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

Van der Aerschot M. [1], Swanepoel D. W.[1,2,3,4], Mahomed-Asmail F.[1], Myburgh H.C.[5]
Eikelboom R. H.[1,2,3]

1. Department of Speech-Language Pathology and Audiology, University of Pretoria, Pretoria, South Africa

2. Ear Sciences Centre, School of Surgery, The University of Western Australia, Nedlands, Australia

3. Ear Science Institute Australia, Subiaco, Australia

4. Callier Center for Communication Disorders, University of Texas at Dallas, TX, USA

5. Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa

Address for correspondence:

Prof. De Wet Swanepoel

Adress: Department of Speech-Language Pathology and Audiology

University of Pretoria, South Africa, 0002

Email: dewet.swanepoel@up.ac.za

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 >3%.

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.

Keywords: supra-aural headphone, screening, calibration, ETSPL, attenuation, frequency response.

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 (Global Burden of Disease 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 remain to be 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., 2015a). 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 person’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), which 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 or without the flat plate 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 and without a flat plate. 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-parametic 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).

Results and discussion

The calibration variability of the Sennheiser HD 202 II with and without flat plate is represented in table 1. Whilst variability was very similar across calibration conditions. Excluding 250 Hz, the standard deviation for the acoustic coupler without the flat plate 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.

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 5 dB. Therefore median values for the Sennheiser HD 202 II differed in 5 dB steps. As a result ETSPL values were derived from measurements as follows: The mean threshold across participants tested with the same headphone (5 headphones were used) was

Table 1: Comparison of mean difference, standard deviation and maximum difference between repeated measurements with and without a flat plate (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

Table 2: Comparison of equivalent threshold sound pressure levels of the Sennheiser HD 202 II, TDH 39, Sennheiser HDA 280 and Interacoustics DD-45 headphones. An ear simulator conforming IEC 60318-1 with conical ring was used. (ISO 389-1, 1998; Poulsen, 2013; Poulsen, 2010)

Frequency (Hz)	Sennheiser HD 202 II	TDH 39	Sennheiser HDA 280	Interacoustics DD-45
250	13.5	27	23.5	26.5
500	11.5	13.5	13	13
750	10	9	4.5	6.5
1000	7	7.5	6.5	6
1500	9.5	7.5	9	8
2000	10.5	9	7.5	8.5
3000	9.5	11.5	8	7.5
4000	12	12	11.5	10.5
6000	20	16	22	21
8000	18.5	15.5	15	12.5

determined. Subsequently the median of these five mean values represented the ETSPL values across frequencies (table 2). 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) without the flat plate.

Table 3: 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
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
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
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
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
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
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

* All: all ears

Table 4: 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	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
left median	9.0	25.0	47.0
left mean	-9.6	-1.2	-3.2
SD	11.7	8.6	11.3
right median	14.0	25.0	52.0
right mean	-8.4	0.0	-0.4
SD	6.9	7.4	11.0
male median	14.0	25.0	52.0
male mean	14.0	23.3	51.8
SD	9.7	9.0	12.7
female median	14.0	25.0	47.0
female mean	16.1	25.6	48.5
SD	9.4	6.5	9.0
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
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

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 3 and table 4). 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.

This study was done on 25 participants with 5 different headphones meeting minimum requirements of the ISO 389-9 (2009) standard. A larger sample would ensure more reliable results and chances on measurement errors would be smaller.

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 according 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. 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.

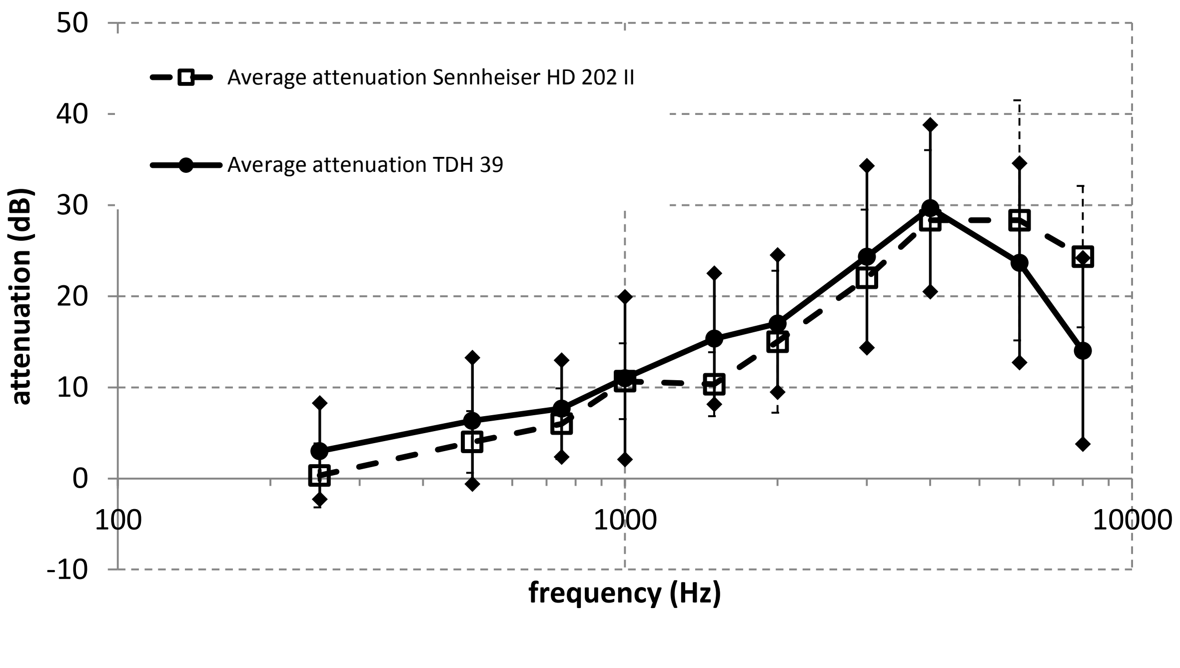

Figure 1. Mean attenuation across frequencies for the Sennheiser HD 202 II and the TDH 39 supra-aural headphones (error bars= 1 SD).

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 5) 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 5: Headphone attenuation and maximum permissible ambient sound pressure levels (MPANL) 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 both attenuations (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 HD 202 II for screening purposes (dB)	36.3	35.7	38.3	42.7	42.0	48.0	51.7	54.7	58.7	63.3

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 250 Hz 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 3% (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 4 audiometer) without having a total harmonic distortion of more than 3% across frequencies (Table 6). Based on output the Sennheiser HD 202 II supra-aural headphones comply with the intensity requirements for a type 4 audiometer (IEC 60645-1, 2012). 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 3% THD.

Table 6: 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 3%, and mean maximum intensity (dB HL) where all five headphones did not exceed 3% 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	95	110	110	110	105	100	90	105	100
Mean dB HL with THD <3% (SD)	90 (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 Sennheiser HD 202 II displays an upwards 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 upwards 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), with notches at 4000 and 10,000 Hz and a low, sloping frequency response at 250 Hz. 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.

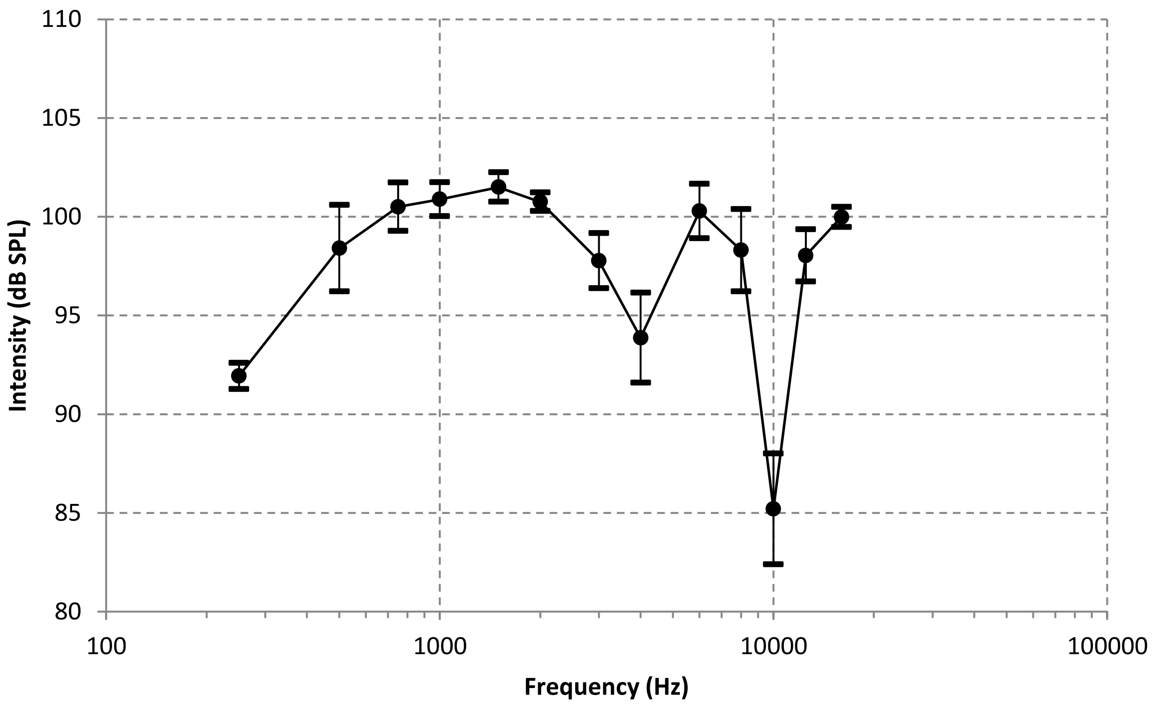

Figure 2. Mean frequency response across frequency spectrum (error bars = 1 SD)

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 4 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 2) 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).
4. Whilst this study is not definitive and requires replication by other laboratories, it establishes the Sennheiser HD 202 II as a potential low-cost audiometric screening headphone.

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. 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.

REFERENCES

American Speech-Language Hearing Association (ASHA). 1997. Guidelines for audiological screening. Rockville.

Arlinger, S. 2003. Negative consequences of uncorrected hearing loss—a review. *Int J Audiol*, 42, 17– S20.

Bamford, J., Fortnum, H., Bristow, K., Smith, J., Vamvakas, G., et al. 2007. Current practice, accuracy, effectiveness and cost-effectiveness of the school entry hearing screen. *Health Technol Assess,* 11, 1-168.

Chong Lo, A., McPherson, B. 2013. Hearing screening for school children: utility of noise-cancelling headphones*. BMC Ear Nose Throat Disord*, 13, 6.

Fagan, J., Jacobs, M. 2009. Survey of ENT services in Africa: need for a comprehensive intervention. *Glob Health Action,* 2, 10-17.

Fellinger, J., Holzinger, D., Gerich, J., Goldberg, D. 2007. Mental distress and quality of life in the hard of hearing*. Acta Psychiatr Scand,* 115, 243–245.

Global Burden of Disease 2013 (GBD). 2015. Global, regional, and national disability-adjusted life years (DALYs) for 306 diseases and injuries and healthy life expectancy

(HALE) for 188 countries, 1990–2013: A systematic analysis for the Global Burden of Disease Study 2013.

Goulios, H., Patuzzi, R. 2008. Audiology education and practice from an international perspective. *Int J Audiol*, 47, 647-664.

International Organization for Standardization 389-1 (ISO). 1998. Acoustics — Reference zero for the calibration of audiometric equipment — Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones. Geneva: ISO

International Organization for Standardization 389-5 (ISO). 2006. Acoustics — Reference zero for the calibration of audiometric equipment — Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz. Geneva: ISO.

International Organization for Standardization 389-9 (ISO). 2009. Acoustics – Reference zero for the calibration of audiometric equipment – Part 9: Preferred test conditions for the determination of reference hearing threshold levels. Geneva: ISO.

International Organization for Standardization 8253-1 (ISO). 2010. Acoustics - Audiometric test methods - Part 1: Basic pure tone air and bone conduction threshold audiometry. Geneva: ISO.

International Organization for Standardization 8253-2 (ISO). 2009. Acoustics -- Audiometric test methods - Part 2: Sound field audiometry with pure-tone and narrow-band test signals. Geneva: ISO.

International Electrical Commission 60318-1 (IEC). 2009. Electroacoustics - Simulators of human head and ear - Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones. Geneva: IEC.

International Electrical Commission 60645-1 (IEC). 2012. Electroacoustics – Audiometric equipment Part 1: Equipment for pure-tone audiometry. Geneva: IEC.

Mahomed-Asmail, F., Swanepoel, D., Eikelboom, R., Soer, M. 2015 a. Validity of automated threshold audiometry: a systematic review and meta-analysis. *Ear Hear,* 34, 745–752.

Mahomed-Asmail, F., Swanepoel, D., Eikelboom R., Myburgh, H., Hall J. 2015 b. Clinical validity of hearScreen(TM) smartphone hearing screening for school children. *Ear Hear*, Post Author Corrections. doi: 10.1097.

Moeller, M. 2000. Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics,* 106, 43-52.

Margolis, R., Madsen B. 2015. The acoustic test environment for hearing tests. *J Am Acad Audiol,* 26, 784-791.

Poulsen, T. 2010. Equivalent threshold sound pressure levels (ETSPL) for Interacoustics DD 45 supra-aural audiometric earphones. *Int J Audiol,* 49, 850–855.

Poulsen, T. 2013. Correction to Table 3, in: Equivalent threshold sound pressure levels (ETSPL) for Sennheiser HDA 280 supra-aural audiometric earphones in the frequency range 125 Hz to 8000 Hz. *Int J Audiol.* 53, 287- 288.

Rowan, D., & Pickering, R. 2011. Letter regarding two recent publications on interaural attenuation in the International Journal of Audiology. *Int J Audiol*. 50, 636-637.

Sennheiser, Personal communication, March 31, 2014.

Stelmachowicz, P., Pittman, A., Hoover, B., Lewis, D., Moeller, M. 2004. The Importance of High-Frequency Audibility in the Speech and Language Development of Children With Hearing Loss. Arch Otolaryngol Head Neck Surg. 130, 556-562

Swanepoel, D., Koekemoer, D., Clark, J. 2010. Intercontinental hearing assessment – a study in tele-audiology. *J Telemed Telecare,* 16, 248-252.

Swanepoel, D., Myburgh, H., Howe, D., Mahomed, F., Eikelboom, R. 2014. Smartphone hearing screening with integrated quality control and data management. *Int J Audiol,* 53, 841-849.

Swanepoel, D., Störbeck, C., Friedland, P. 2009. Early hearing detection and intervention in South Africa. *Int J Pediatr Otorhinolaryngol,* 73, 783–786.

Tesch-Römer, C. 1996. Psychological effects of hearing aid use in older adults. *J Gerontol B Psychol Sci Soc Sci,* 52, 127-138.

Watkin P., McCann D., Law C., Mullee M., Petrou S., et al.2007. Language ability in children with permanent hearing impairment: the influence of early management and family participation. *Pediatrics,* 120, 694-701.

World Health Organisation. 2015. WHO | Deafness and hearing loss. Retrieved from http://www.who.int/mediacentre/factsheets/fs300/en/

Yueh, B., Bogardus, S., Shekelle, P. 2003. Screening and management of adult hearing loss in primary care. *JAMA,* 289, 1976-1985.