AFFORDABLE HEADPHONES FOR ACCESSIBLE SCREENING AUDIOMETRY: AN EVALUATION OF THE SENNHEISER HD202 II SUPRA-AURAL HEADPHONE

By

Mathieu Van der Aerschot

(14312612)

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Department of Speech-Language Pathology and Audiology

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SUPERVISOR: Prof. De Wet Swanepoel

CO-SUPERVISOR: Dr. Faheema Mahomed-Asmail

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DECLARATION

Full name : Mathieu Marc Katty Van der Aerschot

Student Number : 14312612

Degree/Qualification: M.COMMUNICATION PATHOLOGY

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AFFORDABLE HEADPHONES FOR ACCESSIBLE SCREENING AUDIOMETRY: AN EVALUATION OF THE SENNHEISER HD202 II SUPRA-AURAL HEADPHONE.

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ABSTRACT

Title: Affordable headphones for accessible screening audiometry: an evaluation of the Sennheiser HD 202 II headphone.

Candidate: Mathieu Van der Aerschot

Supervisor: Prof. De Wet Swanepoel

Co-supervisor: Dr Faheema Mahomed-Asmail

Department: Speech-Language Pathology and Audiology

Degree: M. Communication Pathology

It is estimated that approximately 360 Million people have a permanent disabling hearing loss (WHO, 2015). The majority of these people live in lower to middle income countries, where screening and follow-up treatment is not always accessible (WHO, 2015). School based hearing screening is one of the procedures that are not always available due to a number of challenges one of which include the high cost of audiometrical headphones. School based hearing screening is performed with an audiometrical headphones and audiometer, it usually can be used to test all school-aged children and adults.

In an attempt to reduce the cost of school based hearing screening, this study evaluated the Sennheiser HD 202 II headphone to establish it as a widely available and cost-effective alternative for audiometrical headphones currently used. The headphones were compared to ISO standards (ISO 389-1, ISO 389-5 and ISO 389-9) and IEC standards (IEC 60318-1 and IEC 60645-1). The following characteristics of the headphone were compared: equivalent threshold sound pressure levels, attenuation, maximum permissible ambient noise levels, force of the headband, total harmonic distortion and frequency response.

After evaluation the Sennheiser HD 202 II does not show the same standard as audiometrical headphones for diagnostic testing. The headphone can however be used for screening purposes if a few measures are taken into account. The correct ETSPL values should be used, disruptive background noise should be avoided and only the frequencies from the research (250- 1600 Hz) can be tested. once these measures are taken into account the Sennheiser HD 202 II proves to be a cost-effective alternative headphone for screening purposes.

Key words

Adult hearing screening

Equivalent threshold sound pressure level

Force of headband

Frequency response

IEC standard

ISO standard

Maximum permissible ambient noise

School based hearing screening

Sennheiser HD 202 II

Total harmonic distortion

Acronyms

ETSPL: equivalent threshold sound pressure level

RETSPL: reference equivalent threshold sound pressure level

WHO: world health organization

THD: total harmonic distortion

MPANL: maximum permissible ambient noise level

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1. Introduction

1.1. Background

The World Health Organization (WHO) estimates that in 2015, there were 360 million people worldwide living with permanent disabling hearing loss; this number represents 5.3% of the global population (WHO, 2015). Out of the aforementioned 360 million people, 91% are adults and over 32 million are children (WHO, 2015). In 2000, the number of people with hearing loss was estimated to be above 250 million (Mathers, Smith & Concha, 2000), resulting in an increase of 110 million people between 2000 and 2015. Due to the increase in prevalence of hearing loss, there is also an increased need for identification. The vast majority of the 360 million people with hearing loss today live in low-to-middle income countries where there is a lower probability of access to care, such as screening, follow-up and treatment (Fagan & Jacobs, 2009; Goulios & Patuzzi, 2008; WHO, 2015).

In South Africa, it is estimated that 5.5 out of every 1000 children are born with hearing loss (Swanepoel, Störbeck & Friedland, 2009) and that 2.2% of children between the ages of six and nine years are in need of some kind of follow-up service (Mahomed-Asmail, Swanepoel & Eikelboom, 2016). In Uganda, the referral rate of school-aged children is 5.5% when hearing screening is performed (Basañez, Nakku, Stangl & Wanna, 2015). In Nicaragua, this number is a staggering 18% (Saunders et al., 2007). Even in developed countries such as the United Kingdom, close to 20% of permanent moderate or greater bilateral, mild bilateral and unilateral impairments remain unidentified by the time children go to school (Bamford et al., 2007). In developing countries where there are no systematic newborn hearing screening programmes, this percentage is likely to be much higher (Madriz, 2001; Mahomed-Asmail, Swanepoel & Eikelboom, 2016).

An American study shows that prevalence of hearing loss in adolescents has increased with 5% since 1996, resulting in almost 20% of adolescents tested having some kind of hearing loss (Shargorodsky, S. Curhan, G. Curhan & Eavey, 2010). If hearing screening is conducted on adults (55 years and older), the referral rate increases significantly – up to 46% (Thodi et al., 2013). Based on these numbers, it is evident that hearing screening is important, not only for newborns, but for the entire population.

Traditionally, screening for hearing loss is performed according to the gold standard of audiometric screening. This entails manual pure tone audiometry with audiometric headphones (for example TDH 39) (Yueh, 2003). However, the cost and accessibility of conventional audiometric equipment and headphones (Wong, 2008) impedes the provision of proper care to people living with hearing loss. Recently, attempts have been made to determine more cost-effective ways to conduct hearing screening through the utilization of widely available novel technologies, such as PC-based audiometry and smartphone-based audiometry (Eysenbach, 2013; McPherson, 2013; Swanepoel, Myburgh, Howe, Mahomed & Eikelboom, 2014). Audiometric headphones, however, remain an expensive component of the screening process. For screening purposes, a cost-effective alternative headphone, assessed and standardized according to current guidelines (ISO 389-9, 2009), may allow improved access to hearing screenings when combined with affordable technology options such as smartphones (Swanepoel, Myburgh, Howe, Mahomed & Eikelboom, 2014).

1.2. Impact of hearing loss

In developed countries, such as the United States, 95% of children are screened at birth (Mehl & Thomson, 1998). Due to the lack of newborn hearing screening programmes in developing countries (Tanon-Anoh, Sanogo-Goneb & Kouassic, 2010), not all newborns have access to hearing screening; hearing screening being an important platform for detecting possible hearing losses.

Early identification of hearing loss is an essential requirement for ensuring optimal development of a child, especially in young children (Moeller, 2000; Kennedy, McCan, Campell & Stevensson, 2007). Hearing loss will negatively affect the speech, language, cognitive, and psychosocial development of a newborn. Children diagnosed late show poorer language and reading comprehension skills compared to children diagnosed before the age of seven months (Yoshinaga-Itano, Sedey, Coulter & Mehl, 1998).

Hearing screening of young children entering school is important for identifying any influence of an undetected hearing loss that may affect a child’s academic performance and socio-emotional wellbeing (Tesch Römer, 1996). Hearing loss hinders receptive vocabulary, verbal ability, and reasoning for school-aged children (Davis, Elfenbein, Schum & Bentler, 1986).

For people of all ages, including adults, untreated hearing losses may lead to an auditory disability, affecting not only the quality of life of the participant with the hearing loss, but also the individuals surrounding the participant (Scarinci, Worrl & Hickson, 2008). The society and economy, especially in developing countries, are also affected (Olussanya, 2012). Cognitive functions, social interaction and mental health have a negative correlation with hearing loss (Arlinger, 2003; Dalton, Cruickshanks, Klein, Wiley & Nondahl, 2003; Fellinger, 2007). Other consequences of hearing loss include the inability to perceive sound, which results in reduced speech recognition ability, especially in difficult listening environments, and reduced ability to detect, identify and localize sounds (Arlinger, 2003).

1.3. Audiometry hearing screening

1.3.1. School-based hearing screening

Routine newborn hearing screening programmes are not always available in developing countries due to scarce resources. Because of this, school entry hearing screening is often the first point of access to hearing screening, if available (Bamford et al., 2007). School-based hearing screening is necessary even if newborn hearing screening was performed. A child can develop a wax plug, otitis media or a slight undetected hearing loss after newborn hearing screening was performed (McPherson, Law & Wong, 2010). This results in hearing loss and the implications of hearing loss.

In South Africa, hearing screening has been part of the Integrated School Health Policy since 2012 (Health Basic Education, 2012). In practice, however, this is still not a reality (Mahomed-Asmail, Swanepoel & Eikelboom, 2016), partially due to the high cost of screening equipment.

There are many benefits of detecting a hearing loss as early as possible; the earlier the hearing loss is detected, the sooner the child can receive adjusted treatment. A study by Picou, Ricketts & Hornsby (2013) has shown that children with a hearing loss exert less listening effort when using hearing aids, which has a positive impact on their concentration level in school. When individuals with a hearing loss are fitted with hearing aids, they can perform at levels similar to those without impaired hearing (WHO, 2015). Detecting these hearing losses is the first step in treating the children in need. By doing so, the hearing-impaired child can perform on a similar level as another student without hearing loss can perform.

1.3.2. Adult hearing screening

Newborn and school-based hearing screening have proven to be effective in identifying hearing-impaired children (Bamford et al., 2007). When extending this reasoning, adult hearing screening should be able to perform equally as well in identifying hearing losses (Smith et al., 2011). According to WHO (2015), One out of three people suffer from age related hearing loss, with the majority living in Asia and Sub-Saharan Africa. This screening usually consists of a questionnaire, an otoscopic examination and pure tone audiometry (ASHA, 1997). In the United States, only 14.2% of people with hearing losses wear hearing aids (Chien & Lin, 2012). In developing countries, this number is likely to be smaller. Speech reception will decay if the hearing loss remains untreated (Gates & Mills, 2005). The sooner the person is identified with a hearing loss, the sooner the person can be treated. This could affect the person's quality of life positively.

1.4. ISO and IEC standard

This study followed the guidelines cited in ISO 389 and IEC 60645. ISO and IEC are international bodies that define the guidelines for equipment and procedures to which the product needs to adhere to. It is important that these guidelines are followed strictly. The guidelines ensure a continuity across all headphones regardless of make or model and makes it possible to compare.

ISO 389 describes the procedures that need to be followed to ensure valid calibrations and ETSPL values. This is crucial as it makes it possible to compare results measured with different headphones. The standard is also valuable to define RETSPL values. The difference between RETSPL and ETSPL values is that RETSPL values are measured by two different independent laboratories while ETSPL values are only measured by one. RETSPL values are more reliable and should be used hen calibrating headphones.

IEC 60645 is an international standard used to classify audiometers and defines the acoustical and electronical components of the headphone under investigation. The relevance to the Sennheiser HD 202 II is that the standard specifically prescribes to which intensities the headphone must be able to reach without interference of THD, this to classify the headphone type. The standard prescribes to what electronical and acoustical aspects the soundwaves emitted by the headphone must adhere to. The force of the headband is also prescribed in this standard.

The standards make it possible to classify headphones and separate them according to use for example some headphones will only be able to be used for screening purposes and diagnostic testing. The standard makes it possible for the user to choose a headphone based on their needs.
The standards also ensure that the headphone is reliable. By choosing the right settings (e.g. RETSPL values), the headphone will be able to produce reliable results during testing of patients.

1.5. Problem statement

The cost price of the equipment used for hearing screening impedes its accessibility and availability, especially in developing countries where the need for the equipment is the greatest. Screening headphones and audiometrical headphones do not have the same requirements, making it possible to use a lower-cost headphone. If this lower-cost headphone would prove to be able to function as a screening headphone in line with ISO and IEC standards, this headphone could be used for screening purposes. This will lower the cost price of equipment, making it more accessible. The ISO and IEC standards give the guidelines on how the measurements of the ETSPL values, attenuation, MPANLs, THD, force of the headband and frequency response should be performed.

A study by Margolis and Madsen (2015) showed the importance of the type of headphone and test environment. Supra-aural, circum-aural and insert earphones were tested in four different test environments ranging from an ideal situation in an audiological booth to a room without any soundproofing. The aim is to determine in which environment the Sennheiser HD 202 II can be used. The study showed that a supra-aural headphone have the least attenuation and insert earphones have the best attenuation. The Sennheiser HD 202 II described in this thesis is a supra-aural headphone. As a supra-aural headphone had the worst attenuation, the maximum permissible ambient noise levels will need to be monitored to define in which situation and which type of testing this headphone can be used for.

The Sennheiser HD 202 II is a widely available and inexpensive off-the-shelf headphone. This study investigates the characteristics of the Sennheiser HD 202 II supra-aural headphone for potential use in screening procedures.

2. Methodology

2.1. Research objectives

The main objectives of this study was to establish ETSPL values for the Sennheiser HD 202 II and to evaluate whether this low-cost, widely available, supra-aural headphone meets the requirements for audiometric headphones as expressed in standards ISO 389-1 (1998), ISO 389-5 (2006), ISO 389-9 (2009), ISO 8253-1 (2010), IEC 60318-1 (2009) and IEC 60645-1 (2012).

To achieve the objective the study was divided in three phases:

1. Determination of the equivalent threshold sound pressure levels (ETSPL) for the HD202 II Sennheiser headphone.

2. Determination of the attenuation provided by the HD202 II Sennheiser headphone.

3. Determination of the objective characteristics of the HD202 II Sennheiser headphone.

2.2. Ethical considerations

Data collection commenced after ethical clearance was provided from the Research Ethics Committee, Faculty of Humanities, University of Pretoria Research, (Appendix A)

2.2.1. Protection from Harm

participants were not harmed in any way during data collection. The participant had the right to withdraw from the study at any point in time without any negative consequences.

2.2.2. Voluntary and Informed Participation

All participants were provided with an informed consent form (Appendix B) in which the purpose of the study and the test procedure were explained. No testing was done unless the participant had read the form and provided written consent.

2.2.3. Confidentiality

Throughout this research the participants' right to privacy was fully respected. No names of participants were used when reporting data. Participants were identified by an alphanumeric code assigned to them by the primary researcher.

Data will be stored at the department of Speech-Language Pathology and Audiology for 15 years, data will be used for archiving and research purposes.

2.3. Phases of the study

Prior to performing any experiment, measurements were made to define whether to use the flat plate or conical ring of the G.R.A.S. 43AA-S2 CCP Ear Simulator Kit.

One Sennheiser HD 202 II headphone was connected to the GSI 61 two-channel clinical audiometer and placed on the artificial ear, equipped with either the conical ring or flat plate. The audiometer was set to emit 70 dB HL. The intensity emitted to the artificial ear was measured by a Rion NL-52 type 1 sound level meter (IEC class 1/ ANSI type 1). Using the same headphone and same intensity, five different measurements were made for both the conical ring and flat plate set up. After every measurement the headphone was removed and replaced on the artificial ear. The measurements of the sound level meter were compared through MS Excel® by calculating the mean difference and mean standard deviation. The measuring setup with the smallest variability across all frequencies was chosen for further work.

The SNR of the smartphone was measured by connecting the smartphone directly to a personal computer equipped with Matlab R2015a (The MathWorks, Inc., Natick, Massachusetts). A 95 dB SPL, 1000 Hz signal was played by the smartphone and the electrical signal was received and analyzed by the personal computer using Matlab.

2.3.1. Phase 1: ETSPL values

In the first phase of the research a quantitative descriptive design was performed to determine the ETSPL values for the Sennheiser HD202-II headphones according to ISO 389-9.

2.3.1.1. Participants

Twenty-five otologically normal participants were selected from Hatfield Main Campus of the University of Pretoria. Participants were required to meet the criteria for otologically normal persons according to the ISO 389-9 (2009) standard. Only if a participant was in normal state of health, had no symptoms of ear disease or wax in the outer ear canal and no history of noise exposure, ototoxic drugs or familial hearing loss the participant was considered as otologically normal (ISO 389-9, 2009). The standard prescribes that the selected sample must consist of participants between 18 and 25 years of age, preferably equal numbers of males and females, all having normal hearing (ISO 389-9, 2009). The selected participants had to be in a normal state of health, free from all signs or symptoms of ear disease, free from obstructing wax in the ear canals and having no history of undue exposure to noise, exposure to potentially ototoxic drugs or familial hearing loss. Minimum information of the patient's hearing was collected by using the "Questionnaire for hearing test" (Appendix C).

Research Equipment

The following equipment was used:

Table 1: Research equipment phase one: ETSPL values.

EQUIPMENT	DESCRIPTION/COMMENT
Welch Allyn 2,5v pocketscope	To visually inspect the outer ear.
GSI tympstar, tympanometer	A comprehensive middle ear tympanometer which was used to assess the middle ear.
GSI 61 2 channel clinical audiometer	A device that was used to perform narrow band noise testing over the frequency range of 125 to 16000 Hz.
Sennheiser HD 202 II (5 different pairs)	This is the low-cost and commercially available headphone under evaluation.
TDH 39 audiometrical headphones	This is an acknowledged audiometrical

	headphone. ETSPL values of this headphone were already measured and stated in ISO 389-1 (1998).
G.R.A.S. 43AA-S2 CCP Ear Simulator Kit According to IEC 60318-1 (2009), also known as 6cc coupler	A main housing containing the sockets for the connection of a condenser microphone and a base plate with a mechanism for clamping the headphone.
Rion NL-52 type 1 sound level meter (IEC class 1/ ANSI type 1)	This device measured the intensity of sound at each frequency. It meets the requirements of IEC and ANSI for a type 1 sound level meter. To ensure accurate results the sound level meter was manually calibrated before each use.
Environmental instruments force gauge	A calibrated spring gauge.
Rion.co Ltd. NC-74 class A acoustic calibrator (94 dB – 1000Hz)	This device emits a pure tone of 94 dB SPL at 1000 Hz.
Huawei G700 (Android 4.2.1) with the “audiometer calibration app”.	The Huawei G700 is a smartphone equipped with android 4.2.1. The audiometer calibration app is an application developed by the University of Pretoria. It is designed to generate sounds and functions as an audiometer. It allows to calibrate the intensity with an accuracy of 0.1 dB. The frequency range of the app covers 250 Hz to 16000 Hz.
Audiometrical booth conforming ISO 8253-1 (2010) standard.	The booth created an environment where accurate testing is possible. This is done by blocking out environmental noises.
Environmental instruments ACM - 800	This device measured the actual

frequency counter	frequency produced by the audiometer when determining the THD.

2.3.1.2. Research Procedures

Prior to the subject's arrival all equipment was calibrated and setup.

First the sound level meter was calibrated. This was done by connecting a calibrated sound source of 94 dB SPL at 1000Hz (Rion.co Ltd. NC-74 class A acoustic calibrator) to an ear simulator which in turn was connected to the sound level meter. The sound level meter was adjusted if 94 dB SPL was not measured.

Once the sound level meter was calibrated, the testing equipment consisting of a Huawei G-700, a GSI-61 audiometer and the Sennheiser HD 202 II was calibrated. With the audiometer functioning as an attenuator, the Huawei G-700 was connected to the audiometer's external channel. Each of the two earphones of the headphone was calibrated separately; the order in which each earphone was calibrated was randomized. The earphone was connected to the ear simulator with a force as determined in phase two of the research. The force was measured using a force gauge. The Huawei G-700 enabled sound generation at a specific frequency and intensity; the intensity of the sound produced could be calibrated with an accuracy of 0.1 dB. Sound levels at different frequencies were calibrated in ascending order starting at 250 and ending at 16000 Hz. For each frequency, the sound generated by the combination Huawei G-700 – Sennheiser HD 202 II was transmitted by the ear simulator and the intensity was measured by the sound level meter (in dB SPL). The dB SPL reading was compared with the SPL value set on the Huawei G-700 and corrected for the ETSPL value of the TDH 39 as given in ISO 389-1 (1998). The intensity of the Huawei sound signal was adjusted so that the sound level meter's reading was identical to a set value of 70 dB plus the ETSPL value of the TDH 39. The settings of the intensity levels required to reach these equivalent readings were stored in the memory of the Huawei G-700 for each earphone, at each frequency, for all headphones used.

The ISO 389-9 (2009) standard allows for a maximum deviation of 0.1% from the intended frequency as applied. The accuracy of the frequencies generated by the

Huawei G-700 was validated by connecting the frequency counter to the sound level meter and comparing the measured frequency to the frequency set on the Huawei.

Once the equipment was calibrated, testing of participants commenced. All participants underwent testing prior to carrying out the ETSPL evaluation with the smartphone and Sennheiser earphone. The evaluation consisted of an otoscopic examination, tympanometry, the questionnaire for hearing tests (Appendix C), and a diagnostic pure tone behavioral audiometric test. All tests were performed by a qualified audiologist.

The diagnostic ear test was administered according to the ascending method (ISO 8253-1, 2010) in steps of 5 dB performed by the researcher. A 1000 Hz tone was tested first, followed by all the higher frequencies. Thereafter the lower frequencies were tested in ascending order starting from 250 Hz, increasing and ending with retesting at 1000 Hz. A TDH 39 headphone was used to perform the threshold testing.

Once the participant passed the diagnostic testing the actual ETSPL determination was carried out . A diagnostic pure tone air conduction audiological test was performed on the participant by the same audiologist. The shortened ascending method (ISO 8253-1) was used. The test was performed in an audiological booth. An evaluation similar to the one performed with the TDH 39 was performed using the Sennheiser HD 202 II. Sound pressure thresholds levels were collected at the various frequencies for all participants.

2.3.1.3. Data analysis

All sound pressure threshold levels were collected in a MS Excel® sheet. The MS Excel® data was transferred to SPSS (v22 Chicago, Illinois, IBM) for further statistical analysis. At each frequency the mean, standard deviation and all quartiles were determined for the different genders, the different ages and the whole group. Potential effects of age and gender were investigated into by applying appropriate statistical techniques as available in SPSS.

2.3.2. Phase 2: Headphone attenuation study

A quantitative within-subject descriptive design was followed to determine the attenuation of the Sennheiser HD202-II supra-aural headphone and to compare it with the attenuation requirements for audiometric headphones as prescribed in the standard ISO 389-9 (2009).

2.3.2.1. Participants

Fifteen otologically normal participants were selected from volunteers of the Hatfield main campus of the University of Pretoria. Participants were required to meet the criteria for otologically normal participants as defined in the ISO 389-9 (2009) standard. ISO 389-9 (2009) prescribes that the participants of the sample had to be between 18 and 25 years of age, present with normal hearing, with an equal number of males and female participants. Normal hearing is defined as being in a normal state of health, being free from all signs or symptoms of ear disease or obstructing wax in the ear canals, and without history of excessive exposure to noise, exposure to potentially ototoxic drugs and no familial hearing loss (Appendix C).

2.3.2.2. Research Equipment

For this phase of the research, the equipment following was used.

Table 2: Research equipment phase two: Headphone attenuation study.

EQUIPMENT	DESCRIPTION/COMMENT
Welch Allyn 2,5V pocketscope	To visually inspect the outer ear.
GSI tympstar tympanometer	The comprehensive middle ear tympanometer was be used to conduct a tympanometry. Results were used to assess the middle ear.
GSI 61 2 channel clinical audiometer	A GSI 61 2 channel clinical audiometer was used to perform narrow band noise testing over the frequency range of 125Hz to 16000 Hz
Sennheiser HD 202 II (5 different pairs)	The low-cost and commercially available headphone under evaluation.
Audiometrical booth conforming to ISO 8253-1 (2010) standard.	The audiometrical booth provided an ideal sound environment for testing the attenuation offered by the headphones. The booth was equipped with speakers

	which will allow sound field testing of the attenuation levels.

2.3.2.3. Research Procedures

The hearing thresholds of the participants were determined in accordance with the shortened ascending method (ISO 8253-1 - 2010). The specific frequencies that were tested were 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000, 10000, 12500 and 16000 Hz.

The participant was seated in the audiometric booth on a chair that was positioned facing a speaker. The participant was positioned one meter away from the speaker. The subject was given instructions on what was expected of him/her. The participant was instructed to push a button every time he or she heard a sound, even if in doubt the participant was encouraged to press the button. A narrowband noise at specific frequencies and intensities was presented. In order to familiarize the participant with the processes, a clearly audible sound was initially presented to the participant. The intensity was then lowered in steps of 20 dB HL till no response occurred. Next the stimulus intensity was raised in steps of 10 dB HL till the participant heard the sound again.

After the familiarization process the actual testing commenced. The frequencies were tested in the following sequence: 1000, 1500, 2000, 3000, 4000, 6000, 8000, 10000, 12500, 16000, 250, 500, 750, 1000 Hz. The first intensity was clearly audible. As all participants had normal hearing the starting intensity was set at 40 dB HL. The intensity was lowered in steps of 10 dB HL until the participant no longer responded. The intensity was raised in steps of five dB HL until a response reoccurred. This process was continued until a response at the minimum intensity was confirmed twice. When all frequencies were tested in free field, the procedure was repeated with the Sennheiser supra-aural earphones positioned on the participant under supervision of the audiologist.

2.3.2.4. Data analysis

After all data was acquired, it was imported into a MS Excel® sheet. The difference between the test session with and without the Sennheiser HD 202 II placed on the participant's head was calculated. The average, mean and standard deviation of the differences per participant was determined. Frequency specific attenuation was compared to the standard ISO 389-9 (2009) as well as the measured attenuation of the TDH 39.

2.3.3. Phase 3: Objective headphone characteristics study

The last phase of the research followed a quantitative descriptive design to measure and describe objective qualities of the Sennheiser HD202-II headphones.

2.3.3.1. Research equipment

The following equipment was used:

Table 3: Research equipment phase three: Objective headphone characteristics study.

EQUIPMENT	DESCRIPTION/COMMENT
GSI 61 2 channel clinical audiometer	The audiometer generated continuous pure tones at specific frequencies and levels of intensity.
Sennheiser HD 202 II (10 different pairs)	The low-cost and commercially available supra-aural headphone being evaluated.
Rion NL-52 type 1 sound level meter (IEC class 1/ ANSI type 1)	This device measured the intensity of sound at each frequency. It meets the requirements of IEC and ANSI for a type 1 sound level meter. To ensure accurate results the sound level meter was manually calibrated before each use.
Rion.co Ltd. NC-74cclass A acoustic calibrator (94 dB – 1000Hz)	This apparatus emitted a pure tone of 94 dB SPL at 1000 Hz and will be used to calibrate the sound level meter (in combination with the ear simulator).
G.R.A.S. 43AA-S2 CCP Ear Simulator Kit According to IEC 60318-1 (2009), also known as	A housing containing a condenser microphone and a mechanism for clamping the headphone under investigation.

6cc coupler	
Newtronics 200 MSPC frequency generator	Equipment used to generate different types of electrical waveforms over a wide range of frequencies.
Hewlett Packard 54600B 2 channel 100 MHz oscilloscope	This device allowed monitoring of the voltage that was produced. It has a bandwidth of 100 MHz. To ensure accurate results the oscilloscope will be calibrated before use.
Environmental instruments ACM - 800 frequency counter	This device measured the actual frequency produced by the audiometer when determining the THD.
Audiometrical booth conforming to ISO 8253-1 (2010) standard	The booth created an environment where accurate testing was possible by blocking out environmental noises.
Environmental instruments force gauge	The force gauge was used to monitor the force applied by the earphone on the ear simulator.
Force of headphone instrument	This device was specifically designed for this research and consisted of an aluminium plate, two strain gauges, a calibrated weight of ~0.5 kg and a strain indicator.

2.3.3.2. Research procedures

Force of the headband

Standard IEC 60645-1 (2012) stipulates that the force exerted by the headband of the headphone be measured and is within a given range (four to five Newton) for a specific geometrical configuration. The headband was stretched out to the prescribed geometrical configuration a force gauge was used to read the mass applied to stretch out the headband to the specific geometrical configuration.

The force of the headband was derived from the strain differential on the gauges using the following formulae:

$$F = m\,X\,a$$

With:
F= the force exerted by the headband
m= the equivalent mass applied by the headphone on the structure (m2)
a= gravitational acceleration constant (9.81m/s^2)

The average for each of the headband forces was calculated and used as the average force of the headband.

Total harmonic distortion (THD)

The setup for the procedure to determine the THD values consisted of an audiometer, five different headphones (10 earphones), an ear simulator and a sound level meter. The headphones, ear simulator and sound level meter were located in an audiometrical booth according to the ISO 8253-1 (2010) standard. The audiometer was connected to the headphone. One earphone at a time was attached to the ear simulator with a force equal to the force of the headband as determined beforehand. The order in which the earphones were tested, was randomized. The coupler was attached to the sound level meter. At each frequency (250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000, 10000, 12500 and 16000 Hz) increasing intensities were presented in steps of five dB ranging from 20 to 110 dB SPL in order to find the intensity at which a THD level of three percent is exceeded (IEC 60645-1, 2012). The intensity of the nominal frequency and its four closest harmonics were measured by using the sound level meter. This procedure was repeated for each earphone. The formula used to calculate the THD from the intensities of the fundamental and its four closest harmonics is stated in the paragraph “data analysis”.

Frequency response

To measure the frequency response a frequency generator was set to generate a 428 mV sinewave signal at different frequencies. The value of the voltage was chosen to be identical to the value as that used by Sennheiser to measure the frequency response of the HD 202 II. The voltage was monitored by the oscilloscope, and the frequencies were monitored with a frequency counter. The frequency generator was connected to the earphone, which was attached to the ear simulator; the ear simulator was connected to the sound level meter. The sound level meter measured the intensity of sound generated at each frequency which was documented.

2.3.3.3. Data analysis

Total harmonic distortion

For all frequencies up to 8000 Hz and each applied sound intensity level, the intensities of the fundamental wave and its four closest harmonics was documented in a MS Excel® sheet. This procedure was repeated for each earphone.

The total harmonic distortion was calculated as:

$$THD = 100\ X \left[\frac{10^{\frac{H1}{20}} + 10^{\frac{H2}{20}} + 10^{\frac{H3}{20}} + 10^{\frac{H4}{20}}}{10^{\frac{F1}{20}}}\right]$$

with F1 being the intensity of the first fundamental and H1 to H4 being the intensities of the four harmonics closest to the fundamental.

At a given frequency the highest intensity at which all earphones have a THD below three percent was determined. That intensity was used as the highest intensity where the Sennheiser headphone can reliably test a specific frequency.

Force of the headband

The average of three headband force measurements was taken for 10 headbands. The mean of these averages was measured and used as the force of the headband.

Frequency response

The average frequency response across six earphones (three headphones) at all specified frequencies was reported.

3. Research article: Affordable headphones for accessible screening audiometry: an evaluation of the Sennheiser HD 202 II supra-aural headphone

Authors:

Van der Aerschot M.

Swanepoel De Wet

Mahomed-Asmail Faheema

Myburgh Herman

Eikelboom Robert

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ABSTRACT

Objective:

Evaluation of the Sennheiser HD 202 II supra-aural headphones as an alternative headphone to enable more affordable hearing screening.

Design:

Study 1 measured the equivalent threshold sound pressure levels (ETSPL) of the Sennheiser HD 202 II. Study 2 evaluated the attenuation of the headphones. Study 3 determined headphone characteristics by analyzing the total harmonic distortion (THD), frequency response and force of the headband.

Study sample:

Twenty-five participants were included in study 1 and fifteen in study 2 with ages ranging between 18 and 25. No participants were involved in study 3.

Results:

The Sennheiser HD 202 II ETSPLs (250 – 16000 Hz) showed no significant effects on ETSPL for ear laterality, gender or age. Attenuation was not significantly different ($p>0.01$) to TDH 39 except at 8000 Hz ($p<0.01$). Maximum permissible ambient noise levels (MPANL) were specified accordingly. The force of the headband was 3.1N. THD measurements showed that between 500 and 8000 Hz intensities of 90 dB HL and higher can be reached without THD larger than three percent.

Conclusion:

Sennheiser HD 202 II supra-aural headphones can be used as an affordable headphone for screening audiometry provided reported MPANLs, maximum intensities and ETSPL values are employed.

Abbreviations:

ETSPL: Equivalent Threshold Sound Pressure Level

MPANL: Maximum Permissible Ambient Noise Level

HL: Hearing Level

SPL: Sound Pressure Level

INTRODUCTION

The World Health Organization (WHO, 2014) estimates that there are 360 million people worldwide living with a permanent disabling hearing loss. If milder and transient losses are included, this figure can exceed 1.2 billion, making hearing loss the fifth most significant contributor to the global burden of disease (World Health Organization 2013, 2015). The vast majority of affected individuals live in lower to lower-middle income countries where access to care, which includes screening, follow-up and treatment, is mostly unavailable (Fagan & Jacobs, 2009; Goulios & Patuzzi, 2008; WHO, 2013b).

Early identification of a hearing loss is an essential requirement to ensure optimal development in children (Moeller, 2000; Watkin et al., 2007). Screening for hearing in school-aged children is important to negate the influence of an undetected hearing loss that may affect a child's academic performance and socio-emotional well-being (Arlinger, 2003; Fellinger et. al, 2007; Tesch Römer, 1996). In developed countries such as the United Kingdom close to 20% of permanent moderate or greater bilateral, mild bilateral and unilateral impairments are unidentified around the time of school entry (Bamford et al., 2007). In developing countries where there are no systematic newborn hearing screening programmes this proportion is likely much higher (Swanepoel et al., 2010). School entry hearing screening is therefore often the first point of access to hearing screening for most children (Bamford et al., 2007).

The gold standard for hearing screening of school-aged children is pure tone audiometry with audiometrical headphones (e.g., TDH 39; Yueh, 2003). However, the cost and accessibility of screening equipment along with a shortage of trained personnel are prohibitive to the provision of widespread audiometric screening (Swanepoel et al., 2009; Mahomed-Asmail et al., 2015). Recently attempts have been made to determine more cost-effective ways to conduct hearing screening by utilizing widely available and inexpensive technologies including personal computers and smartphones (Chong Lo & McPherson, 2013; Swanepoel et al. 2014; Mahomed-Asmail et al., 2015b). However, audiometric headphones adhering to International Organization for Standardization (ISO) calibration standards (ISO 389-9: 2009) remain an expensive component of the screening process typically ranging from $400 to $800 United States dollars. A cost-effective commercially available headphone coupled to a personal computer or smartphone-based audiometers could ensure low-cost screening and improve access to hearing health care (Swanepoel et al., 2014). Such a headphone would require Equivalent Threshold Sound Pressure Levels (ETSPLs) to be determined according to current guidelines (ISO 389-9: 2009) and electro-acoustic characteristics that are sufficient for screening audiometry (IEC 60645-1, 2012). Developing this for extended high frequencies (10,000 – 16,000 Hz) may also offer the possibility of monitoring for early noise or otoxicity related hearing loss (Stelmachowicz et al., 2004).

This study therefore investigated the characteristics of a low-cost widely available commercial headphone, the Sennheiser HD 202 II supra-aural headphone, for use in audiometric screening. The investigation was divided into three studies to establish the following characteristics of the Sennheiser HD 202 II headphone i) ETSPL values (conventional and extended high frequencies), ii) attenuation and iii) objective headphone characteristics including the force of the headband, total harmonic distortion and the frequency response.

STUDY 1: EQUIVALENT THRESHOLD SOUND PRESSURE LEVELS

ETSPL values are required to define calibration values conforming 0 dB HL per specific frequency for a specific headphone in a specific laboratory. All testing was performed according to the ISO 389-9 (2009) standard. ETSPL's for extended high frequencies (EHFs) were also measured in this study. Effect of age, gender, ear and headphone on the ETSPL values were also investigated.

Participants

Participants were selected through purposive sampling from the student body of the University of Pretoria. Institutional Review Board clearance was provided by the Research Ethics Committee. Twenty-five participants between the ages of 18 and 25 years (mean: 20.7, SD: 2.1) equally distributed in gender were selected using the criteria for otologically normal participants as defined by ISO 389-9 (2009). Participants were divided into two age categories; category one included participants between 18 to 20 years of age, whilst category two included participants between 21 and 25 years of age. The "questionnaire for hearing test" (ISO 389-9: 2009) was performed in combination with otoscopy and tympanometry. The purpose of the questionnaire was to obtain information about the state of the participant's hearing. Hearing threshold audiometry was performed only if the participant passed the "questionnaire for hearing test", had no obstructions in the outer ear canal and a middle ear pressure of ±50 daPa.

Materials and methods

The equipment used was a GSI 61 audiometer, five different pairs of Sennheiser HD 202 II headphones, a Huawei G-700 smartphone, a G.R.A.S. 43AA-S2 CCP Ear Simulator Kit (complying with ISO 60318-1: 2009 & ISO 60318-2: 1998), a Rion NL-52 type 1 sound level meter and an audiometric booth as required by ISO 8253-1 (2010).

Prior to testing the Huawei G-700 (Android OS 4.2) was loaded with a validated pure tone generation and calibration application (Swanepoel et al. 2014). The smartphone's total harmonic distortion (THD) and signal to noise ratio was verified with the audio jack connected to a computer running Matlab R2015a (The MathWorks, Inc., Natick, Massachusetts). At outputs ranging from 88 dB (250 Hz) to 95 dB (1000 Hz) THD's were below three percent at all frequencies except for 500Hz where it was three percent at 93 dB. The smartphone SNR was determined with the same setup using a 95 dB 1000Hz signal with a bandwidth filter at the signal and at 60 Hz. The smartphone audio output SNR was 58.6 dB.

The smartphone (Huawei G-700) was subsequently calibrated with the Sennheiser HD 202 II's headphones according to the ETSPL values of the TDH 39 as stated in ISO 389-1 (1998) and ISO 389-5 (2006). This was done to have a similar initial calibration point for all headphones. This smartphone application has been designed to calibrate, store and generate pure tone signals with an intensity specificity of 0.1 dB on each specific frequency. The GSI 61 audiometer was solely used as an attenuator with the smartphone application used as a signal generator. The frequency specificity, rise and fall time complied with the specifications provided by the IEC 60645-1 (2012). The Huawei G-700 was connected to the audiometer, which was connected to the headphone, which was clamped on the ear simulator kit with a force of 3.1N (as determined in study 3). The ear simulator kit was attached to the sound level meter. Each earphone was calibrated separately by using the calibration application in such a way that the intensity (in SPL) on each frequency matched the

ETSPL values of the TDH 39 as stated in ISO 389-1 (1998). The calibration process was performed by measuring the sound pressure level with the sound level meter. The difference between the measured value and the ETSPL value of the TDH 39 was compensated for by adjusting the sound pressure level on the smartphone. This was the initial calibration for Sennheiser HD 202 II headphones.

The above calibration setup was also used to determine whether the acoustic coupler should be used with a flat plate or a conical ring when calibrating Sennheiser HD202 II headphones. Calibration variability was determined by recording the difference in sound pressure level between two different measurements using the same setup and equipment. This was done with a flat plate and a conical ring. The sound pressure used as the input was equivalent to the sound pressure level of 70 dB HL for the TDH 39 across the different frequencies.

To define the ETSPL levels the following procedure was used. The ascending method (ISO 8253-1: 2010) of 5 dB increments was followed to determine the hearing thresholds of both ears. Participants were instructed to put on the headphones themselves under supervision of the qualified tester and were told to press the response button every time a sound was heard. A familiarization process was performed before determining the thresholds (ISO 8253-1: 2010). Threshold testing commenced at 40 dB HL at 1000 Hz followed by testing the higher frequencies and subsequently the lower frequencies. After five participants were tested with a headphone, the calibration for the next headphone commenced before testing the next 5 different participants.

Non-parametric statistical analysis of the data was used as it was judged by the Shapiro-Wilk test not to be normally distributed. The Mann-Whitney U test was used to validate if there was a significant difference between the ETSPL values for different gender, ears and ages across frequencies. The Kruskal-Wallis (Bonferroni adjustment) test was used to analyze whether there was a significant difference between the ETSPL values per headphone across frequencies. All statistical analyses for this and subsequent experiments were done with SPSS v22 (IBM Corporation, Chicago, Illinois). Because of a small sample size an alpha level of 0,01 was chosen (Rowan & Pickering, 2011).

Results and discussion

The calibration variability of the Sennheiser HD 202 II with a flat plate and a conical ring is represented in Table 4. Whilst variability was very similar across calibration conditions. Excluding 250 Hz, the standard deviation for the acoustic coupler with the conical ring demonstrated to be slightly lower overall. Since screening audiometry typically excludes 250Hz, and the Sennheiser HD 202 II headphones are supra-aural headphones the acoustic coupler without the flat plate was employed to determine ETSPLs in this study.

Table 4: Comparison of mean difference, standard deviation and maximum difference between repeated measurements using a flat plate and a conical ring (diff = difference; SD = standard deviation).

Frequency (Hz)	250	500	750	1000	1500	2000	3000	4000	6000	8000	Total
Mean diff conical ring (dB)	1.9	0.8	0.5	0.4	0.4	0.4	0.8	1.0	0.5	0.1	0.7
Mean diff SD conical ring	2.1	0.9	0.5	0.4	0.4	0.5	0.7	0.9	1.7	0.4	0.8
Mean diff flat plate (dB)	-0.5	-0.1	0.2	-0.3	-0.3	-0.4	-0.2	0.0	-0.3	0.0	-0.2
Mean diff SD flat plate	1.0	1.0	0.6	0.7	0.5	0.4	0.5	1.2	1.2	0.4	0.8

The calibration values of the TDH 39 were used to calibrate the Sennheiser HD 202 II as a starting point and threshold testing was performed in steps of five dB. Therefore median values for the Sennheiser HD 202 II differed in five dB steps. As a result ETSPL values were derived from measurements as follows: The mean threshold across participants tested with the same headphone (five headphones were used) was determined. Subsequently the median of these five mean values represented the ETSPL values across frequencies (Table 5). These values represent the advised ETSPL values by using a G.R.A.S. 43AA-S2 CCP 6 cc coupler with the 0.5 inch microphone (IEC 60318-1 & -2) using the conical ring.

Table 5: Comparison of equivalent threshold sound pressure levels of the Sennheiser HD 202 II and the TDH 39. An ear simulator conforming IEC 60318-1 with conical ring was used. (ISO 389-1, 1998)

Frequency (Hz)	Sennheiser HD 202 II	TDH 39
250	13.5*	27*
500	11.5	13.5
750	10	9
1000	7	7.5
1500	9.5	7.5
2000	10.5	9
3000	9.5	11.5
4000	12	12
6000	20	16
8000	18.5	15.5

*: significantly different.

Across all frequencies there was no significant difference (p>0.01) in ETSPL values between left and right ears male and female participants, younger and the older population and the five different headphones used (Table 6 and Table 7). An alpha of 0.01 was adapted based on the amount of observations (Rowan & Pickering, 2011). At 250 Hz the HD 202 II had a significantly smaller ETSPL value than the TDH 39 (p<0.01) whilst at 8000 Hz the ETSPL values of the Sennheiser HD 202 II were greater than those of the TDH 39. These ETSPLs requires replication by other laboratories.

Table 6: Equivalent threshold sound pressure levels for the Sennheiser HD202 II supra-aural headphones. All measurements were performed using an ear simulator that complies with IEC 60318-1. All values are represented in dB SPL except for the values of the standard deviations, which are presented in dB.

Frequency (HZ)	250	500	750	1000	1500	2000	3000	4000	6000	8000
all median*	12.0	8.5	9.0	7.5	7.5	9.0	11.5	12.0	21.0	20.5
all mean	14.7	13.5	9.0	7.5	7.5	9.0	11.5	12.0	16.0	15.5
all st.dev	4.5	4.7	3.8	5.2	5.0	4.5	4.7	6.3	7.7	7.7
all max	22.0	18.5	14.0	22.5	22.5	19.0	21.5	32.0	36.0	40.5
all min	7.0	3.5	-1.0	2.5	2.5	4.0	1.5	2.0	6.0	5.5
n	50	50	50	50	50	50	50	50	50	50
left median	14.5	8.5	9.0	7.5	12.5	9.0	11.5	12.0	21.0	15.5
left mean	15.3	-2.6	-1.0	0.0	2.8	1.2	-2.0	1.8	6.2	3.6
SD	4.2	4.4	3.8	5.2	5.6	4.4	4.3	6.4	8.3	7.3
n	25	25	25	25	25	25	25	25	25	25
right median	12.0	8.5	9.0	7.5	7.5	9.0	11.5	12.0	21.0	20.5
right mean	14.1	-2.0	0.0	1.0	2.2	2.0	-1.4	0.6	3.4	4.8
SD	4.7	5.0	3.8	5.2	4.3	4.6	5.1	6.2	6.9	8.2
n	25	25	25	25	25	25	25	25	25	25
male median	14.5	13.5	9.0	7.5	7.5	9.0	11.5	12.0	21.0	20.5
male mean	14.7	12.2	9.2	7.7	9.4	10.9	9.4	13.5	21.6	20.5
SD	4.8	4.8	3.3	5.4	5.5	4.0	4.0	7.2	8.0	8.2
n	26	26	26	26	26	26	26	26	26	26
female median	12.0	8.5	9.0	7.5	12.5	9.0	9.0	12.0	21.0	20.5
female mean	14.7	10.2	7.8	8.3	10.6	10.3	10.3	12.8	20.0	18.8
SD	4.2	4.3	4.2	5.0	4.4	4.9	5.4	5.2	7.4	7.2
n	24	24	24	24	24	24	24	24	24	24
mean of median headphone	13.5	11.5	10.0	7.0	9.5	10.5	9.5	12.0	20.0	18.5
18-20 mean	14.1	9.8	8.5	9.3	12.0	12.0	8.8	12.8	21.3	20.5
18-20 median	12.0	8.5	9.0	7.5	12.5	14.0	9.0	12.0	21.5	20.5
SD	4.8	3.6	4.6	5.7	5.1	5.2	4.4	7.3	8.7	8.9
n	20	20	20	20	20	20	20	20	20	20

21-25 mean	15.4	12.2	8.5	7.2	8.7	9.7	10.5	13.5	20.5	19.2
21-25 median	14.5	13.5	9.0	7.5	7.5	9.0	11.5	12.0	21.0	20.5
SD	3.9	5.1	3.3	4.7	4.5	3.7	4.8	5.6	7.1	6.9
n	30	30	30	30	30	30	30	30	30	30

* All: all ears

Table 7: Equivalent threshold sound pressure levels for the Sennheiser HD202 II supra-aural headphones for the extended high frequencies. All measurements were performed by using an ear simulator that complies with IEC 60318-1. All values are represented in dB SPL except for the values of the standard deviations which are presented in dB.

Frequency (Hz)	**10 000**	**12 500**	**16 000**
all median *	14.0	25.0	47.0
all mean	24.0	25.0	52.0
all st.dev	9.5	7.9	11.1
all max	44.0	45.0	72.0
all min	-1.0	5.0	32.0
n	50	50	50
left median	9.0	25.0	47.0
left mean	-9.6	-1.2	-3.2
SD	11.7	8.6	11.3
n	25	25	25
right median	14.0	25.0	52.0
right mean	-8.4	0.0	-0.4
SD	6.9	7.4	11.0
n	25	25	25
male median	14.0	25.0	52.0
male mean	14.0	23.3	51.8
SD	9.7	9.0	12.7
n	26	26	26
female median	14.0	25.0	47.0
female mean	16.1	25.6	48.5
SD	9.4	6.5	9.0
n	24	24	24

mean of median headphone	12.5	24.0	47.5
18-20 mean	16.0	24.0	47.5
18-20 median	11.5	22.5	42.0
SD	11.3	9.1	12.0
n	20	20	20
21-25 mean	14.3	24.7	52.0
21-25 median	14.0	25.0	49.5
SD	8.3	7.2	10.3
n	30	30	30

* All: all ears

This study was done on 25 participants with 5 different headphones meeting minimum requirements of the ISO 389-9 (2009) standard. Each headphone was used to test five participants. A larger sample would ensure more reliable results and chances on measurement errors would be smaller.
No indication of variance introduced by repeated positioning of the headphones on the same subject was suspected. For future research it would be a priority to investigate this.

STUDY 2: ATTENUATION

Attenuation characteristics of the HD 202 II headphone were measured to determine its maximum permissible ambient noise levels (MPANLs).

Participants

Convenience sampling was used with the same selection criteria as study 1 to obtain fifteen otologically normal participants between 18 to 25 years old (mean: 20.4; SD: 2.1). Additionally otoscopy, tympanometry and diagnostic pure tone audiometry was administered to ensure the participant was otologically normal. A participant was only included in the research if he/she passed all aforementioned tests. In the case of diagnostic audiometry, hearing thresholds at all frequencies had to be <15 dB HL with the exception of one frequency being >15 dB HL (ISO 389-9: 2009).

Materials and method

Testing was performed in a sound booth adhering to ISO 8253-1 (2010) standards. Each participant's hearing thresholds were established in quasi-free sound field (ISO 8253-2:2009) using the ascending method (ISO 8253-1: 2010). The participant was seated in the booth 1 meter away and facing the Radioear SP90 audiometric speaker system. The GSI 61 audiometer was used to present the desired intensities at specified frequencies. Participants were tested with and without headphones placed on their ears. In total the participants were tested three times. Once without headphones and once with the two different pairs of headphones, the Sennheiser HD 202 II and TDH 39. Testing without headphones was performed first; the participants themselves, under supervision of a qualified tester, positioned the unplugged headphones. The order headphones were used for the trials was randomized by alternating between the different headphones. Five different pairs of Sennheiser HD202 II headphones were used in total, each used to test five different subjects. The stimulus type and intensity was controlled via a GSI 61 audiometer. Free-field pure tone thresholds were determined at 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz.

Data analyses included descriptive statistics and determination of normality of the distribution of the data (Shapiro-Wilk test). A paired samples t-test was used per frequency to determine if there was a significant difference between the attenuation of the Sennheiser HD 202 II and the TDH 39.

The MPANLs were calculated by adding the difference between the attenuation of the Sennheiser HD 202 II and the TDH 39 to the prescribed MPANLs as in ISO 8253-1 (2010). This was done as there are only MPANLs available for the TDH 39. By using the difference in attenuation for both headphones the MPANLs for the TDH 39 was adjusted to specify MPANLs for the Sennheiser HD 202 II. These calculated MPANLs are those for testing up to 0 dB with the Sennheiser HD 202 II and not 20 dB as the American Speech-Language-Hearing Association (ASHA, 1997) recommends. Twenty dB was added (ISO 8253-1:2010) to get the recommended MPANLs for hearing screening down to 20 dB HL.

Results and discussion

There was no statistically significant difference in attenuation across the evaluated frequencies between the HD 202 II and the TDH 39 (Figure 1) except at 8000 Hz ($p < 0.01$). At 8000 Hz the attenuation of the Sennheiser HD 202 II was 10.3 dB higher than the TDH 39.

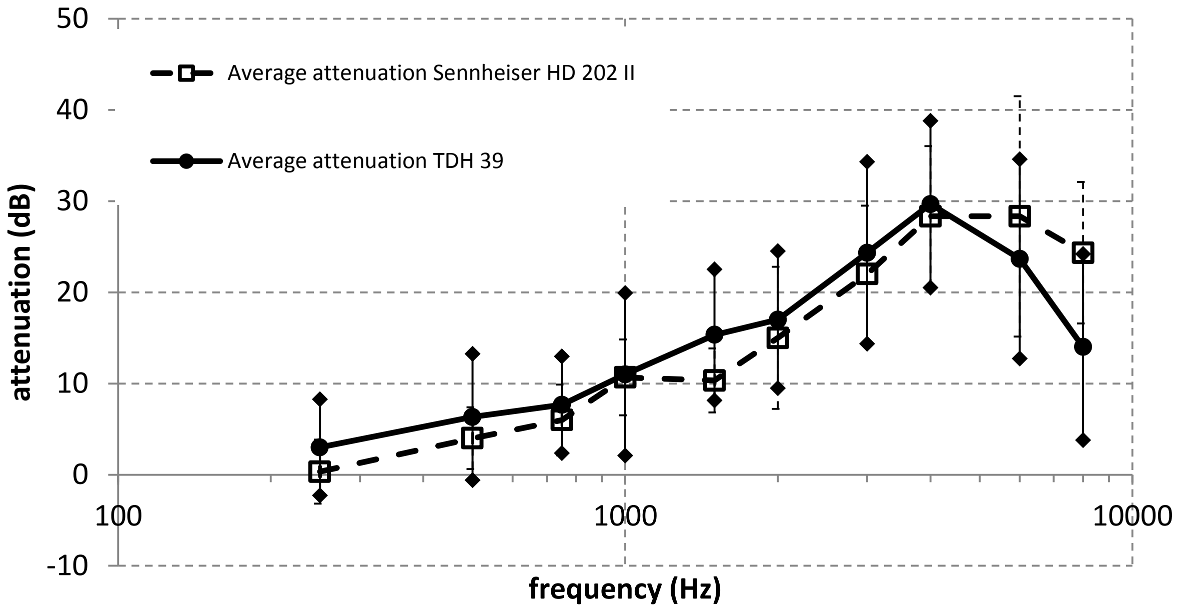

Figure 1. Mean attenuation across frequencies for the Sennheiser HD 202 II and the TDH 39 supra-aural headphones (error bars= 1 SD).

MPANLs are directly related to the attenuation of the headphone. The higher the attenuation, the higher the MPANL. The TDH 39 had higher MPANLs on the lower frequencies than the Sennheiser HD 202 II due to slightly higher attenuation at those frequencies. In contrast the Sennheiser HD 202 II had slightly higher MPANLs in the high frequencies.

When utilizing the Sennheiser HD 202 II for hearing screening the MPANL (Table 8) should not be exceeded to ensure reliable threshold testing. ASHA recommends a room is found with as little ambient noise as possible when performing screening (ASHA, 1997). In a recent report by Margolis and Madsen (2015) the MPANLs for a variety of headphones were compared. Based on MPANLs and attenuation they defined which headphones could be used in which noise environments for audiometry. In the article it is stated that the TDH 50 can be used in noise environments comparable to a quiet room. One of the reported headphones is the TDH 50, which has a similar attenuation as the Sennheiser HD 202 II. Therefore the Sennheiser HD 202 II can also be used to perform hearing screening in a quiet room. (Margolis & Madsen, 2015; ASHA, 1997).

Table 8: Headphone attenuation and maximum permissible ambient sound pressure levels (MPANL) for screening purposes of the Sennheiser HD 202 II expressed in dB. (Att – Attenuation)

Frequency (Hz)	250	500	750	1000	1500	2000	3000	4000	6000	8000
Att TDH 39 measured (dB)	3.0	6.3	7.7	11.0	15.3	17.0	24.3	29.7	23.7	14.0*
Att HD 202 II measured (dB)	0.3	4.0	6.0	10.7	10.3	15.0	22.0	28.3	28.3	24.3*
Difference between attenuation of the TDH 39 and The HD 202 II (dB)	2.7	2.3	1.7	0.3	5.0	2.0	2.3	1.3	-4.7	-10.3
MPANL TDH 39 (ISO 8253-1) (dB)	19.0	18.0	20.0	23.0	27.0	30.0	34.0	36.0	34.0	33.0
MPANL HD 202 II (dB)	16.3	15.7	18.3	22.7	22.0	28.0	31.7	34.7	38.7	43.3
MPANL allowed when screening using the HD 202 II (dB)	36.3	35.7	38.3	42.7	42.0	48.0	51.7	54.7	58.7	63.3

*: significantly different.

STUDY 3: OBJECTIVE HEADPHONE CHARACTERISTICS

This consisted of three phases to determine a) mean force of the headband; b) total harmonic distortion and; c) frequency response of the Sennheiser HD 202 II headphone.

Material and method

Phase 1: Force of the headband

A calibrated spring gauge was used to measure the force of five headbands. The cushions of the earphones were removed and the earphones were drawn apart to reach an ear-to-ear width of 145 mm at a height of 129 mm according to IEC 60645-1 (2012). The force was recorded from the spring gauge for five separate headphones.

Phase 2: Total harmonic distortion

The total harmonic distortion (THD) of ten different Sennheiser HD 202 II headphones (from five headphone pairs) were measured. The measurement setup included a GSI 61 audiometer, five different pairs of Sennheiser HD 202 II headphones, a G.R.A.S. 43AA-S2 CCP Ear Simulator Kit (IEC 60318-1 & -2) and a Rion NL-52 type 1 sound level meter (IEC class 1/ ANSI type 1). All measurements were performed in an audiological booth in conformity to the ISO 8253-1 (2010) standard. The audiometer was used to generate sounds of different frequencies ranging from 125 to 8000 Hz, with intensities increasing in steps of 5 dB. The sound was produced by the headphone, which was clamped on the ear simulator kit with a force of 3.1 N (as determined in phase 1 of this study). The sound level meter was connected to the ear simulator kit (IEC 60318-1 & -2). For each 5 dB intensity step the sound pressure level of the main frequency and its four closest harmonics were measured by using individual narrow band filters of the sound level meter. The dB SPL readings of the sound level meter were converted into THD values. The THD was derived from the sound pressure level of the harmonics by using the following formula:

$$THD = 100\ X \left[\frac{10^{\frac{H1}{20}} + 10^{\frac{H2}{20}} + 10^{\frac{H3}{20}} + 10^{\frac{H4}{20}}}{10^{\frac{F1}{20}}} \right]$$

The highest sound pressure level (in 5 dB steps) with a THD of lower than three percent (IEC 60645-1, 2012) was determined for each earphone.

Phase 3: Frequency response

The frequency response of six earphones, from three Sennheiser HD202 II headphone pairs, were measured. The equipment consisted of a Newtronics 200 MSPC frequency generator, an ACM - 800 frequency counter, a G.R.A.S. 43AA-S2 CCP Ear Simulator Kit (IEC 60318-1 & -2) and a Rion NL-52 type 1 sound level meter (IEC class 1/ ANSI type 1). The frequency generator was used to generate pure tones of a specific level and frequency. To do so the voltage was set to 428 mV, identical to the value used by the manufacturer (Sennheiser) for measuring the frequency response (Sennheiser, 2014). This voltage results in an average sound pressure level of about 100 dB SPL at 1000 Hz for the six different headphones. The frequency counter was used to control the frequency. The sound was emitted by the earphone and measured by the ear simulator in dB SPL.

Results and discussion

Phase 1: Force of the headband

For the standard geometry specified in ISO 389-9 (2009) the mean force of the headbands was 3.1N (SD: 0.1 N) between the 5 headbands. The measured force of the headband was lower than the specified force of 4.5 N to 5.5 N for diagnostic headphones stated in ISO 389-1 (1998). The Sennheiser HD 202 II, however, provides adequate attenuation and has a consistent headband force across the sample measured.

Phase 2: Total harmonic distortion

To comply with the IEC 60645-1 standard for audiometer types, the headphone should be able to test up to specified intensities (70 dB HL on all frequencies from 250 to 8000 Hz for a type four audiometer) without having a total harmonic distortion of more than three percent across frequencies (Table 9). Based on output the Sennheiser HD 202 II supra-aural headphones comply with the intensity requirements for a type four audiometer (IEC 60645-1, 2012). A type four audiometer is characterized by the ability to accurately reach an intensity of 70 dB HL without interference of distortion on the following frequencies: 250, 500, 1000, 2000, 3000, 4000, 6000 Hz. It fails only on the type 3 requirements at 500 and 4000 Hz. At 500 Hz the headphone can only be used up to 95 dB HL and at 4000 Hz only up to 90 dB HL before exceeding three percent THD.

The total harmonic distortion on 125 Hz exceeded three percent when an intensity of 70 dB HL was exerted. Therefore the headphone is not suited for testing 125 Hz. Being able to perform screening on 125 Hz is not a requirement to comply with IEC 60645-1.

Table 9: Mean (Standard Deviation), total harmonic distortion (THD) per frequency at 70 and 90 dB HL, maximum intensity (dB HL; in steps of 5 dB) where all five tested headphones reached a maximum THD not exceeding three percent, and mean maximum intensity (dB HL) where all five headphones did not exceed three percent THD.

Frequency Hz	**250**	**500**	**750**	**1000**	**1500**	**2000**	**3000**	**4000**	**6000**	**8000**
Mean THD at 90 dB HL (SD)	2.99 (0.2)	0.55 (0)	0.36 (0)	0.42 (0)	0.33 (0)	0.42 (0)	0.92 (0)	2.00 (0.2)	0.33 (0)	0.34 (0)
Mean THD at 70 dB HL (SD)	0.57 (2.0)	0.46 (0)	0.4 (0)	0.51 (0)	0.43 (0.1)	0.49 (0)	0.51 (0.6)	0.81 (0.5)	0.32 (0)	0.37 (0)
Max dB HL with THD < 3%	80	105	110	110	110	110	115	100	105	100
Mean dB HL with THD < 3% (SD)	70 (6.7)	100.5 (5)	107.5 (0.8)	110 (0)	110 (0)	108 (1.8)	103.5 (8.3)	94 (4.4)	105 (0.0)	100 (0.0)

Phase 3: Frequency response

The frequency response of the Sennheiser HD 202 II was measured and plotted into a figure. The Sennheiser HD 202 II displays an onwards sloping frequency response from 250 Hz up to 1500 Hz. After 1500 Hz the frequency response displays a downwards slope with a low point at 4000 Hz. The frequency response peaks onwards at 6000 and 8000 Hz to fall down again at 10,000 Hz. There is another upward peak on 12,500 and 16,000 Hz (Figure 2). According to the IEC 60645-1 standard the output sound pressure level generated by a headphone for a constant voltage should not differ more than 4 dB from the mean output for the frequency range 250 Hz to 4000 Hz. The output of the frequency range above 4000 Hz should not differ +4 and -11 dB from the mean output. The Sennheiser HD 202 II complies with both of these requirements.

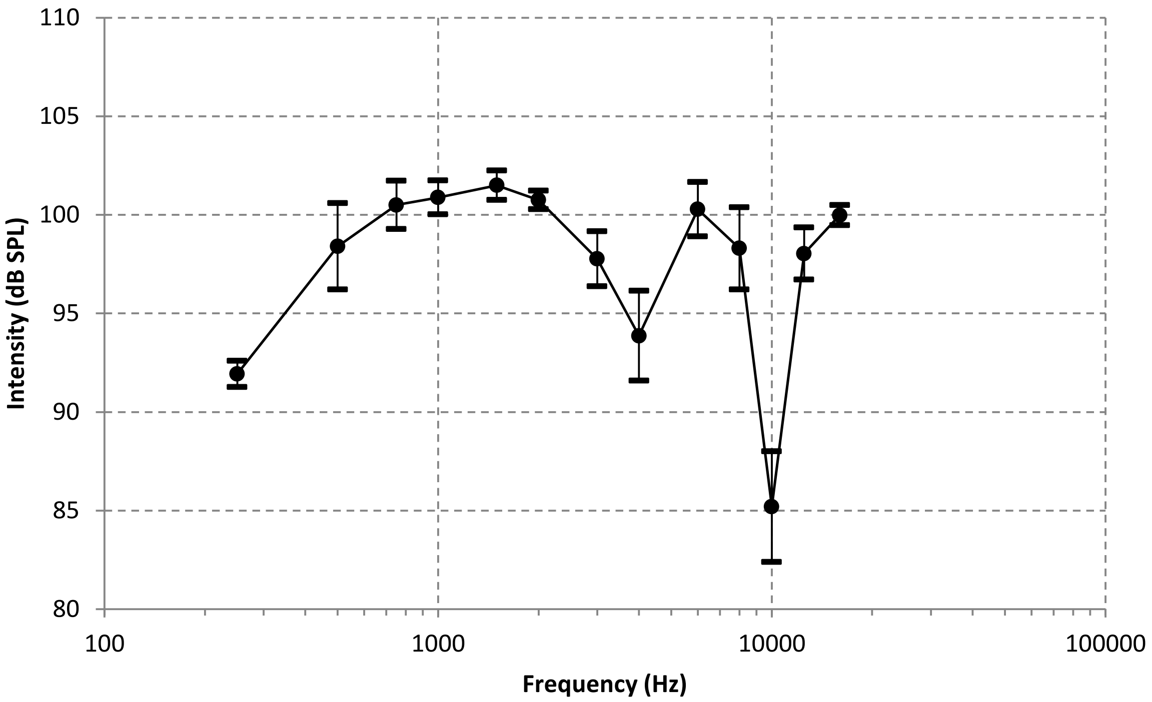

Figure 2. Mean frequency response across frequency spectrum (error bars = 1 SD)

CONCLUSION

The results of this study indicate that the Sennheiser HD 202 II supra-aural headphone can be used for screening audiometry adhering to requirements of a type four audiometer (IEC 60645-1:2012). It may therefore offer an affordable alternative for hearing screening purposes. The following four deductions from the study findings can ensure accurate hearing screening with the Sennheiser HD 202 II supra-aural headphone:

1. A quiet room is used for testing purposes considering the MPANL's for this headphone.
2. Specified ETSPL values (Table 5) must be used to calibrate test equipment.
3. The following frequencies (in Hz) can be tested accurately up to the according intensities (in dB HL): 250 (80), 500 (95), 750 (110), 1000 (110), 1500 (110), 2000 (105), 3000 (100), 4000 (90), 6000 (105), 8000 (100), 10,000 (105), 12,500 (95) and 16,000 Hz (70 dB HL).

It is important to keep in mind that this study is a first step towards prescribing a cost-effective headphone for screening audiometry. More independent validation is required before Reference ETSPL values can be established for standardization purposes. In order to officially establish ETSPL values separate testing must be done by two independent laboratories (Poulsen & Oakley, 2009). This headphone also does not comply with all requirements in IEC 60645-1(2001) for audiometrical diagnostic testing since the force of the headband is lower than desired and 125 Hz cannot be tested due to the THD which is too high.

4. Discussion and conclusion

4.1. Discussion of results

Permanent disabling hearing loss affects 5.3% of the global population (WHO, 2015). The vast majority of this population live in lower and lower-middle income countries where public healthcare is mostly unavailable (Fagan & Jacobs, 2009; Goulios & Patuzzi, 2008; WHO, 2015). Early identification of hearing loss is an essential requirement for ensuring optimal development in children (Moeller, 2000; Watkin et al., 2007). Newborn hearing screening should be a child's first exposure to hearing screening, but is not always accessible, especially in developing countries. The unavailability of newborn hearing screening increases the need for school-based hearing screening. Screening for hearing in school-aged children is important for negating the influence of an undetected hearing loss that may affect a child's academic performance and socio-emotional wellbeing (Arlinger, 2003; Fellinger, Holzinger, Gerich & Goldberg, 2007; Tesch Römer, 1996). In developed countries, such as the United Kingdom, close to 20% of permanent moderate or greater bilateral, mild bilateral and unilateral impairments are unidentified by the time of school entry (Bamford et al., 2007). In developing countries where there are no systematic newborn hearing screening programmes, this proportion is likely to be much higher (Swanepoel, Koekemoer & Clark, 2010). Due to the lack of newborn hearing screening programmes, school-based hearing screening often turns out to be the child's first point of access to hearing screening (Bamford et al., 2007).

Screening can also be conducted on adults, although there is substantial evidence that this is more of an exception than a rule (Yueh, Bogardus & Schekelle, 2003). If hearing screening is performed, up to 46% of screened adults are referred (Thodi et al., 2013). Despite this referral rate, hearing screening is not executed in an objective manner during the medical check-ups of adults (McCullagh & Frank, 2013). Hearing loss in adults can result in negative social, psychological and economical effects (ASHA, 1997). When a hearing loss is treated, the participant will be able to have a better quality of life. Identifying this hearing loss by hearing screening is the first step to increasing the participant's quality of life (Smith et al., 2011).

Hearing screening should be performed with a headphone complying with ISO 389-1 (1998), ISO 389-5 (2006) and ISO 389-9 (2009) standards, which results in the use of expensive audiometric headphones (for example TDH 39). The purpose of this study was to determine if an entry-level cost-effective Sennheiser HD 202 II headphone could be used as a screening headphone according to ISO 389-1 (1998), ISO 389-5 (2006), ISO 38-9 (2009) ISO 8253-1 (2010), ISO 8253-2 (2009), IEC 60318-1 (2009) and IEC 60645-1 (2012) standards. If this headphone complies with all the aforementioned standards, it could prove to be a cost-effective, easily accessible alternative to expensive audiometrical headphones.

The following results were found:

4.1.1. ETSPL values

ETSPL values are the values used to calibrate a headphone. In this way, it is possible to compare thresholds measured in dB HL to other measurements taken with other headphones. The ETSPL values make it possible to perform audiometry/screening accurately and compare the results with thresholds measured with different equipment.

No significant difference in results of the gender, ear, age or headphone was found in this study. Even though it is not regularly used for screening, there is a difference of 13.5 dB between the ETSPL value of the Sennheiser HD 202 II and the TDH 39 on 250 Hz. Using wrong ETSPL values may lead to misleading results and the false passing of hearing screening of hearing impaired participants.

ISO 389-9 prescribes a sample size of 25 subjects. Other studies by Poulsen (2013), for example, also use this sample size. This is the minimum required sample size; a larger sample size would make the statistical conclusions more feasible.

A similar study by Poulsen (2013) does not calibrate the Sennheiser HD 202 II headphones before measuring ETSPL values. ISO 389-9 (2009) does not indicate which method is correct. In this study, all headphones had the same initial calibration, making all results differ in steps of five decibels from this initial calibration. In order to compensate for this, it was decided to use the following procedure to determine ETSPL values: The mean threshold across participants tested with the same headphone (five headphones were used) was determined. Subsequently, the median of these five mean values represented the ETSPL values across frequencies. If the method prescribed by Poulsen (2013) was used, the results would have been more accurate.

4.1.2. Attenuation

The second study phase dealt with the attenuation and MPANLs (maximum permissive ambient noise levels) of the Sennheiser HD 202 II headphone and how it compares to other headphones. The attenuation measures how much noise the headphones can block out; the attenuation is directly related to the maximum permissible ambient noise levels. The MPANLs indicate how much background noise is allowed before the accuracy of thresholds are compromised.

The attenuation of the Sennheiser HD 202 II is high at 8000 Hz, but is low at 250 Hz compared to TDH 39 headphones. Only at 8000 Hz is this difference statistically significant ($p< 0{,}05$), making the attenuation of the Sennheiser HD 202 II significantly better than the attenuation of the TDH 39. The attenuation of the Sennheiser HD 202 II was on average 10,3 dB better than the attenuation of the TDH 39 across the frequencies ranging from 250 Hz to 8000 Hz.

There was no significant difference in attenuation between the Sennheiser HD 202 II measured in this study and the attenuation of the Sennheiser HDA 280 and the HD 380 measured by Poulsen ($p<0{,}05$) (Poulsen, 2010; Poulsen & Oakley, 2009). There was a significant difference in attenuation between the insert earphones and the Sennheiser HD 202 II measured in this study on the frequency range from 250 Hz to 3000 Hz ($p> 0{,}05$). The insert earphones had significantly better attenuation on the low frequencies.

The attenuation affects the MPANLs. The larger the attenuation, the larger the MPANLs are allowed to be per specific frequency. To ensure accurate testing, the environmental noise should not exceed the MPANLs. These values should be taken into account when testing a participant and interpreting the results. The Sennheiser HD 202 II does not have a significantly different attenuation compared to the TDH 39, therefore this headphone can be used in similar listening environments. Although the Sennheiser HD 202 II has a much lower cost price compared to the TDH 39 headphones, the attenuation is not significantly worse; it even better on 8000 Hz than that of the TDH 39. The TDH 39 is a headphone currently used for audiometrical purposes.

When a school health team performs hearing screening, the attenuation needs to be as high as possible as there is a lot of background noise in a school environment (Lebogang, 2007). Because of the high amount of background noise, it is advised that the tester performs screening in a room that is as quiet as possible and maintains awareness of the background noise.

4.1.3. Objective headphone characteristics

Objective headphone characteristics include three sub-sections, namely force of the headband, total harmonic distortion, and frequency response.

Force of the headband

The force of 5 different headbands of the Sennheiser HD 202 II was measured and the average was calculated. The average headband force is 3,1 N. This value was used throughout the research and the researcher made sure that the correct force was applied on the earphone.

ISO 389-9 (2009) prescribes that the force should be between four and five newton. The headband of the Sennheiser HD 202 II does not apply enough force. The main purpose of measuring the force of the headband is to ensure that enough attenuation is presented (Zannin & Gerges, 2006). As described, the headband of the Sennheiser HD 202 II produces adequate attenuation. Although the force of the headband is lower than prescribed, the attenuation is still high enough to ensure accurate testing.

Total harmonic distortion

Total harmonic distortion is measured in order to define how much unwanted noise is present on the harmonics of the fundamental frequency. When the total harmonic distortion is too high, the subject might hear the distorted signal on the harmonic and not the intended signal on the fundamental frequency. This will lead to misleading results during hearing screening.

In this study, the average THD on 70 dB HL and 90 dB HL, the average intensity where a THD closest to, but not exceeding 3%, and the maximum intensity where all earphones reached a THD lower than 3%, were measured. According to IEC 60645-1 (2012), a headphone should be able to reach 100 dB HL on the frequency range of 250 Hz to 8000 Hz in order to be used with a type 3 audiometer. A THD of more than 3% was measured on 500 Hz and 4000 Hz for the Sennheiser HD 202 II, resulting in the Sennheiser HD 202 II only being classified as a type four audiometer. In order to be used with a type four audiometer, the THD should not exceed 3% when an intensity of 70 dB HL is played on the frequency range of 500 Hz to 8000 Hz. The THD on 125 Hz exceeded 3% when testing 40 dB, therefore it was decided to exclude this frequency from the research.

The THD of the Sennheiser HD 202 II on 500 Hz and 4000 Hz restricts its use up to 100 dB. For screening purposes, the headphone should only be able to test up to 40 dB HL (ASHA, 1997). The Sennheiser HD 202 II can test up to 40 dB HL on all frequencies without interference of distortion. The Sennheiser HD 202 II can therefore only be used as a screening headphone and not as a diagnostic headphone (IEC 60645-1, 2012). The Sennheiser HD 202 II can be used as a screening headphone across the whole screening frequency spectrum.

Frequency response

To comply with the IEC 60645-1 (2012) standard, the output sound pressure level generated by a diagnostic headphone for a constant voltage should not differ with more than 4 dB from the average output for the frequency range from 250 Hz to 4 kHz. The output of the frequency range above 4 kHz should not differ with +4 dB and -11 dB from the average output. The Sennheiser HD 202 II complies with this standard.

4.2. Clinical implications and recommendations

The majority of South African newborns do not have access to newborn hearing screening (Meyer, Swanepoel, le Roux & van der Linde, 2012; Swanepoel, Störbeck & Friedland, 2009). As a consequence, school-based hearing screening is often the first opportunity to perform hearing screening (Mahomed-Asmail, Swanepoel & Eikelboom, 2016). Unfortunately, not all school health teams have access to the equipment required for hearing screening; in part due to the high cost of the equipment and due to limited accessibility (Wong, 2008).

Based on the results of this research, one can conclude that the Sennheiser HD 202 II headphone could be used as equipment for hearing screening. Sennheiser HD 202 II headphones are widely available and have a much lower cost price than traditional audiometrical headphones that are used for hearing screening. The Sennheiser HD 202 II headphone could present a low-cost and easily accessible alternative to the audiometrical headphones currently used for performing hearing screening.

The cost of screening equipment could decrease significantly by using low-cost headphones, especially if combined with other cost-effective equipment such as smartphone-based audiometry (Mahomed-Asmail, Swanepoel, Eikelboom, Myburgh & Hall, 2016). If the cost of screening equipment is reduced, more schools will be able to provide school-based hearing screening (McPherson, Law & Wong, 2010). If more schools are able to provide school-based hearing screening, more children with hearing loss will be identified at an earlier stage. Identifying hearing loss is of utmost importance, as the sooner children suffering from hearing disorders are identified and treated, the better they will perform in school (Picou, Ricketts & Hornsby, 2013).

The limitations of the Sennheiser HD 202 II should be taken into account when testing: The Sennheiser HD 202 II can only be used for screening purposes, as it does not comply with all the requirements for audiometrical headphones. Testing with these headphones requires the background noise to be minimized. School environments can be loud, making testing a challenge. It is recommended that tests are performed in a quiet room, away from disruptive sound sources. The values in this study are ETSPL's and not RETSPL's, meaning that the values are a starting point. In order for these ETSPL values to be standardized, another laboratory will have to perform similar research. Despite these aspects, the Sennheiser HD 202 II headphone does provide a cost-effective alternative for the audiometrical headphones currently used.

4.3. Critical evaluation

4.3.1. Strengths of the study

The testing procedure follows the procedure prescribed in ISO 389-9 (2009). This ensures accurate and reliable results (Grob, 2003). It makes comparing the Sennheiser HD 202 II headphone to the golden standard possible.

Participants were selected in such a way that they would comply with ISO 389-9 (2009). ISO 389-9 prescribes that 25 subjects, both male and female, between 18 and 25 years old should be tested. By performing an otoscopy and tympanometry, the subjects were ensured to be otologically normal. By doing this, the measured thresholds were sure to be normal. If their thresholds had not been normal, the ETSPL values would not have been reliable.

An audiometrical booth conforming to ISO 8253-1 (2010) was used to ensure that the MPANL's were not exceeded. If this booth would not have been used, ambient noise could have interrupted the results making the results values unreliable. The appropriate testing method was used to ensure that the subjects knew what was expected of them, resulting in accurate test results. Calibration of each headphone was performed according ISO 8253-1 (2010) standards, ensuring accurate measurements (Galagher, 2015).

It is uncommon for hearing screening to involve extended high frequency testing (American Academy of Audiology (AAA), 2011; American Speech-Language-Hearing Association, 1997; Integrated School Health Policy (ISHP), 2012), while extended high frequencies are important to localize sounds (Best et al., 2005), hold information used to understand speech (Rodríguez et al., 2009) and help to monitor ototoxic-induced hearing losses (Valiente, Berrocal, Fidalgo, Trinidad & Camacho, 2014). Determining the ETSPL values for the EHF's of the Sennheiser HD 202 II makes the headphone utilizable for these purposes. While the extended high frequencies hold important information (Best et al., 2005; Rodrìguez et al., 2009), they still remain overlooked in most studies. Because this study included the extended high frequencies, the Sennheiser HD 202 II has a wider range of possibilities when being used in the field.

The strength of this study lies in the procedure used. By following the specific ISO and IEC standards, accurate and reliable measurements were assured.

4.3.2. Limitations of study

25 subjects were tested; this number complies with the ISO 389-9 (2009) standard, however, a larger sample would have increased the power of the conclusion (Biau, Kernéis & Porcher, 2008).

A similar study by Poulsen (2013) used a different method to calculate the ETSPL values. In that study, the headphones were not calibrated beforehand. After establishing the thresholds of the participants, the intensity of the output by the headphones was measured. This leads to a bigger variety of the results. ISO 389-9 (2009) does not specify how the average of the ETSPL values should be calculated. If the procedure designed by Poulsen (2013) was used, the comparison between ETSPL values would have been more robust.

4.4. Future research

In this research, ETSPL values for the Sennheiser HD 202 II headphone have been established. Performing a similar analysis in another independent laboratory would allow the researcher to determine RETSPL values for the device. Once RETSPL values are available, the Sennheiser HD 202 II headphone could be seen as a cost-effective alternative headphone for screening purposes.

When performing hearing screening in the field, ideal testing conditions, as used in this research, are not necessarily met. The reliability of the Sennheiser HD 202 II headphone should be examined when being used in the field. This will make it possible to make a comparison with other headphones, such as the TDH 39.

Another possibility for further research is comparing referral rates of this headphone and the standard headphone when used in the field. If the referral rates are similar, this headphone will prove to be a cost-effective alternative ready to be used in the field.

4.5. Conclusion

The aim of this study was to research a possible cost-effective alternative headphone for screening purposes. Expensive audiometric headphones are currently used for screening. This cost-effective headphone could make screening more accessible. The Sennheiser HD 202 II does not comply with all requirements to be considered a diagnostic headphone. The Sennheiser HD 202 II could, however, be used as a cost-effective screening headphone when considering the following:

- The correct ETSPL values given in Table 5 are to be used in order to ensure accurate testing and comparability with results of different headphones.

- The maximum ambient noise levels should not be exceeded. If these values are exceeded, accurate results cannot be guaranteed. The purpose of hearing screening is to give an accurate first view of the possible hearing loss. Testing will preferably be done in an environment that is as silent as possible.

- Only the frequencies specified in this article from 250 Hz up to 16000 Hz could be tested, as other frequencies would need more research. 125 Hz was excluded based on the results from the THD.

The ETSPL values given in this article are only a starting point for establishing RESTPL values. More elaborate research should be done in order to ensure official RESTPL values for the Sennheiser HD 202 II headphone.

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6. Appendices

Appendix A: Ethical clearance form

Appendix B: Informed consent form

Appendix C: Questionnaire for hearing tests

Appendix A: Ethical clearance form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

14 October 2015

Dear Prof Vinck

Project:	**Affordable headphones for accessible screening audiometry: an evaluation of the Sennheiser HD202II Supra-Aural headphone**
Researcher:	**A van der Aerschot**
Supervisor:	**Prof DCD Swanepoel**
Department:	**Speech-Language pathology and Audiology**
Reference number:	**82308111 (GW20150815HS)**

Thank you for the response to the Committee's correspondence 1 September 2015.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 14 October 2015. 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.

The Committee requests you to convey this approval to the course coordinators.

We wish you success with the project.

Sincerely

Prof. Karen Harris
Acting Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: karen.harris@up.ac.za

Kindly note that your original signed approval certificate will be sent to your supervisor via the Head of Department. Please liaise with your supervisor.

Appendix B: Informed consent form

Date:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Dear Participant,

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

The current project aims to standardize a low-cost headphone (Sennheiser HD202 II supra aural headphones) for audiometric testing. The project entails determining the attenuation and reference equivalent threshold sound pressure levels for this supra aural headphone. Findings of this study will indicate the suitability of this headphone for audiometric testing. If found to be appropriate it will provide an inexpensive and modern alternative to existing audiometric headphones.

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:

- **Examination** of ear canal using an otoscopie
- **Tympanometry** will be done
- **Diagnostic testing of hearing** will be done with earphones. **All** participants will have their hearing tested twice (Sennheiser HD202 headphones and TDH 39 headphones)
- **The Attenuation** of the headphones will be tested
- **Results of the hearing screening** will be communicated to you verbally. In addition a **written report** and recommendations will be made available

Relevant information:

- Participants will be required to be between 18 and 25 years old. Residents with expected normal or normal hearing (Thresholds at 10 dB HL or less, except for 1 frequency with the maximum of 15 dB HL) may participate in the study
- There will be no charge for the tests
- Tests will be performed by a qualified audiologist
- Tests will be done at the department of Speech-Language Pathology and Audiology, University of Pretoria.
- Each participant’s hearing will be tested TWICE
- The attenuation of the headphones will be tested

- A test session should not exceed 40 minutes
- You have the right to withdraw from the study at any time
- All information will be treated as confidential. You will be assigned a code for data processing so as to protect your privacy
- None of the procedures are invasive or painful.

All data will be stored for 15 years at the department Speech-Language Pathology and Audiology, University of Pretoria for research and archiving purposes.

Should you wish to participate in this project please complete the ‘Informed Consent’ form provided.

For further information contact Prof Swanepoel at 012 4204280.

Sincerely

Professor De Wet Swanepoel

Principal Investigator

INFORMED CONSENT:

MY PARTICIPATION IN A HEARING SCREENING PROJECT

<u>Please complete the following:</u>

I ____________________________________, hereby confirm that I have read

the above-stated information on this hearing screening project.

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

Appendix C: Questionnaire for hearing tests

Questionnaire for hearing tests

1.	**Name:**	**Date of birth:**	**Gender:**
2.	**Have you ever had trouble with your hearing (for example, infections, ear noises, drainage, etc.?)**		
	Yes	No	If yes, please detail:
3.	**Have you ever had an operation in your ear?**		
	Yes	No	If yes, please detail:
4.	**Have you ever taken drugs, tablets or been given injections that affected your hearing?**		
	Yes	No	
5.	**Have you worked for several years in a place that was very noisy, i.e. where it was difficult to communicate?**		
	Yes	No	If yes, please detail:
6.	**Did you wear any hearing protector at that time?**		
	Yes	No	
7.	**Do you attend pop/rock concerts or discotheques?**		
	Never	Once a year	More than once a year
8.	**Do you play any musical instrument?**		
	Yes	No	If yes, please specify:
9.	**Do you listen to personal wearable players?**		
	Never	Less than 2 hours per week	More than 2 hours per week
10.	**Have you been exposed to any loud sounds from, e.g. motorbikes, chain-saws, gunfire, fire-crackers or explosions?**		
	Yes	No	If yes, what kind and how often:
11.	**Does/did anyone in your immediate family have a hearing disorder?**		
	Yes	No	If yes, please specify:
12.	**Have you ever had a hearing test before?**		
	Yes	No	If yes, when and where:
I agree to the storage of my data and their use in connection with the threshold measurements			
Date:		Signature:	

An answer YES to the following questions should be further explored and might lead to an exclusion from further testing, or results should be deleted from the material: 2, 3, 4, 5, 7 (more than once a year), 8 (rock band, symphony orchestra), 9 (more than 2 hours per week), 10, 11.