain participants for research is not considered as unethical. However, there are some instances where it is considered as ethically inappropriate, such as; when the participant is in a dependency relationship with the researcher, when the research is degrading or involves high risk or when undue influence occurs (Grant & Sugarman, 2004). However, this study was not degrading, it did not involve any risks and the participants were not in a dependency relationship with the researcher. Therefore, the use of incentives as rewards in this study could be regarded as ethically appropriate.

Respect for confidentiality and privacy

The participants' right to privacy must be respected in any research study (Leedy & Ormrod, 2016). The nature and quality of individual participants' performance should be kept confidential by the researcher (Leedy & Ormrod, 2016). During this study, all personal or sensitive information was kept confidential. The participants were allocated alpha-numeric codes, e.g. Participant01. The codes were used during data analysis to ensure confidentiality and were only known to the researcher and supervisors.

Data storage

The data will be stored electronically for 15 years in the Department of Speech-Language Pathology and Audiology at the University of Pretoria for research purposes. This will not include any identifying information of the participants. Furthermore, in the event of publication, no personal or sensitive information will be disclosed.

Plagiarism

The study and written report were the researcher's original work. The researcher used the APA 7th edition referencing style to acknowledge accurate references of the sources used in this study.

2.4 Sampling methods and participants

For phase 1 of the study (experiment 2), convenience sampling was used to recruit participants. Convenience sampling is a non-probability sampling method where people who are readily available to the researcher are asked to participate in the research (Leedy & Ormrod, 2016). A sample of 19 participants (10 females and 9 males) between 20-35 years of age were recruited at hearX group for phase 1 (experiment 2) of the study.

For phase 2 of the study, snowball sampling (chain-referral sampling) was used to recruit participants. Snowball sampling is a non-probability sampling method where participants with target characteristics are recruited through referrals made by existing participants (Naderifar et al., 2017). SurveyMonkey was used to create an online recruitment survey which included questions regarding age, gender, listening habits, location and contact details. Referrals (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 (Table 1). A sample of 40 participants (male and female) 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 phase 2 of the study.

Selection criteria

Table 1 provides the selection criteria (inclusion and exclusion) which was used to select participants for phase 2 of the study.

Table 1. Inclusion and exclusion criteria for participants selected for phase 2 of the study

Characteristic	**Description**	**Rationale**
Age	Participants between the ages of 18-35 years were included.	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 listening devices.

Listening intensity	Participants who self-reported in the recruitment survey (Appendix C) that they listen to music/other media through their personal listening devices at a volume of 75% or higher were included.	Participants who self-reported high sound exposure through their PAS were included. PAS devices can produce a maximum output ranging from 97 up to 102 dBA (Portnuff et al., 2011). Therefore, if individuals were to be exposed to 75% of the maximum output of PAS for a minimum of 10 hours per week, they were likely to exceed their sound exposure limits and benefit from the dbTrack application's feedback.
Listening duration	Participants who self-reported in the recruitment survey (Appendix C) that they make use of personal listening devices at least 5 days a week or for a minimum of 10 hours per week were included.	
Android technology	Participants were included if they indicated in the recruitment survey (Appendix C) that they make use of Android technology.	The customized version of the dbTrack application was compatible with Android devices only.
Audiology students	Audiology students from the Department of Speech-Language Pathology and Audiology were excluded from the study.	Audiology students were excluded from the study to prevent bias.

2.5 Materials and apparatus

Study setting

The study setting for phase 1 of the study was contrived as it was conducted in a sound-treated laboratory. The study setting of phase 2 of the study was non-contrived as it took place in the participant's natural environment.

Material and equipment for data collection

Table 2 provides details on the equipment that was used for phase 1 of this study.

Table 2. Material and equipment for data collection for phase 1

Material or equipment	**Rationale**
dbTrack sound-level monitoring earphones (Westone laboratories, Colorado Springs, USA) with its accompanying dbTrack smartphone application (hearX group, Pretoria, South Africa)	Sound level measurements were conducted using the dbTrack sound-level monitoring earphones with its accompanying dbTrack application.
Samsung A320 device	The dbTrack application was installed on a Samsung A320 device and the dbTrack earphones were connected to the smartphone for the sound level measurements.
dbTrack calibrator, USB cable and power source	The dbTrack calibrator was connected to a power source using a USB cable to calibrate the in-ear microphone of each pair of earphones before the sound level measurements were conducted.
Music playlist	An mp3 music playlist was created on the Samsung A320 device consisting of 8 songs (28.46 minutes in total). This mp3 playlist was pre-selected on the smartphone to be used throughout all of the measurements. 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.
Occluded Ear Simulator and SLM	An Occluded Ear Simulator coupler based on IEC 60318-4 (GRAS: RA0045-S1) was also used for sound level measurements with a Rion NL-52 SLM which complies with the following standards: IEC 61672-1: 2002 Class 1, ANSI S1.4-1983 Type 1, ANSI S1.4A-1985 Type 1, ANSI S1.43-1997 Type 1, JISC 1509-1: 2005 Class 1.

Table 3 provides details on the equipment that was used for phase 2 of this study.

Table 3. Material and equipment for data collection for phase 2

Material or equipment	**Rationale**
Survey regarding sound exposure through PAS	This survey was created to explore participants' self-reported listening behaviour as well as motivation to change listening behaviour at the beginning of the study. It consisted of 11 questions regarding sound exposure through PAS.

dbTrack sound-level monitoring earphones (Westone laboratories, Colorado Springs, USA) and silicone earphone tips	The dbTrack sound-level monitoring earphones are balanced armature, full-range, noise-cancelling earphones with built-in microphones to measure in-ear sound exposure in real-time (dbTrack, 2018). Each participant received a pair of dbTrack earphones and a pair of custom-fit silicone earphone tips for the duration of the study.
dbTrack smartphone application (hearX group, Pretoria, South Africa).	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 i.e. 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 World Health Organization (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. Each

	participant had to download and install the customized version of the dbTrack app onto their PAS through an Android Package Kit (APK) file.
dbTrack calibrator, USB cable and MacBook Air laptop as a power source	A dbTrack calibrator was connected to a MacBook Air laptop as a power source with a USB cable to calibrate the dbTrack earphones with each participant's smartphone to ensure accurate sound monitoring.
FAQ document	An information leaflet with frequently asked questions regarding possible technical difficulties and their solutions was provided to the participants to ensure accurate and reliable sound measurements.
dbTrack cloud-based portal	The dbTrack app synced the recorded listening behaviours 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.
Hearing health information	After the first 2 weeks (pretest), the brief information guide on hearing health was provided 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.

Survey regarding feedback on the study	This 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 behaviours as well as the impact of the COVID-19 pandemic and lockdown period on listening behaviours.

2.6 Data collection procedure

Phase 1: Accuracy and reliability of sound-level monitoring earphones

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 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.

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 dbTrack (Westone) 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 dbTrack (Westone) 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.

Phase 2: Effect of sound-level monitoring earphones with smartphone feedback and hearing health information on listening behaviours in young adults

Data were collected from 14 February 2020 until 11 August 2020. Participants were asked to complete the online survey regarding sound exposure through PAS. 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 APK file. The dbTrack app was in "research mode" i.e. the smartphone feedback feature was disabled. Each participant was provided with a pair of 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 information leaflet with questions regarding possible technical difficulties and their solutions, which was also explained to them verbally (Appendix H). 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 behaviour during the intervention period. However, it was mentioned that the app will change over time.

The intervention was designed using the COM-B model (Michie et al., 2014). The COM-B model aids in explaining behaviour in context and provides a foundation for designing an intervention that will target behaviour change (Michie et al., 2014). The COM-B model has successfully been used in studies in the field of audiology as a theoretical basis for behaviour change (Barker et al., 2016; Maidment et al., 2019). This model proposes that for individuals to engage in certain behaviour, they must be physically and psychologically capable (C), they must have the physical and social opportunity (O), as well as the motivation (M), which refers to the reflective and automatic mechanisms that activate or inhibit behaviour (Michie et al., 2014). The intervention protocol consisted of sound-level monitoring earphones and smartphone feedback with a brief hearing health information guide on safe listening.

After the first 2 weeks (pretest), the brief information guide on hearing health was provided before the smartphone feedback was enabled on the dbTrack app for the posttest condition. The guide was shared electronically with the participants by the first author. 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 (Appendix I). 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), the smartphone feedback was automatically enabled on the dbTrack app, allowing participants to monitor their listening activity. The app gave real-time feedback to the participants based on their listening behaviours (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, yellow indicating moderate risk and red indicating high risk. The app provided the participants with detailed historical information to track their listening habits, guided them on safe listening and raised awareness on damaging sound levels.

After the 4-weeks, participants were provided with a link to complete the second online survey with questions regarding feedback on the study. After completing the study, participants returned the earphones and they received a R150 online shopping voucher as a reward for their participation.

2.7 Data analysis

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

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 to 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 behaviours in young adults

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 behaviours (average daily intensities, durations and sound dosages) measured during pre- and posttest conditions were retrieved from the dbTrack portal, coded in Microsoft Excel and transferred to Statistic Package Social Sciences (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. 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. 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 ($r = 0.5$).

2.8 Validity & reliability

According to Kaur, Stoltzfus, and Yellapu (2018), reliability refers to the consistency of a measurement and validity refers to the extent to which the scores from a measurement represent the variable they are intended to. Reliability and validity were both ensured for this study. The dbTrack technology used in this study is a validated tool (dbTrack, 2018). The accuracy and reliability of the dbTrack sound-level monitoring earphones were proved in the first phase of the study. The in-ear microphone of each pair of earphones was calibrated before it was used for sound-level measurements in both phases of the study. Furthermore, the researcher made use of the dbTrack cloud-based portal to monitor each participants' listening activity on a daily basis.

CHAPTER 3: RESEARCH ARTICLE

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

Authors: Megan Knoetze, Faheema Mahomed-Asmail, Vinaya Manchaiah and De Wet Swanepoel

Journal: Ear and Hearing

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Results from this study were presented at the South African Association of Audiologists virtual conference on the 31st of October 2020.

Note: This article was edited according to the editorial specifications of the journal and may differ from the editorial style of the rest of this dissertation.

3.1 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.

3.2 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.

3.3. 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 2 for the calibration setup using the dbTrack calibrator (Fig. 2).

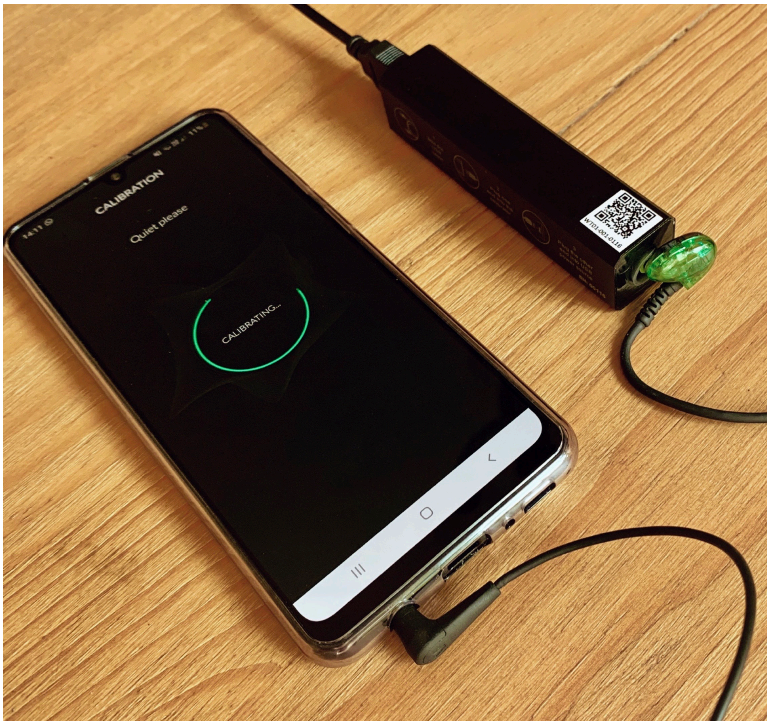


Figure 2. Calibration setup for the calibration of the in-ear microphone of the dbTrack sound-level monitoring earphones

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 Appendix H).

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 Appendix I). 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 3A-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. 3).

A B C

Figure 3. 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).

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.

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 ($r = 0.5$).

3.4 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 4). The maximum Leq difference between repeated measures across earphones (n = 7) was also less than 1 dBZ (Table 4). 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 4. 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 5). 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 5. 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 Appendix J).

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 6.

Table 6. Average daily intensity, duration and sound dose measured by the sound-level monitoring earphones during pretest and posttest conditions (n = 40)

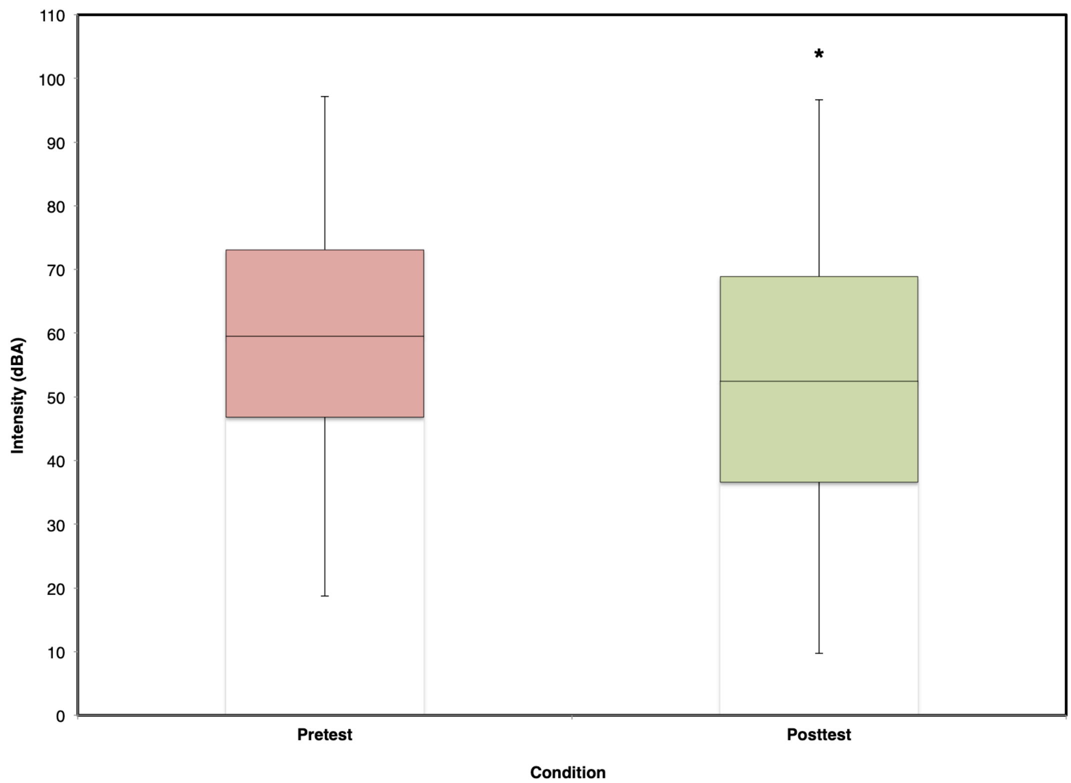
	Pretest	Posttest	Difference	Effect size
Intensity ***Mean (SD)***	59.6 (18.6) dBA	51 (21.4) dBA	8.7 (18.3) dBA*	0.474[a]
Duration ***Mean (SD)***	65.6 (52.4) minutes	58 (57.6) minutes	7.6 (46.6) minutes	0.163[a]
Sound dose ***Mean (SD)***	5912.7 (24479.9)%	1784.3 (6845.9)%	4128.4 (24965.5)% **	-0.373[b]

*Significant difference ($p < 0.05$; Paired-samples *t* test)

**Significant difference ($p < 0.05$; Wilcoxon signed-rank test)

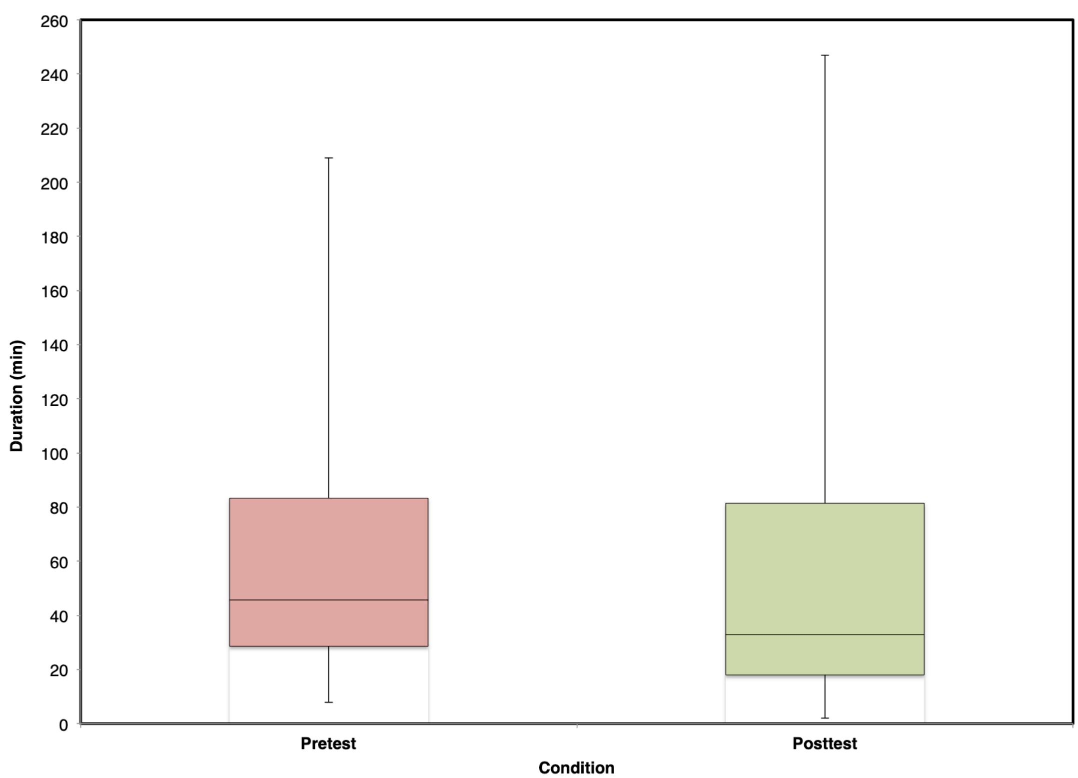
[a]Cohen's *d*
[b]*r* value (Z/√N)

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. Differences in average daily sound dose were not normally distributed ($p < 0.05$), therefore, Wilcoxon signed-rank test was used to analyze the data. 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 4 for box-and-whisker plots of average daily (A) intensity (B) duration and (C) sound dose measured during pre- and posttest conditions (Fig. 4A-C).



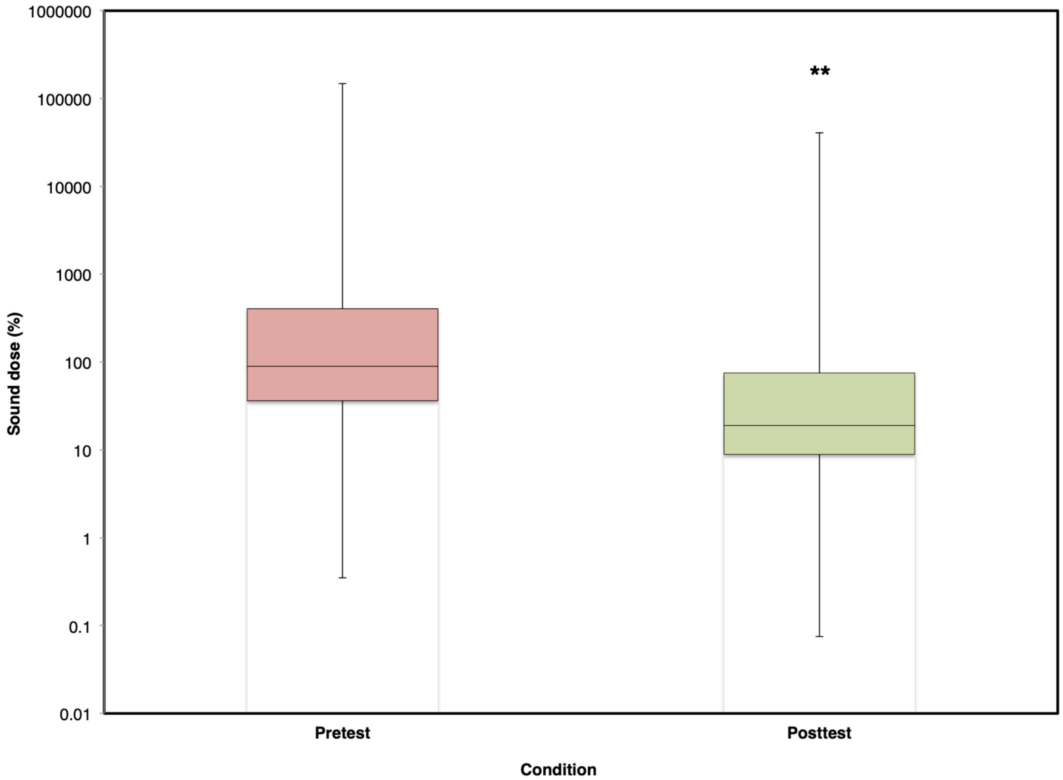
110
100
90
80
70
60
50
40
30
20
10
0
Intensity (dBA)
*
Pretest
Posttest
Condition

A



260
240
220
200
180
160
140
120
100
80
60
40
20
0
Duration (min)
Pretest
Posttest
Condition

B



C

Figure 4. 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 behaviour. 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 behaviour, 46.7% reported that they used their

PAS more and 36.7% reported that they used their PAS less.

3.5 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. 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. Furthermore, notifications delivered by the app could be tailored by means of altering the frequency of notifications to prevent users from becoming disinterested in the app's feedback.

3.6 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.

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CHAPTER 4: DISCUSSION AND CONCLUSIONS

4.1 Summary of results

Phase 1: Accuracy and reliability of sound-level monitoring earphones

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 behaviours 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. Phase 1 of the current study investigated the accuracy and reliability of 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 American National Standard Institute (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 behaviours in young adults

Participants' self-reported listening behaviour and motivation to develop safe listening habits were surveyed at the beginning of phase 2. Most participants (87.5%) reported 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 of listening to music/other media using their PAS for a minimum of 10 hours per week at a volume of 75% most of the time. However, listening behaviour 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 behaviour and logged listening behaviour (Hodgetts et al., 2009; Kaplan-Neeman et al., 2017; Portnuff et al., 2013). Nearly all participants (92.5%) indicated that they watch videos using their PAS. Therefore, future studies regarding PAS use should also include exposure to other types of media such as videos and gaming in addition to music exposure (Sunghwa You & Kwak, 2020).

Phase 2 of the study implemented an intervention protocol based on the COM-B model to determine the effect of dbTrack (Westone) sound-level monitoring earphones with smartphone feedback and hearing health information as an intervention to develop healthy listening behaviours in young adults. We hypothesized that by addressing the capabilities and opportunities, it would drive the participants' motivation to change their listening behaviour. To address the participants' psychological capability (i.e.

knowledge), the intervention included hearing health information to educate the participants about RNIHL and the consequences thereof, as well as the importance of safe listening habits. Furthermore, to address the participants' physical capability (i.e. skills), real-time smartphone feedback was provided via the dbTrack app, which was used to train and enable the participants to adopt safer listening habits. 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 sound-level monitoring earphones and its accompanying dbTrack app to monitor their listening behaviour. 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 behaviour 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 behaviour. It is important to highlight that 90% of participants indicated that smartphone feedback played the biggest role in motivating them to change their listening behaviour. 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 behaviour. 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.

4.2 Clinical implications

Hearing loss continues to increase globally and millions of people around the world are suffering the consequences of unaddressed hearing loss (World Health Organization, 2017). Furthermore, unaddressed hearing loss poses an overall cost of 750 billion international dollars annually (World Health Organization, 2017). According to the WHO, half of all cases of hearing loss can be prevented through public health measures (World Health Organization, 2020). Hearing loss prevention forms part of audiologists' scope of practice (American Speech-Language-Hearing Association, 2018). This includes hearing conservation and hearing preservation. Preventing NIHL either from occupational or recreational settings is a priority for audiological care.

Millions of young people around the world are at risk of acquiring an RNIHL due to the unsafe use of PAS (World Health Organization, 2015). Although RNIHL is a totally preventable condition, it still remains a challenge to persuade young people to adopt safe listening habits (Gopal et al., 2019). Audiologists have the responsibility to raise awareness and educate individuals about the effects of RNIHL associated with unsafe listening practices. However, educational programs alone have not been effective in changing listening behaviour in PAS users (Khan et al., 2018). Currently, there are no other public health interventions to help prevent young adults from acquiring an RNIHL. Therefore, this study has important implications towards effective intervention to enable young adults to develop safe listening habits and prevent RNIHL.

The current study was the first to investigate the effect of sound-level monitoring earphones with smartphone feedback and hearing health information as an intervention to develop healthy listening behaviours in young adults. Subsequently, it was the first study to implement the recommendations of the global WHO-ITU standard for safe listening devices and systems. The dbTrack (Westone) sound-level monitoring earphones with a calibrated in-ear microphone were demonstrated reliable and accurate measures of PAS exposure. Using the dbTrack (Westone) sound-level monitoring earphones with smartphone feedback and hearing health information resulted in a significant decrease in daily intensity and sound dose with small and medium effect sizes, respectively. Sound dose was the most important variable in which change was observed and based on the effect size calculations the intervention had the largest effect on sound dose out of all three variables.

This study, therefore, demonstrates an effective method to promote safe listening behaviour in young adults and prevent RNIHL. Technologies should look at 1) increasing the accuracy of in-ear monitoring for reliable measures that allow sound dose tracking; 2) self-monitoring using an application such as the dbTrack app which provides real-time feedback; and 3) behavour change principles embedded and underlying the feedback to maximize the effect of the technology. The findings can further be used to advocate for governments as well as manufacturers of personal audio devices, including smartphones, to implement the recommendations and features of the WHO-ITU standard for safe listening devices and systems in order to help prevent RNIHL. Efforts towards hearing loss prevention using smart technologies and behavioural change principles have the potential to significantly reduce the long-term cost associated with untreated hearing loss.

4.3 Critical evaluation

The strengths and limitations of this study were critically assessed and are discussed below.

Strengths of the study

- Phase 1 of the study validated the accuracy and reliability of the sound-level monitoring earphones used in phase 2. Thus, participants' in-ear sound levels measured with the earphones in phase 2 during pre-test and post-test conditions were accurate and reliable.

- A within-subjects pretest-posttest design was used in phase 1 (experiment 2) and phase 2 of the study, allowing the participants to serve as their own controls. Within-subjects designs eliminate or reduce problems concerning individual differences and have more statistical power when compared to between-subjects designs (Charness et al., 2012).
- In phase 2, individualized assisted calibration of the sound-level monitoring earphones was done with each participant's smartphone to ensure accurate sound monitoring throughout the study.
- A customized version of the dbTrack application was used in phase 2, which allowed blinding of the participants to any feedback from the application during pre-test condition. Therefore, the application could not influence their listening behaviours during pre-test condition.
- Participants' listening behaviours were measured using an objective tool with their own smartphone devices. Studies have shown inconsistencies between self-reported listening behaviour and logged listening behaviour (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 objective 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.
- Interventions that were designed to reduce RNIHL related to PAS specifically are scarce in the peer-reviewed literature (Portnuff, 2016). This study provided first-time evidence on the effect of sound-level monitoring earphones and hearing health information as an intervention to promote healthy listening behaviours in young adults.
- 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). The WHO-ITU standard was developed by a wide range of stakeholders and is based on the best available knowledge and the latest evidence on criteria for hearing loss caused by sound exposure as well as hearing loss prevention principles (World Health Organization & International Telecommunication Union, 2019).

Study limitations

- This study's main limitations were the small sample size and high variability in results since it might have reduced the statistical power of the study.
- Possible sampling bias in phase 2 since a non-probability snowball sampling method was used. Initial participants tend to refer people who they know really well and who have similar traits to them. Therefore, the sample of this study might only represent a small sub-group of the population.
- 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. Real-ear measurements could have confirmed the in-ear sound levels measured by the earphones to validate the accuracy of the earphone measurements inside the ear canal.
- The COVID-19 pandemic and lockdown influenced the study's results since most of the data collection for this study took place during the pandemic and lockdown period. This affected participants' daily routines including their listening behaviours. The post-study survey revealed that 83.3% of participants felt that the COVID-19 pandemic and lockdown period had influenced their normal listening behaviours (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.
- 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. Participants with high sound dose percentages during the posttest condition received multiple notifications from the app, which they might have 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 behaviour.

- 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. Furthermore, a number of other factors may also have influenced the participants' listening behaviours throughout the 4-week study period. These included exams, work, family events and religious events.
- This study only made use of Android technology, 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.
- The study did not include a follow-up experiment after a few weeks/months in order to determine whether the effects of the intervention were sustained over time.

4.4 Future research

- It is recommended that future research studies make use of a different sampling method, such as simple random sampling, to avoid sampling bias and to ensure that the sample represents a larger portion of the population.
- Furthermore, future research studies should use a larger sample size. 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 behaviours.

- Samples of different ages should be included to determine whether the intervention can inform preventative strategies in other age groups.
- A longer study period can be used to determine whether the effects of the intervention are sustained.
- Notifications delivered by the app could be tailored by means of altering the frequency of notifications to prevent users from becoming disinterested in the app's feedback.
- Future research studies should consider using participants who make use of IOS technology instead of Android technology since the internal compressors can be switched off with IOS technology and possibly decrease variability of results.
- Real-ear measurements can be conducted to assess the participants' in-ear sound levels in addition to the real-ear coupler measurements.
- The hearing health information can be presented differently using multimedia materials, such as videos since it might be more engaging.

4.5 Conclusions

This study's 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.

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APPENDICES

Appendix A: Ethical approval letter (Phase 1)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

18 September 2017

Dear Prof Swanepoel

Project:	**In-ear sound monitoring with earphones: exposure levels and on listening behaviour**
Researcher:	**DCD Swanepoel**
Department:	**Speech-Languages Pathology and Audiology**
Reference number:	**Staff research (GW20170823HS)**

Thank you for the application that was submitted for ethics review

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 18 September 2017. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should your actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project.

Sincerely

Prof Maxi Schoeman
Deputy Dean: Postgraduate and Research Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: tracey.andrew@up.ac.za

Appendix B: Ethical approval letter (Phase 2)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Humanities 100.
1919 - 2019
Research Ethics Committee

11 February 2020

Dear Miss MC Knoetze

Project Title:	Changes in listening behaviour using smartphone monitoring of in-ear sound levels
Researcher:	Miss MC Knoetze
Supervisor:	Prof DCDW Swanepoel
Department:	Speech Language Path and Aud
Reference number:	16005725 (HUM014/1219)
Degree:	Masters

I have pleasure in informing you that the above application was **approved** by the Research Ethics Committee on 30 January 2020. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project.

Sincerely

Prof Maxi Schoeman
Deputy Dean: Postgraduate and Research Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: PGHumanities@up.ac.za

Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Appendix C: Participant recruitment survey (Phase 2)

surveymonkey.com

Participant Selection Survey

1. What is your full name?

2. How old are you?

3. Do you make use of Android technology to listen to music/other media?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

4. Do you listen to music/other media through your personal listening device more than 5 days a week using earphones?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

surveymonkey.com

5. Do you listen to music/other media through your personal listening device more than 10 hours a week using earphones?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

6. Do you normally set the volume higher than 75% when listening to music/other media through your personal listening device using earphones?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

7. In which area of Pretoria are you situated?

8. Please provide me with your email address.

Done

Appendix D: Participant informed consent letter (Phase 1)

Appendix A: Informed Consent Letter

Date:

Dear Colleague,

RE: PARTICIPATION IN HEARING TESTS AS PART OF A RESEARCH PROJECT

You are invited to participate in a research study that is being conducted by hearX SA. This letter will help you decide if you want to participate. Before you agree to take part, you should fully understand what is involved. If you have any questions that this letter does not fully explain, please do not hesitate to contact one of the people conducting the research (Reani Fouche, Mathieu Van der Aerschot or Hendre Page).

1. The nature and purpose of this study:
Prolonged exposure to excessive noise can result in noise induced hearing loss, which is becoming an increasing problem in younger adults due to the high levels of noise experienced using personal sound devices like smartphones and MP3's. Listen Longer are producing earphones that aims to determine the average noise exposure of listeners who listen to recreational noise for various amounts of time.

2. Procedures:
All tests will be non-invasive, without charge and results will be made available to you. Should you agree to participate in this study the following procedures will be followed:

Listen Longer headphones and App
You will be provided with high-quality earphones for use. Twice you will have to listen for 7 consecutive days to music. The length and loudness of the music will be specified by the researcher. You will either have to listen to music for one hour at an intensity lower than 80 dB, or two hours at an intensity louder than 80 dB.

3. Risk and discomfort involved
All tests will be non-invasive, and no risk is involved in participating in the study.
The period of time and intensity is specifically chosen to not harm the participants.

4. Possible benefits of this study
Participants will receive a lunch voucher and stand a chance to win a prize at the end. The results of this study may provide the researchers with information regarding the listening behaviors in young adults following the use of dBTrack earphones to monitor average sound exposure.

5. What are your rights as a participant?

Your participation in this study is entirely voluntary. You may decline to participate or stop at any time during the examination.

7. Compensation

Your participation is entirely voluntary and you will be compensated for participation. Each participant will receive a lunch voucher and a free hearing screening will be performed.

8. Confidentiality

All your information will be kept confidential. Once the datasheet has been completed by Mathieu Van der Aerschot, a number will be allocated to your entry on the datasheet. Your name will not appear on any document. Research articles in scientific journals will not include any information that could identify you.

INFORMED CONSENT:
MY PARTICIPATION IN THE DBTRACK RESEARCH STUDY

Please complete the following:

I ___________________________________, hereby confirm that I have read the above-stated information on this research project and that I was provided the opportunity to ask questions, and that they have been answered satisfactorily. I hereby consent to participation in this study. I understand that the data will be used for research purposes, in accordance with the information provided in the information letter.

___________________________ ____________________
Signature Date

____
Contact number/s

For further information contact Reani, Mathieu or Hendre.

Sincerely,

Professor De Wet Swanepoel
Investigator

Professor Bart Vinck
Investigator

Appendix E: Participant informed consent letter (Phase 2)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Participant,

INFORMED CONSENT LETTER

I, Megan Clarissa Knoetze, currently a Master student at the Department of Speech-Language Pathology and Audiology at the University of Pretoria will be conducting a study to determine the effect of in-app feedback on smartphone listening levels. Thank you for considering participating in the research study entitled 'Changes in listening behaviour using smartphone monitoring of in-ear sound levels'.

Before you agree to take part in this study, you should fully understand what is involved. Kindly read this form and ask questions, should you have any.

The following procedures will take place:
During this study, we will be meeting at a suitable time and place where you will be required to fill in two questionnaires namely 'Noise exposure through personal listening devices' and the Youth Attitude to Noise Scale (YANS) in attempt to explore your listening behaviour and attitude towards noise respectively. During the meeting, you will be provided with a set of earphones and a smartphone application (dBTrack) will be loaded onto your personal listening device for four weeks to track your listening activity. You will be required to utilize your device as you normally would on a daily basis and utilize the earphones provided to you. Thereafter, you will be required to complete the Youth Attitude to Noise Scale (YANS) once again. After the study, you will have to return the earphones to me at a suitable time and place.

Risks and Benefits:
There are no risks involved during this study and you will not be influenced negatively in any way. The benefit that this study includes is that each participant will receive a takealot voucher worth of R150 as a reward for their participation after completing the study.

Participant's rights:
Participation is voluntary; you may withdraw from participation in the study at any time without any negative consequences.

Room 3-5, Communication Pathology Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 4280
Fax +27 (0)12 420 3517
Email dewet.swanepoel@up.ac.za
www.up.ac.za

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Confidentiality:

All personal or sensitive information will be kept confidential. You will be allocated an alpha-numeric code, e.g. B021. The code will be used during data analysis in order to ensure confidentiality. The code will only be known to the researcher and supervisors. In the event of publication of this research project, no personally identifying or sensitive information will be disclosed.

Data storage:
The data will be stored electronically as well as in hard copy for 15 years at the University of Pretoria in the Department of Speech-Language Pathology and Audiology for research purposes.

Should you require any additional information, or clarification on the information stated above, please feel free to contact Megan Clarissa Knoetze on 0724970442.

Should you wish to participate in this research project, kindly complete the informed consent form.

Researcher
Miss Megan Clarissa Knoetze

Supervisor
Prof De Wet Swanepoel

Supervisor
Dr Faheema Mahomed-Asmail

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

PARTICIPATION IN THE STUDY: CHANGES IN LISTENING BEHAVIOUR WITH SMARTPHONE MONITORING OF IN-EAR SOUND LEVELS:

I_____________________________, hereby confirm that I have read and understood the above information and that I was given the opportunity to ask questions about the research study.

I hereby give consent to participate in the research study titled 'Changes in listening behaviour using smartphone monitoring of in-ear sound levels'. I understand that my participation is voluntary and that I can withdraw at any time during the study. I also understand that the data will be used for research purposes.

____
Signature of the participant

____
Date

____
Contact number(s)

Appendix F: Survey regarding sound exposure through PAS

Sound exposure through personal audio systems

Please fill in the questionnaire as accurate as possible. You are allowed to tick more than one box.

* Required

What is your participant code? *

Your answer

1. When did you start listening to music or other media through your personal listening device(s)? *

- [ ] Less than a year ago
- [ ] 1 year ago
- [ ] 2 years ago
- [ ] 3 years ago
- [ ] 4 years ago
- [ ] 5 years ago

2. Do you use earphones or headphones when you're listening to music through your personal listening device(s)? *

- [ ] Earphones
- [ ] Headphones

3. How often do you listen to music or other media? *

- [ ] Every day of the week
- [ ] 6 days a week
- [ ] 5 days a week
- [ ] Less than 5 days a week

4. On average, what time do you spend listening to music or other media on a weekly basis? *

- [ ] 10-11 hours
- [ ] 11-12 hours
- [ ] 12-13 hours
- [ ] 14-15 hours
- [ ] More than 15 hours

5. When do you enjoy listening to music or other media the most? *

- [ ] When you are relaxing
- [ ] When you are studying/working
- [ ] When you are exercising
- [ ] When you want to block out other noise
- [ ] Other

6. On what volume do you normally listen to music or other media? *

- [ ] 25% or less
- [ ] 50%
- [ ] 75%
- [ ] 100%

7. Does your mood affect how soft or loud you set the volume? *

- [ ] Yes
- [ ] No
- [ ] Sometimes

8. Do you find that your hearing is worse or that you hear a ringing in your ears after listening to music or other media? *

after listening to music or other media? *

- [ ] Yes
- [ ] No
- [ ] Sometimes

9. Do you use your personal listening device(s) to listen to anything other than music? *

- [ ] Videos
- [ ] Games
- [ ] Movies
- [ ] Radio
- [ ] Podcasts
- [ ] Other

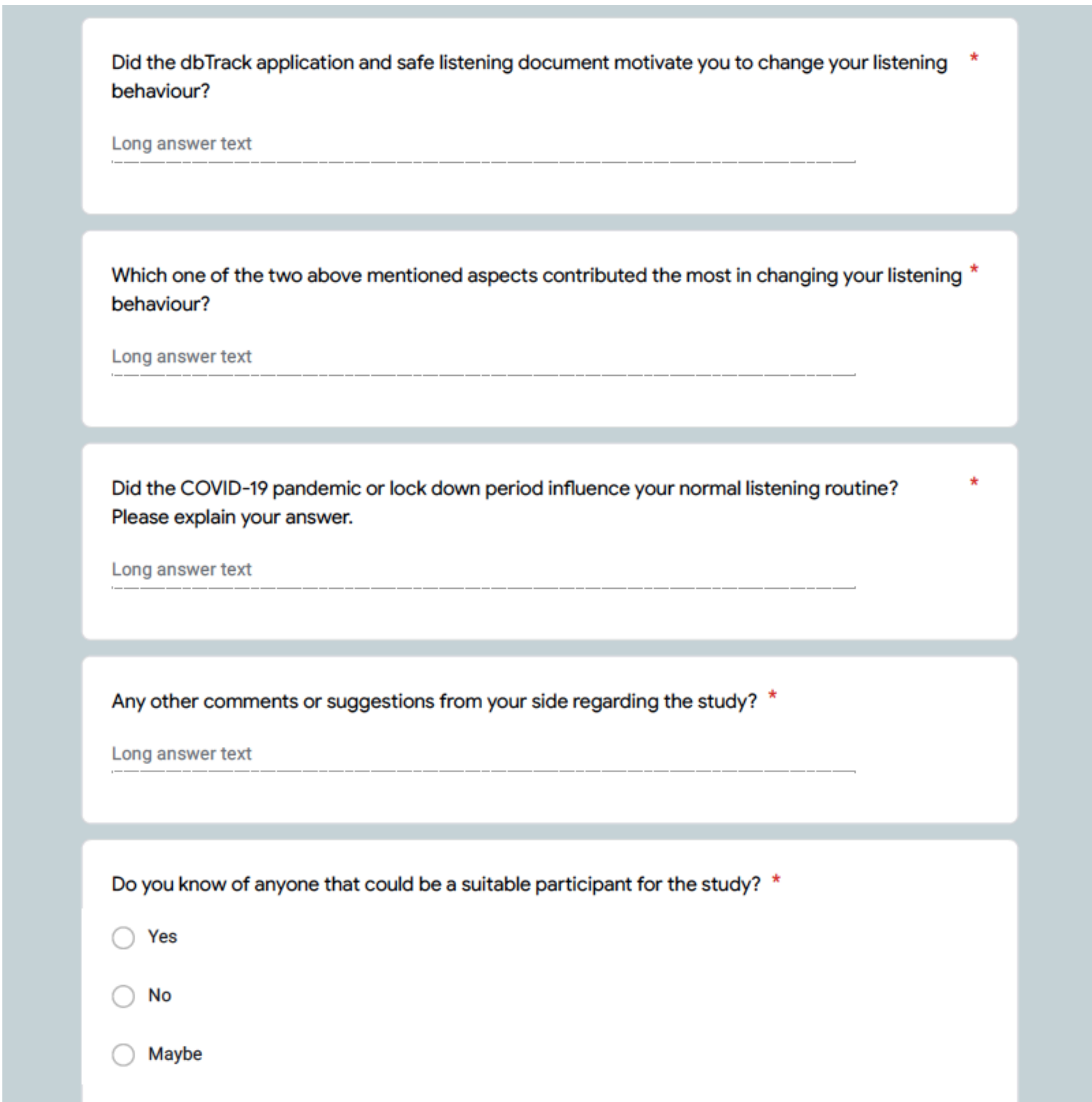
10. What is your opinion on your hearing status? *

- [ ] I have normal hearing
- [ ] I have a mild hearing loss
- [ ] I have a moderate hearing loss
- [ ] I have a severe to profound hearing loss
- [ ] Other

11. How motivated are you to develop safe listening habits when listening to media through your personal listening device(s)? *

- [ ] Not motivated
- [ ] Slightly motivated
- [ ] Average
- [ ] Motivated
- [ ] Very Motivated

Appendix G: Survey regarding feedback about the study



Did the dbTrack application and safe listening document motivate you to change your listening behaviour? *

Long answer text

Which one of the two above mentioned aspects contributed the most in changing your listening behaviour? *

Long answer text

Did the COVID-19 pandemic or lock down period influence your normal listening routine? Please explain your answer. *

Long answer text

Any other comments or suggestions from your side regarding the study? *

Long answer text

Do you know of anyone that could be a suitable participant for the study? *

- Yes
- No
- Maybe

Appendix H: FAQ

FAQ

1. What should I do if the green icon indicating active sound monitoring is not showing while I am busy listening to music/other media?
Restart your device and open the dbTrack app. If the icon still does not appear, please contact the researcher as soon as possible.

2. What should I do if the dbTrack app indicates that I am signed out?
Ask the researcher to provide you with your user details to sign back in.

3. What happens when I receive a call on my device?
You need to unplug your dbTrack earphones, as the sound sensor included in the earphones uses the microphone communication channel to update the dbTrack app on the sound levels measured inside the ear.

4. Can I send a voice note when the dbTrack earphones are plugged in? No. You can listen to a voice note, but you need to unplug your dbTrack earphones when you want to record and send a voice note as the sound sensor included in the earphones uses the microphone communication channel to update the dbTrack app on the sound levels measured inside the ear.

5. Can I use other earphones with the dbTrack app?
No. The dbTrack app only works with the dbTrack earphones, therefore, please only use dbTrack earphones throughout the study period.

6. Does the dbTrack app work when I am offline?
Yes, internet connection is only required for the initial setup and data syncing.

7. How much battery power does the dbTrack app use?
The dbTrack app has been optimized to use as little battery power as possible and it is generally in line with standard music player apps.

Hearing Health Information

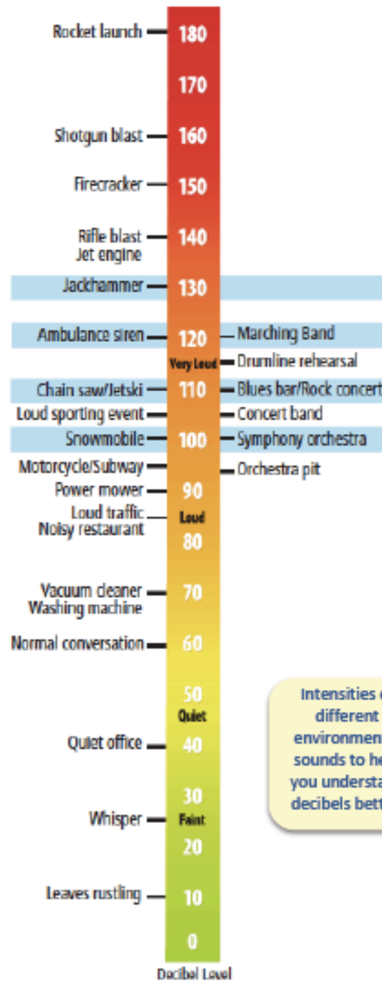
The World Health Organization estimates that 1 out of 2 young people are at risk of hearing loss due to unsafe listening habits.

- Exposure to loud sounds (e.g. music or noise) causes fatigue of the sensory cells of the ear. This results in temporary hearing loss or tinnitus (a ringing sensation in the ear).
- However, when the exposure to sound is particularly loud, regular or prolonged, it can permanently damage the ear's sensory cells and other structures, resulting in **irreversible** recreational noise-induced hearing loss. The high-frequency range (i.e. high-pitched sounds) is impacted first and may not be noticeable immediately.
- Continued exposure to loud sounds leads to the progression of hearing loss, ultimately affecting speech comprehension, perception of meaningful environmental sounds and quality of life.
- Since hearing loss tends to disrupt interpersonal communication, some individuals experience significant levels of distress as a result of their hearing difficulties.
- Exposure to loud sounds in young people also contributes to age-related hearing loss.
- Hearing loss can affect many aspects of life, including a person's social and educational development, as well as the ability to work.
- Some people may be more susceptible to hearing loss than others. Genetic predisposition, chronic conditions such as diabetes are known to increase the risk of acquiring noise-induced hearing loss. Since we cannot tell who the most susceptible individuals are, prevention is the most effective way to avoid hearing loss.

A way to avoid acquiring recreational noise-induced hearing loss is by adopting safe listening habits. Safe listening depends on the intensity (loudness measured in decibels), duration (length of time) and frequency (how often) of the exposure. These three factors are interrelated and contribute to the overall sound dose that one's ears are exposed to.

The louder the sound is, the less time you can safely listen to it. When using your personal listening device, sound levels of 80 dB are considered safe for 40 hours per week. The permissible time for safe listening decreases as sound levels increase (see example below).

dB(A) SPL	Weekly (*1.6 Pa²h*)
107	4.5 minutes
104	9.5 minutes
101	37.5 minutes
98	75 minutes
95	2.5 hours
92	5 hours
89	10 hours
86	20 hours
83	20 hours
80	40 hours



Intensities of different environmental sounds to help you understand decibels better.

Safe listening tips to prevent recreational noise-induced hearing loss:

Tip 1: Lower the volume (keep in mind the table above).

Tip 2: Limit your listening time, as it would lower the overall sound dose your ears are exposed to.

Tip 3: Monitor your listening habits.

Tip 4: Use carefully fitted noise-cancelling earphones/headphones to allow music to be heard at lower sound levels.

Tip 5: Hearing screening can help to identify the onset of hearing loss at an early stage.

World Health Organisation (2019)

Appendix J: Pretest survey responses on sound exposure through personal audio systems

Question	**Options**	**Responses** **% (n)**
Number of years using a PAS	Less than one year	0% (0)
	1 year	0% (0)
	2 years	5% (2)
	3 years	2.5% (1)
	4 years	5% (2)
	5 years	87.5% (35)
Transducer type	Earphones	62.5% (25)
	Headphones	10% (4)
	Both	27.5% (11)
Days per week using a PAS	Less than 5 days a week	0% (0)
	5 days a week	27.5% (11)
	6 days a week	17.5% (7)
	7 days a week	55% (22)
Amount of listening time per week	10-11 hours	45% (18)
	11-12 hours	12.5% (5)
	12-13 hours	12.5% (5)
	13-14 hours	0% (0)
	14-15 hours	12.5% (5)
	More than 15 hours	17.5% (7)
Listening intensity*	Less than 25%	0% (0)
	50%	20% (8)
	75%	70% (28)
	100%	30% (12)
Activities while using a PAS*	Relaxing	8.5% (33)
	Working/studying	70% (28)
	Exercising	72.5% (29)
	Block out other noise	45% (18)
Effect of mood on listening behavior	Yes	40% (16)
	No	17.5% (7)
	Sometimes	42.5% (17)
Media other than music*	Videos	92.5% (37)
	Games	45% (18)
	Movies	47.5% (19)
	Radio	35% (14)
	Podcasts	15% (6)
Experience of temporary hearing loss or tinnitus after using a PAS	Yes	10% (4)
	No	55% (22)
	Sometimes	35% (14)
Opinion on hearing status	Normal hearing	80% (32)
	Mild hearing loss	15% (6)
	Moderate hearing loss	5% (2)
	Severe to profound hearing loss	0% (0)
Motivation to develop safe listening habits	Not motivated	2.5% (1)
	Slightly motivated	10% (4)
	Average	20% (8)
	Motivated	32.5% (13)
	Very Motivated	35% (14)

*Participants could select more than one option.

Appendix K: Article accepted for publication in Ear and Hearing

☆ **Ear and Hearing** Inbox - Google 12 January 2021 at 00:32 EH

EANDH Decision

To: Megan Knoetze,

Reply-To: Ear and Hearing

You are being carbon copied ("cc:'d") on an e-mail "To" "De Wet Swanepoel" dewet.swanepoel@up.ac.za
CC: bielefeld.6@osu.edu, "Megan Clarissa Knoetze" meggieknoetze@gmail.com, "Faheema Mahomed-Asmail" faheema.mahomed@up.ac.za, "Vinaya Manchaiah" vmanchaiah@lamar.edu

RE: EANDH-D-20-00453R2
"Sound-Level Monitoring Earphones With Smartphone Feedback as an Intervention to Promote Healthy Listening Behaviors in Young Adults"

Dear Dr. Swanepoel,

I am pleased to inform you that your work has now been accepted for publication in Ear and Hearing. All manuscript materials will be forwarded immediately to the production staff. In general, articles are published-ahead-of-print (PAP) within 8-10 weeks of acceptance. This can vary depending on the level of corrections required during the author's proof stage. You may view articles as they are posted ahead of print, and sign up for PAP alerts, on the EANDH journal website: https://journals.lww.com/ear-hearing/toc/publishahead

Thank you for choosing Ear and Hearing as the venue for your important work. Your contribution as an author is critically important to the Journal, our readers and the field. Your involvement in future peer review is just as vital to the continued excellence of our Journal. That is why it is so important that you consider accepting the offer to review papers for Ear and Hearing if asked. Finding authors with subject matter expertise is a critical part of the peer review process and your help in this area is most appreciated. Thank you for considering these potential future requests.

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3. **Within 48 hours of receiving this e-mail:** Go to http://wolterskluwer.qconnect.com to pay for open access. If you have not previously used this site to place an order, you will need to register for an account (your login will be different from your Editorial Manager login). When placing your order, you will be asked for the following information. Please enter exactly as shown:
a. Article Title - Sound-Level Monitoring Earphones With Smartphone Feedback as an Intervention to Promote Healthy Listening Behaviors in Young Adults
b. Manuscript Number - EANDH-D-20-00453R2

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Thank you for submitting your interesting and important work to the journal.

With Kind Regards,
Brenda
Brenda Ryals, PhD
Editor-in-Chief
Ear and Hearing

****

Eric Bielefeld

Section Editor