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Reliability of digits-in-noise test using different digital devices, transducers and sound file types

A dissertation submitted in fulfilment of the requirements for the degree

MA AUDIOLOGY

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DECLARATION OF PLAGIARISM

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DEPARTMENT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY

DECLARATION

Full Name: Kyla Eichhorn

Student number: 14006422

Degree: MA (Audiology)

I declare that this research report is my original work. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements.

I understand what plagiarism is and I am aware of the University of Pretoria’s policy in this regard.

22/02/2018

SIGNATURE **DATE**

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ABSTRACT

Objective: This study evaluated the reliability of the digits-in-noise (DIN) test application across various low and high-end digital devices utilizing different transducers and sound file types.

Design: The study utilized a cross-sectional within-subject design.

Methods: The study consisted of two objectives. In the first objective, 40 normal hearing participants aged between 18 to 24 years (mean: 20; SD= 1.9) were recruited. Speech Reception Thresholds (SRTs) across Android smartphones (one low-end and one high-end smartphone), as well as an Android tablet coupled with different transducers (headphones and earphones) were compared. For the second objective, participants comprised of 12 normal-hearing females aged between 23 to 24 years (mean: 23, SD= 0.5). SRTs were compared across three different sound file types (OGG file, AAC file and MP3 file).

Results: There was no significant difference in the SRTs between electronic devices or transducers used ($p < 0.05$). Furthermore, between the different sound files used, the difference was also not significant ($p < 0.05$).

Conclusions: The DIN test is reliable when conducted across different electronic devices, regardless of the transducer or sound file type used. Therefore, the DIN test is clinically valid when downloaded and performed on Android devices despite the cost of the device thus offering greater usability in a variety of audiological contexts.

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LIST OF ABBREVIATIONS AND ACRONYMS

DAC	Digital to Analogue Converter
DIN	Digits-in-Noise
ISO	International Organisation for Standardisation
LMIC	Low-middle income countries
mHealth	Mobile Health
SD	Standard Deviation
SNR	Signal-to-Noise Ratio
SRT	Speech Reception Threshold
WHO	World Health Organization

KEYWORDS

Digits in Noise

Digital Devices

Transducers

Sound File Types

CHAPTER 1: INTRODUCTION

According to the World Health Organization (WHO, 2018), there are approximately 466 million individuals (6.1% of the world's population) living throughout the world with a permanent disabling hearing loss. This estimate is projected to rise to 630 million by 2030 and to over 900 million (or one in every ten people) by 2050 (WHO, 2018). Hearing loss is ranked the second most common contributor to the global burden of disease (Global Burden of Disease, 2016). Furthermore, with an exponentially growing population size and an increase in life expectancies throughout the world, hearing loss is an area of great concern.

Undetected and untreated hearing loss is associated with restricted socialization, isolation, depression, loneliness, anger, and a lack of self-confidence ultimately resulting in poor quality of life (Gopinath et al., 2011; Olusanya, Neumann & Saunders, 2014; Davis et al., 2016). Those affected by hearing loss are also more prone to cognitive impairments and an increased risk of dementia (Davis et al., 2016). These individuals also tend to experience higher stress levels in the workplace, higher unemployment rates and earlier retirement (Gopinath et al., 2011; Olusanya et al., 2014; Davis et al., 2016; WHO, 2018). The annual global economic cost associated with hearing loss is estimated to be $750 billion (WHO, 2018). Therefore, prevention, identification and treatment of hearing loss should be a global priority (Chadha, Cieza & Krug, 2018).

More than two-thirds of individuals with a hearing loss live in low-middle income countries (LMIC's) and despite the high prevalence, hearing health care services are mostly unavailable in these regions (Fagan & Jacobs, 2009; Mulwafu, Ensink, Kuper & Fagan, 2017; WHO, 2018). For every million people in sub-Saharan Africa, there is an average estimate of one audiologist (Fagan & Jacobs, 2009). Not only are audiological services scarce, they are also difficult for most to access, this is due to the spatial coverage of the public transport which is unreliable and often unaffordable (Fagan & Jacobs, 2009). The shortage of audiologists and otolaryngologists in these regions, lack of basic equipment, poor training facilities, and limited awareness of hearing healthcare are all factors contributing to limited access and accessibility to services (Mulwafu et al., 2017). While the audiogram conducted in a sound-treated booth is considered the gold standard for diagnosing a hearing loss, access is often limited by financial, geographic, and logistical barriers (Fagan & Jacobs, 2009; Windmill & Freeman, 2013; Mulwafu et al., 2017).

Barriers to accessing hearing healthcare are not only limited to LMIC's and are also evident in high-income countries, for example, remote rural regions (i.e. parts of Australia and Alaska) or even inner-city communities (Swanepoel et al., 2010). The USA sees demand for audiological services that is significantly greater than the capacity of professionals able to provide these services (Windmill & Freeman, 2013). Windmill and Freeman (2013) found that for audiological services to meet the demand of the USA population growth projected over the next 30 years, the number of individuals entering the field will have to increase by 50%. To address these statistics, a committee was established by The National Academies of Sciences, Engineering, and Medicine to evaluate the affordability and accessibility of hearing health care for adults in the US. Their report, published in 2016, recommends institutional, technological, and regulatory changes to aid consumers in obtaining and successfully utilizing affordable, high-quality services ("Hearing Health Care for Adults" 2016).

One promising avenue to address access issues, recommended in the report, is by utilizing connected technologies with the capability of employing telehealth ("Hearing Health Care for Adults" 2016). Telehealth offers opportunities for uniquely providing access to hearing health care services to underserved populations worldwide (Swanepoel et al, 2010; Swanepoel et al, 2014; Yousuf Hussein et al., 2015).

Mobile health (mHealth) is a category of telehealth that capitalizes on advances in mobile phone penetration and other technologies to promote, deliver and monitor health care services (Clark & Swanepoel, 2014). By the year 2020, access to smartphones is estimated to be 80% globally (The Economist, 2015). The growing penetration of personal digital devices means that smartphone apps, under two board categories of clinical (medically regulated) and consumer apps, could provide widespread access to hearing screening in high-income and LMIC's.

Clinical smartphone apps utilize equipment adhering to international calibration standards e.g. ISO and typically assess hearing sensitivity across tones of different frequencies (Bright & Pallawela, 2016). Clinical hearing assessment apps act as alternative audiometers for health care workers while providing the advantages of affordability and accessibility by being mobile with touchscreen functionality (Swanepoel et al., 2019). A study by Yousuf Hussein et al. (2015) demonstrated the effectiveness of these clinically validated tools by implementing them into community-based screening programs for children and adults in LMICs. Inexpensive, clinically certified Android-based test solutions with calibrated headphones were used (Yousuf Hussein et al., 2015). Tools, which are often not available on app stores.

Numerous consumer apps on Android and iOS platforms have been developed and show promising results for hearing health care. However, screening applications using pure tone audiometry-based tests such as uHear™ and EarTrumpet on iPhone and iPods demonstrate limited accuracy as equipment calibration is required and tests are not valid without standard Apple earphones (Bright & Pallawela, 2016). Other limitations to consider relating to the use of iOS-based devices pertains to the fact that they are premium products with poor penetration in LIMICs where the need for services is typically greatest (Swanepoel et al., 2014. Yousuf Hussein et al., 2015).

In contrast to pure tone audiometry, speech- based consumer apps have been found to be accurate across various digital devices and transducers as they do not require calibration (Smits et al., 2006; Potgieter et al., 2016). These tests determine what individuals with hearing loss find most challenging, comprehending speech in the presence of background noise, and are therefore considered to be more ecologically valid compared to pure tone audiometry (De Sousa et al. 2018; Swanepoel et al., 2019).

In 2016, a national speech-based smartphone hearing test app was launched in South Africa as "hearZA" and recently by WHO as "hearWHO" on Android and iOS platforms. The test uses three digits presented in speech- shaped background noise (Smits et al, 2004; Zokoll et al., 2012; Potgieter et al., 2016). The test will then measure the speech reception threshold (SRT), i.e. the signal-to-noise ratio (SNR) that corresponds to 50%

intelligibility (Smits & Houtgast, 2007). The mean SRT and speech recognition functions correspond to previous developed telephone-based digits-in-noise (DIN) tests (Potgieter et al., 2016).

To date, there is a shortage of research evidence ensuring reliability across devices, especially between high- and low-end devices. The study conducted by Potgieter et al. (2016), validated the DIN test on an Android smartphone platform with credible success. However, the study was limited by its use of only two types of low-end smartphone devices (one Samsung Trend and four Vodafone Smart Kicka's) and did not include other digital devices. Furthermore, transducer types were compared which included three intraconchal earphones accompanying a Vodaphone Smart Kicka, a Samsung Galaxy S4 mini and a Samsung Galaxy S5 and two supra-aural headphone types (Sennheiser HD 202 II headphone and a TDH 50-P audiometric headphone). These transducer types were found to have no significant difference in test results (Potgieter et al., 2016).

Moreover, mobile devices range from low- to high-end smartphones and tablets which have different digital to analogue converters (DAC's) that may influence the audio quality of the device as a whole. This implies that the results obtained may differ depending on the quality of the device's DAC, as well as the transducer type used to obtain test results. The DIN test is available for download on numerous digital devices in conjunction with being administered using different transducers and sound file types. The use of different sound files has not yet been investigated. As larger scale roll-outs of digital devices occur worldwide, it becomes essential to ensure the reliability across population-based consumer testing. Android is the most popular smartphone operating system worldwide who's devices tend to be cheaper and largely more available in LIMICs (Katariya, 2017). Therefore, the objective of this study is to investigate the reliability of the smartphone-based DIN test across various Android devices while furthering the research on the validity of transducer types and to determine the reliability of the DIN test across different sound file types.

CHAPTER 2: METHODOLOGY

2.1 Research aims

To determine the reliability of the DIN test using different digital devices, transducers and sound file types.

2.2 Research design

This study employed a cross-sectional within-subject, quasi-experimental research design which attempts to collect quantifiable or quantitative data with two or more variables (Leedy & Ormrod, 2010). Objective one of the research study design aimed to determine whether the DIN smartphone test app can be utilized reliably across numerous digital devices as well as comparing its reliability across transducers (using headphones versus earphones). Objective two of the study evaluated the DIN tests reliability when downloaded using various sound file types. A repeated measures design was followed to compare the SRT of three sound file types in objective two. The data yielded from this study is quantitative.

2.3 Research participants

As part of objective one of the study, 40 normal hearing participants with pure-tone thresholds ≤ 15dB HL at each octave frequency from 250 to 8000Hz participated. All participants were otologically normal, as assessed by the ISO 389-1 questionnaire (Appendix D) for otologically normal hearing (International Standards Organization [ISO] 389-1, 2017). All participants had no visual outer ear abnormalities and were confirmed to have no middle-ear abnormality on tympanometry (Type A tympanogram). Mean age of the participants was 20 years (1.9 SD) ranging from 18 to 24 years (90% female). Participants were first language English speaking or were highly proficient in English as self-reported on a rating scale of 1-10 (Potgieter et al., 2018). Only participants who rated English proficiency 7 and higher participated in the study.

For objective two of the study,12 normal-hearing female participants were recruited (pure-tone thresholds ≤ 15dB HL at each octave frequency from 250 to 8000Hz (ISO 389-1, 1998). Mean age of participants was 23 years (0.5 SD), ranging from 23 to 24 years. All participants of objective two adhered to the inclusion criteria indicated for objective one of the study.

Table 1 presents an overview of the participant selection criteria, the exclusion criteria, the participant sample size and the source of participants.

Table 1: Summary of criteria for participant participation

Participant Criteria	Description
Participant selection criteria	• Normal hearing (hearing thresholds between 0dB and 15dB HL at 250Hz-8000Hz in both ears). Pure-tone audiometry was conducted to ensure these participants met the criteria. • Otologically normal i.e. normal state of health and presented with no ear disease and obstructive wax in the ear canals and no history of excessive exposure to noise, potential ototoxic drugs or family history of hearing loss as determined by the International Organisation for Standardisation (ISO) 389-1 questionnaire (Appendix D) • Type A tympanograms in both ears. • Male or female participants. • Aged between 18 to 25 years old. • Participants were first language English speakers or proficient in English as a second language. This was self- determined by the participant by rating their proficiency on a scale on 1-10 on the DIN test app (Potgieter et al., 2018). Only those with a rating of 7 or higher were accepted for the study. The participants were required to read through the participant information letter and to sign the informed consent form (Appendix B) if they were willing to

	participate in the study. Only once informed consent had been obtained in writing from the participant, were they included in the study.
Exclusion criteria	• Below 18 year of age • Hearing thresholds above (worse than) 15dB HL at 250Hz-8000Hz in both ears • Non Type A tympanograms • Not English or proficient in English as a second language
Participant sample size ***Objective One:*** ***Objective Two:***	 40 participants 12 participants
Recruitment of participants	The participants were students recruited from the Department of Speech Language Pathology and Audiology at the University of Pretoria. Permission from the Director of Student Affairs to recruit participants had been obtained (Appendix A). Other participants included volunteers such as colleagues, acquaintances, family members and friends. All of whom were required to provide informed consent (Appendix B) before the commencement of the study.

2.4 Research Equipment and Apparatus

2.4.1 Equipment for participant selection and data collection

Table 2 provides a detailed summary of all the equipment that was utilized in both objectives one and two of this study.

Table 2: Summary of equipment used in the study

Test	Equipment	Purpose
ISO Questionnaire	ISO 389-1 questionnaire for otologically normal hearing	To determine if participants met the otological normal candidacy requirements of the study
Otoscopy	Welch Allyn PocketScope Otoscope 22891	To examine the external auditory meatus bilaterally to detect any abnormalities in the ear canal
Tympanometry	226-Hz probe tone (GSI Tympstar, Grason-Stadler) tympanometer	To determine the status of the participants middle ear
Pure-tone audiometry	Grason-stadler GSI 61 Clinical Audiometer	To determine the hearing sensitivity of the participants
Digits-in-Noise test	-Samsung Galaxy S4 GT-19505 smartphone (High-end) -Samsung Galaxy Trend NEO smartphone (Low-end) -Samsung Galaxy Tablet 3Lite SM-T116 -Intraconchal earphones accompanying an entry-level smartphone (Samsung Fame Lite) -Supra-aural Sennheiser HD202 II headphones (Sennheiser, Wedemark, Germany) - Acer Intel iCore laptop using Supra-aural Sennheiser HDA 280 headphones (Sennheiser, Wedemark, Germany)	Used to determine the SRT’s of each participant and rate their proficiency in English on a scale of 1-10 (Potgieter et al., 2018).

2.5 Research Procedures

Participant selection criteria was based on the hearing status of the individual (refer to Table 1 for selection criteria). Written consent from the Director of Student Affairs at the University of Pretoria (Appendix A) had been granted in order to recruit participants. Participants were required to read the participant information letter and provide informed consent (Appendix B) before any data collection would take place.

In order to achieve the research aim of objective one of the study, the research procedure consisted of two separate testing days. This was to balance out any training or fatigue effect across tests. Four DIN test conditions were conducted on the first test day with the remaining two DIN test conditions conducted on the second test day. Both testing days of objective one were conducted 5-10 days apart.

The first testing day of objective one included the ISO 389-1 questionnaire, otoscopy, tympanometry and pure tone audiometry in order to determine if participants met the candidacy criteria.

For objective two of the study, pure tone audiometry conducted in a sound-treated booth was used to determine the hearing thresholds of the participants. Using the Acer Intel iCore laptop coupled to Supra-aural Sennheiser HDA 280 headphones (Sennheiser, Wedemark, Germany), the DIN test was conducted by each participant three times. Each time using a different sound file type (OGG file, AAC file and an MP3 file).

2.5.1 Objective I - Reliability of DIN across digital devices and transducers

Objective 1 consisted of:

- ISO 389-1 questionnaire for otologically normal hearing individuals (Appendix D)
- Otoscopy
- Tympanometry
- Pure tone audiometry
- DIN smartphone test application.

The ISO 389-1 questionnaire (Appendix D), was used to determine whether otologically normal candidacy criteria is met i.e. normal state of health and presents with no signs and symptoms of ear disease, obstructing wax in the ear canals and no history of excessive exposure to noise, potential ototoxic drugs or family history of hearing loss.

An otoscopic examination was performed in order to examine the external auditory meatus bilaterally to detect any abnormalities in the ear canal.

Tympanometry was performed to determine the overall functioning of the middle ear. Results were documented as Type A or non-type A tympanogram on the data collection sheet (Appendix C). To meet the candidacy criteria results needed to indicate Type A tympanograms in both ears. This requires ear canal volume to be between 0.8 – 2.0 ml, compliance between 0.3ml – 1.8ml and middle ear pressure between -100 daPa to +50 daPa (Stach, 2010).

Pure tone audiometry was used to determine the hearing thresholds of the participants between 250-8000Hz. The modified Hughson– Westlake method was used to seek pure-tone air thresholds (Hughson & Westlake, 1944). Air conduction testing involves pure tones that are presented through headphones to the participant in a sound-proof booth at different frequencies and intensity levels. Each participant received clear instructions that they need to press the response button whenever the stimulus is heard through the headphones. The intensity of the sound in dB HL will decrease at each specific frequency until a threshold is obtained.

Participants that presented with a hearing loss (thresholds >15dBHL) or non-Type A tympanograms were to be referred to the Department of Speech Therapy and Audiology at the University of Pretoria for further investigation.

The DIN test is a smartphone-based speech-in-noise test that measures the signal-to-noise ratio; this is where the listener recognizes 50% of digit triplets correctly in the presence of background noise. This test involves listening and identifying three digits (which are selected randomly from 120 unique digit triplets) in the presence of background noise. Based on the participants' selected intensity, the first digit triplet is presented. If the response was correct, the initial three steps decreased by 4dB SNR, followed by a 2dB adaptive procedure for the remaining 20 steps. If the response was incorrect, the SNR increased by 2dB. The SRT is then calculated as an average of the last 19 responses of each of the 23-digit triplets presented during the test (Potgieter, et al., 2016; Potgieter, et al., 2018). A binaural antiphasic stimulus paradigm was used for this objective of the study using a 180-degree phase shift for the speech signal presented to the ears (De Sousa et al., 2019).

The first four conditions carried out on the first test day (in which order was counterbalanced through a Latin square) included the high-end smartphone (Samsung Galaxy S4) and headphones (Supra-aural Sennheiser HD202 II headphones), the high-end smartphone (Samsung Galaxy S4) and earphones (intraconchal earphones accompanying a Samsung Fame Lite) followed by the low-end smartphone (Samsung Galaxy Trend NEO) and headphones (Supra-aural Sennheiser HD202 II headphones) and then the low-end smartphone (Samsung Galaxy Trend NEO) and earphones (Samsung Fame Lite earphones).

The remaining two test conditions, carried out on the second test day (5-10 days later), consisted of the tablet (Samsung Galaxy Tablet 3Lite SM-T116) and headphones (Supra-aural Sennheiser HD202 II headphones), and then the tablet (Samsung Galaxy Tablet 3Lite SM-T116) with earphones (Samsung Fame Lite earphones).

2.5.2 Objective II - Reliability of the DIN across sound file types.

The purpose of objective two was to determine if different sound files would differentially affect the DIN test results. The DIN smartphone application was conducted on an Acer Intel iCore laptop using Supra-aural Sennheiser HDA 280 headphones (Sennheiser, Wedemark, Germany).

Pure tone audiometry conducted in a sound-treated booth was used to determine the hearing thresholds of the participants. The modified Hughson– Westlake method was used to obtain participants pure tone air conduction thresholds (Hughson & Westlake

1944). The test, performed in a sound-proof booth, was conducted three times each on a different sound file type.

The conditions are listed as follows:

- C1- OGG File (OGG files stream and alter high-quality digital multimedia files)
- C2-AAC File (AAC files produce better audio quality then MP3 but not OGG)
- C3-MP3 File (MP3 files produce poorer sound quality compared to AAC and OGG files and take up more physical space compare to the above two)

The DIN test then measured the SRT for each participant for each sound file. The DIN were presented using binaural in-phase stimuli for this objective of the study.

2.6 Ethical considerations

It is imperative for ethical considerations to be addressed in order to protect the rights and welfare of the participants involved in the study (Leedy & Ormrod, 2010). Ethical clearance was obtained from the Research Ethics Committee of the Faculty of Humanities, at the University of Pretoria (Appendix E).

Consent

The participants in a study should be informed of the nature of the study as well as their level of involvement in the study (Leedy & Omrod, 2010). Written informed consent was obtained from all research participants before the commencement of any tests (Appendix B). In addition, participants were made aware that participation was voluntary, and that they could withdraw from the study at any time.

Permission to use students as participants for this study had been obtained from the Director of Student Affairs at the University of Pretoria (Appendix A).

Risks and safety

The risks involved in participating in a study should not be greater than the normal risks of one's everyday living (Leedy & Ormrod, 2010). There were no risks involved in participating in the study. By reading through the informed consent form (Appendix

B) participants were made aware that this study does not entail any medical risks or discomforts.

Sharing of results

Results obtained from this research study will be shared in the form of a scientific article and dissertation, which will be made available to the professionals in the field of Audiology.

Data storage

Data will be stored at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for 15 years for research and archiving purposes.

Anticipated benefits

The participants of this study did not benefit directly from the study but the results have helped researchers determine the reliability of the DIN test across various digital devices thus confirming its validity as a tool for the detection of hearing loss. However, participants may have benefited from this study by obtaining a free hearing evaluation.

Confidentiality

The participants of this study were informed that all of the information gathered will be kept confidential. According to Leedy and Omrod (2010), the privacy of participants should be respected. Anonymity was ensured by providing each participant with an alpha-numerical number during data collection. During data collection and statistical analysis, no identifying information of the participants was used. As a result, participants will not be identifiable. This was explained to the participants verbally and is noted in the participant information letter.

2.7 Data analysis

Data analyses was performed using SPSS (IBM SPSS v25.0; Armonk New York). Results were entered into a data-capturing sheet for statistical analysis. Descriptive statistical measures were used to analyse the mean, minimum and maximum values of the SRT's obtained on the various digital devices when using headphones and earphones. The effect of technology type (digital device) and headset type (transducer used) on the SRT was assessed using a two-way repeated measure analysis of variance (ANOVA). Post hoc comparisons (p>0.05) used Bonferroni adjustment for multiple comparisons. The Wilcoxon Signed Rank test was used to compare data between the OGG, ACC and MP3 sound files to assess whether their SRT's mean ranks differed.

CHAPTER 3: RESEARCH ARTICLE

Reliability of the digits-in-noise test using different digital devices, transducers and sound file types

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3.1 Abstract

Purpose: Hearing screening for consumers on smartphones using digits-in-noise tests are becoming widespread. This study evaluated the reliability of the antiphasic digits-in-noise (DIN) test using different quality digital devices, transducers and sound file types.

Method: The study had two objectives utilizing a cross-sectional within-subject design. The first objective evaluated speech reception thresholds (SRTs) determined with the antiphasic DIN test using low- and high-end digital devices (smartphones and tablet) coupled with different transducers (headphones and earphones). Forty normal hearing participants between 18 to 24 years of age (mean 20.7; SD 1.9) participated in this objective. The second objective compared DIN SRTs determined using different sound file types (OGG file, AAC file and MP3 file) in 12 normal-hearing young females (mean age 20.3 years; SD 0.5).

Results: There was no significant difference in SRTs between digital devices or transducers ($p < 0.05$). Sound files type also demonstrated no significant difference in SRTs ($p < 0.05$).

Conclusions: The DIN test is reliable across a range of different digital devices, transducer and sound file types. DIN tests on digital platforms can therefore provide reliable hearing screening to consumers.

3.2 Introduction

An estimated 466 million people throughout the world live with a permanent disabling hearing loss (WHO, 2018). Undetected and untreated hearing loss is associated with restricted socialization, isolation, depression, loneliness, anger, and a lack of self-confidence ultimately resulting in a poor quality of life (Gopinath et al., 2011; Olusanya, Neumann & Saunders, 2014; Davis et al., 2016). Those affected by hearing loss are more prone to cognitive impairments and an increased risk of dementia (Davis et al., 2016). These individuals also tend to experience higher stress levels in the workplace, higher unemployment rates and earlier retirement (Gopinath et al., 2011; Olusanya et al., 2014; Davis et al., 2016; WHO, 2018). The annual global economic cost associated with hearing loss is estimated to be $750 billion (WHO, 2018). Therefore, prevention, identification and treatment of hearing loss has been identified as a global imperative (Chadha, Cieza & Krug, 2018).

Early detection of hearing loss can potentially negate or reduce many of these negative effects (Wilson, Tucci, Merson & O'Donoghue, 2017; Chadha, Cieza & Krug, 2018). One promising early identification solution would be to harness the opportunities in eHealth to increase access to hearing care to underserved populations (Swanepoel et al, 2010; Swanepoel et al, 2014; Yousuf Hussein et al., 2015). Mobile health (mHealth), a sub-category of eHealth, capitalizes on advances in mobile phone penetration and other technologies to promote, deliver and monitor health care services (Clark & Swanepoel, 2014; Yousuf Hussein et al., 2015). By the year 2020, adult smartphone ownership is estimated to be 80% globally (The Economist, 2015). The growing penetration of personal digital devices means that smartphone-based consumer hearing tests could provide widespread access to screening across different socio-economic strata (Potgieter et al., 2016; De Sousa et al., 2018; Swanepoel et al., In Press).

Speech-based consumer smartphone applications using digits-in-noise (DIN) testing are proving to be successful with widespread uptake (Potgieter et al. 2018; Swanepoel et al., In Press). These tests assess an individual’s ability to recognize speech in noise, a task persons with hearing loss find most challenging, making it a more ecologically valid test than traditional pure tone audiometry (Smits, Merkus & Houtgast, 2006;

Potgieter et al., 2016; Swanepoel et al., In Press). Many countries including the Netherlands, US, Australia and Germany originally offered landline telephone versions of the DIN test (Smits et al, 2004; Jansen, Luts, Wagener, Frachet & Wouters, 2010; Watson, Kidd, Miller, Smits & Humes, 2012; Zokoll et al., 2012; Potgieter et al., 2016) as national screening tests. In 2016, the national hearing test of South Africa, hearZA, was launched as the first national smartphone DIN test (Potgieter et al., 2016; Potgieter et al. 2018; De Sousa et al. 2018). These self-administered tests use three random digits presented in speech-shaped background noise (Smits et al, 2004; Jansen et al, 2010; Watson et al, 2012; Zokoll et al., 2012; Potgieter et al., 2016). The test determines the speech reception threshold (SRT), i.e. the signal-to-noise ratio (SNR) that corresponds to 50% intelligibility (Smits & Houtgast, 2007).

More recently an improved DIN stimulus using antiphasic stimuli presented binaurally has demonstrated its sensitivity as a screening tool that can identify sensorineural, conductive, and asymmetrical hearing losses in under 3 minutes (De Sousa et al., 2018; De Sousa et al., In Press; Swanepoel et al., In Press). The antiphasic DIN test uses speech that has a 180° phase shift between the ears. Harnessing the advantages of the antiphasic DIN test paradigm the WHO recently released the hearWHO application for iOS and Android to increase hearing health care access globally (Swanepoel et al., In Press).

The DIN test can be downloaded on numerous digital devices in conjunction with being administered using different transducers and sound file types. While this may aid in enhancing the widespread use and uptake of the DIN test it remains possible that using various digital platforms, transducers and sound file types may influence the reliability of the DIN test for consumer testing. To date, there is limited evidence on the reliability across devices, especially between high and low-end consumer devices. Potgieter et al. (2016) evaluated the DIN test on a limited number of smartphones and transducers which demonstrated no significant difference on within-subject test performance (Potgieter et al., 2016). Digital devices employing a range of different quality digital to analogue converters could potentially influence sound quality in addition to different transducer types. Different sound file types used across mobile platforms (e.g. iOS and Android) may also potentially influence test reliability. This study, therefore, evaluated a range of digital devices (lower- to higher-end) with different transducers and digital sound files to determine the reliability of the DIN test as a consumer hearing screening option.

3.3 Materials and methods

The present study was approved and conducted following institutional board review (reference: GW20180120HS). The research followed a comparative within-subject-study design with two objectives. Firstly, to evaluate the reliability of the antiphasic DIN test across devices and transducers and secondly to evaluate the reliability of the test across sound file types.

3.3.1 Participants

Objective 1 –Reliability of the DIN test across digital devices and transducers

Forty normal hearing participants with pure-tone thresholds ≤ 15dB HL at each octave frequency from 250 to 8000Hz participated in the study. All participants were otologically normal, as assessed by the ISO 389-1 checklist for otologally normal hearing (International Standards Organization [ISO] 389-1:2017). All participants had no visual outer ear abnormalities and were confirmed to have no middle-ear abnormality on tympanometry (type A tympanogram). Mean age of the participants was 20.7 years (1.9 SD) ranging from 18 to 24 years (90% female). Participants were first language English speaking or were very proficient in English as self-reported on a rating scale of 1-10 (Potgieter et al., 2018). Only participants who rated their English proficiency 7 and higher participated in the study.

Objective 2 – Reliability of the DIN test across sound file types

Twelve normal-hearing female participants were recruited (pure-tone thresholds ≤ 15dB HL at each octave frequency from 250 to 8000Hz (ISO 389-1, 2017). Mean age of participants was 20.3 years (0.5 SD), ranging from 23 to 24 and adhered to the same inclusion criteria specified for objective 1.

3.3.2 Equipment

Hearing screening

The ISO 389-1 checklist for otologically normal hearing individuals was utilised to determine whether otologically normal candidacy criteria was met i.e. normal state of health and presents with no signs and symptoms of ear disease, obstructing wax in the ear canals and no history of excessive exposure to noise, potential ototoxic drugs or family history of hearing loss.

A Welch Allyn PocketScope Otoscope 22891 was used to examine the external auditory meatus bilaterally to detect any abnormalities in the ear canal. A GSI Tympstar, Grasen-Stadler using a 226Hz probe tone was used to conduct tympanometry.

Audiometry was conducted using the Grason-Stadler GSI 61 clinical audiometer calibrated annually and utilizing Telephonics TDH-50P audiometric earphones. Testing was conducted in a sound booth, frequencies tested included 250-8000Hz. The modified Hughson– Westlake method was used to seek pure-tone air thresholds (Hughson & Westlake 1944).

Digits-in-noise

As part of objective 1 of the study the South African English DIN test (Potgieter et al. 2016; Potgieter et al. 2018) was conducted on a Samsung Galaxy S4 smartphone (high-end smartphone >$500), a Samsung Galaxy Trend NEO smartphone (low-end smartphone under $80) and a Tablet (Samsung Galaxy Tablet 3Lite SM-T116). The antiphasic DIN was performed on all three digital devices using Supra-aural Sennheiser HD202 II headphones (Sennheiser, Wedemark, Germany) as well as intraconchal earphones accompanying an entry-level smartphone (Samsung Fame Lite). Data was collected using an Android OS application loaded onto the smartphones and tablet.

For objective 2 of the study, the DIN smartphone application was conducted on a laptop (Acer Intel iCore laptop) using Supra-aural Sennheiser HDA 280 headphones (Sennheiser, Wedemark, Germany). The DIN test was performed using OGG, ACC and MP3 sound files for the speech and noise signals presented diotically. OGG is a free, open container format created under unrestricted software patents by the Xiph.Org Foundation (Ogg Vorbis). It allows users to stream and alter high-quality digital multimedia files. AAC stands for either MPEG2/MPEG4 Advanced Audio Coding. AAC can produce better audio quality than MP3 using less physical space for the files. MP3 stands for MPEG1 (or MPEG2) Audio Layer III. Files encoded in MP3 have a quality very similar to that of the CD audio tracks but are much smaller in size.

3.3.3 Procedures

Objective 1 –Reliability of the DIN across digital devices and transducers

Research procedures consisted of two testing days that took place between 5 to 10 days apart. All participant selection criteria screening took place on the first test day. The six test conditions were separated so that four conditions were carried out on the first test day, while the remaining two conditions were carried out on the second test day. Each condition, regardless of which week it was conducted in, was randomized according to a Latin Square. Tests were conducted on separate days to reduce any fatigue effects. All six test conditions were performed in a soundproof booth.

Before the digit triplets were presented, the participant was instructed to select a comfortable listening intensity. Based on the participants' selected intensity, the first digit triplet is presented. If the response was correct, the initial three steps decreased by 4dB SNR, followed by a 2dB adaptive procedure for the remaining 20 steps. If the response was incorrect, the SNR increased by 2dB. The SRT is then calculated as an average of the last 19 responses of each of the 23-digit triplets presented during the test (De Sousa et al., In Press; Potgieter, et al., 2016; Potgieter, et al., 2018). A binaural antiphasic stimulus paradigm was used for this objective of the study using a 180-degree phase shift for the speech signal presented to the ears (De Sousa et al., In Press).

The first four conditions were conducted on the first day and the last two conditions were conducted on a second day. Test conditions included the 1) high-end smartphone (Samsung Galaxy S4) and headphones (Supra-aural Sennheiser HD202 II); 2) high-end smartphone (Samsung Galaxy S4) and intraconchal earphones

(Samsung Fame Lite); 3) low-end smartphone (Samsung Galaxy Trend NEO) and headphones (Supra-aural Sennheiser HD202 II); 4) low-end smartphone (Samsung Galaxy Trend NEO) and intraconchal earphones (Samsung Fame Lite); 5) tablet (Samsung Galaxy Tablet 3Lite SM-T116) and headphones (Supra-aural Sennheiser HD202 II) and; 6) tablet (Samsung Galaxy Tablet 3Lite SM-T116) with intraconchal earphones (Samsung Fame Lite).

Objective 2 – Reliability of the DIN across sound file types

Three repetitions of the DIN test were conducted in random order using a different sound file type (OGG file, AAC file and on an MP3 file) presented in a counter-balanced test order within each subject. Before the digit triplets were presented, the participant was instructed to select a comfortable listening intensity. Based on the participants' selected intensity, the first digit triplet is presented. A 2dB adaptive procedure increasing or decreasing the SNR based on correct or incorrect responses was conducted for 23-digit triplets presented. The SRT is calculated as an average of the last 19 responses (Potgieter, et al., 2016; Potgieter, et al., 2018). A binaural diotic stimulus paradigm was used for this objective.

3.3.4 Data analysis

Statistical analysis was conducted using SPSS (IBM SPSS v25.0; Armonk New York). Descriptive statistical measures were used to analyse the mean, minimum and maximum values of the SRT's obtained on the various digital devices when using headphones and earphones. The effect of technology type and transducer type on the SRT was assessed using a two-way repeated measures analysis of variance (ANOVA). Post hoc comparisons used Bonferroni adjustment for multiple comparisons. The Wilcoxon Signed Rank test was used to compare data between the OGG, ACC and MP3 sound files to assess whether SRT means ranks differed.

3.4 Results

Objective 1 – Reliability of the DIN test across digital devices and transducers

SRTs across device and transducer combinations (Table 1) revealed the highest average SRT to be -19.2 dB (low-end smartphone and headphone condition) compared to -19.7 dB for the lowest SRT (tablet and earphone condition).

A two-way repeated measures analysis of variance (ANOVA) was conducted with the type of technology and transducer indicated as within subject factors. The main effect for technology $F[2,78]= 1.718$, $p = 0.186$) and transducer type ($F[1,39]=0.013$, $p=0.91$) was not significant. Post hoc analysis revealed no significant differences between any technology or transducer type ($p>0.05$). Furthermore, there was no significant interaction between types of technology and transducer ($F[2,78]=0.632$, $p=0.534$).

Table 1. Distribution of speech recognition thresholds (dB SNR) across the various digital devices and transducers (n=40)

Device and transducer	Mean	SD	Minimum	Maximum
HE smartphone and headphones	-19.5	1.1	-21.7	-17.2
HE smartphone and earphones	-19.3	1.4	-21.8	-16.2
LE smartphone and headphones	-19.3	1.1	-21.7	-15.6
LE smartphone and earphones	-19.2	1.6	-21.8	-16.2
Tablet and headphones	-19.5	1.1	-21.2	-16.6
Tablet and earphones	-19.7	1.4	-22.5	-16.2

HE smartphone= High-end Samsung Galaxy S4; LE smartphone= Low-end Samsung Galaxy Trend NEO; Headphones= Supra-aural Sennheiser HD202 II headphones; Earphones= Samsung Fame Lite earphones; Tablet= Samsung Galaxy Tablet 3Lite SM-T116; SD= Standard Deviation

Objective 2 – Reliability of the DIN across sound file types

SRT's were averaged across the different sound file types (Table 2). The highest average SRT was (-10.9 dB) for the ACC and MP3 sound files and the lowest average SRT (-11.1 dB) for the OGG sound file.

A Wilcoxon signed rank test indicated no significant median difference in SRT between MP3 and AAC ($z=-0.476$, $p=0.634$), MP3 and OGG ($z=0.000$, $p=1.000$) and ACC and OGG ($z=-0.664$, $p=0.507$).

Table 2. Distribution of speech recognition thresholds (dB SNR) across the three sound file types (n=12)

Sound File Type	Mean	SD	Minimum	Maximum
OGG	-11.1	0.7	-12.4	-9
AAC	-10.9	0.8	-12.4	-9,6
MP3	-10.9	0.9	-12.4	-9,2

SD= Standard Deviation

3.5 Discussion

The reliability of the DIN test was consistent across the various combinations of a device (low and high-end) and transducer (headphones and earphones) types with no statistically significant difference in performance. Furthermore, digital sound file types of different quality also demonstrated no significant effect on test performance.

Intraconchal earphones accompanying an entry-level smartphone (Samsung Fame Lite) compared to higher quality supra-aural headphones (Sennheiser HD202 II) used on a combination of digital devices did not have a significant effect on SRT outcomes using the antiphasic DIN test. This corresponds to initial findings by Potgieter et al. (2016) using the diotic DIN test to determine the effect of transducers on the DIN test. The DIN test, which was reliable across a range of digital devices and transducers, was therefore launched as a downloadable test with widespread consumer uptake (Potgieter et al., 2016; De Sousa et al., 2018; De Sousa et al., In Press; Swanepoel et al., In Press). Comparing performance across very low- (<$80) and high-cost (>$500) devices provides a representative range of assessment in terms of quality.

The sound file size is an important consideration in the development of smartphone applications since it can influence the number of downloads, uninstalls and whether downloads will be restricted to users with WIFI access (Brus Media, 2013). Smaller file sizes can positively affect the cost of downloading an application, particularly important in low-and-middle income countries where internet access is limited, and the cost of mobile data is twice that of developed world regions (International Telecommunication Union, 2017). Different sound file types, including high fidelity large file sizes (e.g. OGG) and compressed file types (ACC and MP3), had no significant effect on DIN test performance. The advantage of conducting DIN tests on digital devices as opposed to landline or cellular lines is the digital signal quality that allows for diagnostic quality SRT testing (Potgieter et al. 2018; Potgieter et al. 2019). These findings support the use of different file types across device platforms and the use of compressed file types for more efficiency in terms of app size.

In a field where technological advances and new versions of electronic devices are continually emerging there is always a possibility that an aberrant result could be obtained from some type of device. Therefore, an apparent limitation to consider is that a finite combination of digital devices and transducers were used in this study. However, this study attempted to employ a range of device quality, transducer types and combinations of these. Moreover, since no significant differences were observed in any of these setups it is reasonable to assume consistency across electronic devices and transducers sufficient for a consumer-based screening test.

Furthermore, all tests were performed exclusively on Android devices. The research application was only available on the Android platform and thus iOS platforms were not part of this study. Future investigations should include iOs platforms.

3.6 Conclusion

Different device and transducer combinations do not have a significant influence on SRT results with a smartphone DIN test. Furthermore, different sound file formats do not have a significant influence on SRT results. Therefore, the successfully developed and validated antiphasic DIN test can be administered reliably using different devices coupled to different transducer types using a range of sound file formats. This allows self-testing as a consumer tool that can increase awareness and facilitate widespread screening for hearing loss at minimal cost.

CONFLICT OF INTEREST STATEMENT

The last author has affiliations with the hearX Group which include equity, consulting, and potential royalties.

CHAPTER 4: DISCUSSION AND CONCLUSION

4.1 Discussion of results

The versatility of the DIN smartphone test app enables it to be downloaded on numerous digital devices whilst being administered using different transducers and sound file types. This could result in possible differences in SRT results, undermining the reliability of the tool across population-based consumer test. To date, there has been limited research evidence supporting the reliability across devices, especially between high- and low-end devices. This study provides a report on the DIN test's reliability using Android devices, despite the type of transducers used and the sound file format on which the test is delivered.

Many consumer-based hearing screening apps are available on Android and iOS platforms. These tests employ either tone-based or speech-based stimuli to ascertain the hearing status of the individual. The vast majority of these apps utilize tone-based stimuli, of which few have been validated against a gold standard measure in the peer-reviewed literature (Bright & Pallawela, 2016). In addition, identified peer-review studies reveal significant variability in accuracies regarding the degree and type of hearing loss, testing environments, transducers/device combinations and phone types (Bright & Pallawela, 2016). Furthermore, the accuracy of these tests is limited since the audiometric calibration of headphones and equipment cannot be supported by consumer-based apps (Bright & Pallawela, 2016).

Moreover, the majority of consumer-based apps are designed to run on Apple's iOS system and although Android and Apple's iOS systems run on more than 99% of the world's smartphones, Android dominates the market with an astonishing 87%, while iOS comes a distant second at 12% (Katariya, 2017). Android's costs are rapidly declining whereas, in contrast, iOS-based devices are expensive premium products with poor penetration in LMICs.

This study, in agreement with Potgieter et al. (2016), found that speech-based consumer apps provide reliable results using various digital devices and transducers. This study found no statistically significant difference in the performance of the DIN test across the various combinations of a device (low and high-end) and transducer (headphones and earphones) types. The DIN test, reliable across a range of digital devices and transducers, could therefore, be used as a downloadable test with widespread consumer uptake (Potgieter et al, 2016; De Sousa et al., 2019).

Objective two of the study determined the effect of the type of sound file type on the SRT results, for which no significant differences were evident. The file size is an essential consideration in the development of smartphone applications as it can influence the number of downloads, uninstalls and whether downloads will be restricted to users with WIFI access (Brus Media, 2013). Smaller file size can positively affect the cost of downloading an application, particularly important in developing world regions where internet access is limited, and the cost of mobile data is twice to that of developed world regions (International Telecommunication Union, 2017). The practical implications of the results of this study indicate that sound file formats with a smaller overall file size can be used in the programming of the DIN test.

These findings stipulate that the successfully developed and validated DIN test can be administered reliably using Android devices coupled to varying available transducer types. This allows the test to serve as a tool to increase awareness of hearing impairment and can successfully supplement hearing testing in settings with limited resources.

4.2 Clinical implications and recommendations

Results of this study indicate that the DIN test can be downloaded and administered reliably across digital Android devices utilizing varying available transducer types. In addition, it also demonstrated that the test remains reliable despite the sound file type used when conducting the test.

A downloadable DIN smartphone test app, such as hearZA or hearWHO, can provide widespread access to rapid and reliable hearing screening as a global initiative (Swanepoel et al., 2019). As a result, the development of the DIN test in various languages is essential in providing optimal access to hearing healthcare for millions (Potgieter et al., 2016; Potgieter et al., 2018; Swanepoel et al., 2019).

In a country like South Africa for example, school-based hearing screening is required as part of the 2012 Integrated School Health Policy. The DIN test could potentially serve as a tool to be downloaded by educators and or parents to facilitate the screening of all children. However, for this to be possible, the DIN test requires the development and validation of context and age specific normative data for the South African version of the app.

The DIN test can serve as a means of early identification and monitoring of hearing. Individuals can download the DIN test from the iOS and Android AppStore on personal devices, granting themselves access to readily available and affordable hearing health care. Furthermore, corporations and companies can use the DIN test app to assess the hearing status of their employees. General employees and employees who are at risk of developing occupational related hearing loss can be identified, monitored regularly and time efficiently without any financial or productivity related constraints. Test applications could then also ensure the appropriate referral pathways for the continuum of management of hearing loss

4.3 Critical evaluation

Critical evaluation of the research study is essential in order to interpret the findings of the research by taking into account its strengths and limitations. These are discussed below:

Strengths of the Study:

This study was the first report on the ability of the DIN test to serve as a valid tool despite the variability in the manner in which the DIN test is administered. Thus, confirming the reliability of the tests to be utilised across various digital devices using different transducers and sound file types. By capitalizing on advances in mobile phone penetration, mHealth solutions provide a unique opportunity for innovative hearing health service-delivery models that can dramatically improve access to and uptake of care. This means that the DIN test can play a significant role in addressing the growing burden of undiagnosed hearing loss by being utilized as a self-administered, population wide hearing screening tool. Tests were randomised according to a Latin square in order to reduce learning and fatigue effects in participants thus enhancing the accuracy of the results obtained. The study also assisted in identifying the limitations that need to be addressed for future research.

Limitations of the Study:

The greatest limitation of this study was that tests were conducted on a small number of digital devices. Only three digital devices were utilized in the current study despite the fact that thousands of digital devices with different hardware and software configurations are available to consumers for administering the DIN test. The study only employed the Android platform while excluding the iOS and web-based platform which is downloadable on computers and laptops. This study was limited by the exclusion of iOS and web-based platforms. Furthermore, testing was conducted in a sound-treated booth which is not representative of a home-based environment whereby the testing is most likely to take place. Thus, future studies should investigate testing in the home environment. Another limitation to the use of this type of intervention is the lack of sufficient evidence on the effectiveness of mobile phone technology in children or elderly people.

4.4 Future research

Based on the critical evaluation of the current research project, recommendations for future research are discussed below:

- Testing of the application should be conducted in a home-based setting to further its reliability in order to correlate test results with studies such as that conducted by De Graaff et al. (2018).
- Future research should utilize a larger sample of Android devices as well as incorporate the inclusion of iOS devices, computers and laptops to further determine the DIN test reliability.
- Normative data, which is also context specific, should be collected for children in order to use the DIN test as a potential tool for school-based hearing screenings.
- The study was limited to a small group of research participants (40 in objective one and 12 in objective two) with good self-reported English-speaking competence (scores ≤7). Future studies should aim to expand data on this group of participants.

- Education in more rural communities regarding the importance and necessity of ear and hearing health care as well as increasing awareness of the DIN test regarding its ease of obtainability will be necessary in order to ensure that users understand and are motivated to have their hearing screened.
- Future participant selection should also include individuals who have a hearing loss as they may be more sensitive in detecting differences between transducers.

4.5 Conclusion

The DIN test is reliable when downloaded by individuals on android devices ranging on the spectrum of low-end devices to high-end devices. This reliability continues despite the type of transducer (headphones or earphones) the device is coupled to. Thus, making it uniquely suited to serve as a hearing test that could be downloaded by persons across the globe and administered using standard transducers. In addition, the results of the test are reliable regardless of the type of sound file used. Ultimately sound file format types with a smaller overall file size can be used to conduct the DIN test. This plays an important role by positively affecting the number of downloads especially in developing contexts where the cost of mobile data is twice that compared to developed contexts. The current study highlighted that further research is needed over a vaster range of digital devices to continuously ensure that the results obtained, despite the type of technology used, is reliable.

REFERENCE LIST

Bright, T., & Pallawela, D. (2016). Validated Smartphone-Based Apps for Ear and Hearing Assessments: A Review. *JMIR Rehabilitation and Assistive Technologies*, 3(2), e13.

Brus Media. (2013). *Optimising the File Size of Your Mobile App*. Retrieved August 14, 2018, from http://www.brusmedia.com/resources/optimising-the-file-size-of-your-mobile-app/

Chadha, S., Cieza, A., & Krug, E. (2018). *Global hearing health: future directions*. Bulletin of The World Health Organization, 96(3), pp.146-146.

Clark, J., & Swanepoel, D. (2014). Technology for hearing loss – as We Know it, and as We Dream it. Disability and Rehabilitation: Assistive Technology, 9(5), pp.408-413.

Culling J.F., Zhao F., & Stephens D. (2005). The viability of speech-in-noise audiometric screening using domestic audio equipment. *International Journal of Audiology*, 44, 691–700.

Davis, A., McMahon, C. M., Pichora-Fuller, K. M., et al. (2016). Aging and hearing health: The life-course approach. Gerontologist, 56(Suppl 2), S256–S267.

De Graaff, F., Huysmans, E., Merkus, P., Goverts, S. T., & Smits, C. (2018). Assessment of speech recognition abilities in quiet and in noise: a comparison between self-administered home testing and testing in the clinic for adult cochlear implant users. *International Journal of Audiology*, 1-9.

De Sousa, K., Swanepoel, D., Moore, D., Myburgh, H., & Smits, C. (2019). Improving Sensitivity of the Digits-in-Noise Test using Antiphasic Stimuli.

De Sousa, K., Swanepoel, D., Moore, D., & Smits, C. (2018). A Smartphone National Hearing Test: Performance and Characteristics of Users. *American Journal of Audiology*, 27(3S), pp.448-454.

Fagan, J. J., & Jacobs, M. (2009). Survey of ENT services in Africa: Need for a comprehensive intervetion. *Global Health Action*, 2, 1932-1939.

Global Burden of Disease (GBD). (2016). Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990 – 2015: A systematic analysis for the global burden of disease study 2015. Lancet, 388, 1545–1602.

Gopinath, B., Schneider, J., McMahon, C., Teber, E., Leeder, S., & Mitchell, P. (2011). Severity of age-related hearing loss is associated with impaired activities of daily living. *Age And Ageing*, 41(2), 195-200.

Hughson, W., & Westlake, H. (1944). Manual for a program outline for rehabilitation of aural casualties both military and civilian. *Transactions – American Academy of Ophthalmology and Otolaryngology*, 48, 1–15.

Information About The OGG File Extension. (2018). Retrieved from https://www.online-convert.com/file-format/ogg

International Standardization Organization (ISO) 389-1. (2017). Acoustics -Reference zero for the calibration of audiometric equipment. Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones. Retrieved from https://www.iso.org/standard/69855.html

International Telecommunications Union. (2018). *ITC Prices 2017*. Retrieved from https://www.itu.int/en/ITU-D/Statistics/Documents/publications/misr2017/IPB2017_E.pdf

Jansen, S., Luts, H., Wagener, K., Frachet, B., & Wouters, J. (2010). The French digit triplet test: A hearing screening tool for speech intelligibility in noise. *International Journal of Audiology*, 49(5), pp.378-387.

Katariya, J. (2017). *Apple Vs Android. A comparative study 2017*. AndroidPub. Retrieved September 14, 2018, from https://android.jlelse.eu/apple-vs-android-a-comparative-study-2017-c5799a0a1683

Leedy, P. D., & Ormrod, J. E. (2010). Practical research: Planning and Design (9th ed.). New Jersey: Pearson Education, Inc.

Multimedia Glossary (n.d.). *AAC, M4A, M4P, OGG, MP3, ID3 Tag, WMA, WAV, OGG Vorbis, etc*. Retrieved August 11, 2018, from https://www.any-audio-converter.com/glossary/audio-glossary.php

Mulwafu, W., Ensink, R., Kuper, H., & Fagan, J. (2017). Survey of ENT services in sub-Saharan Africa: little progress between 2009 and 2015. *Global Health Action*, 10(1), 1289736.

National Academies of Sciences, Engineering, and Medicine. (2016). Hearing Health Care for Adults: Priorities for Improving Access and Affordability. Washington, DC: *The National Academies Press*.

Olusanya, B., Neumann, K., & Saunders, J. (2014). The global burden of disabling hearing impairment: a call to action. *Bulletin Of The World Health Organization*, 92(5), pp.367-373.

Peer, S., & Fagan, J. J. (2014). Hearing loss in the developing world: Evaluating the iPhone mobile device as a screening tool. *South African Medical Journal*, 105(1), pp.35–39.

Potgieter, J. M., Swanepoel, D. W., Myburgh, H. C., Hopper, T. C., & Smits, C. (2016). Development and validation of a smartphone-based digits-in-noise hearing test in South African English. *International Journal of Audiology*, *55*(7), pp.405–411.

Potgieter, J.-M., Swanepoel, D. W., Myburgh, H. C., & Smits, C. (2017). The South African English Smartphone Digits-in-Noise Hearing Test: Effect of Age, Hearing Loss, and Speaking Competence. *Ear and Hearing*, 39(4), pp.656-663.

Smits, C., Goverts, T., & Festen, J.M. (2013). The digits-in-noise test: Assessing auditory speech recognition abilities in noise. *Journal of the Acoustical Society of America*, 133(3), pp.1693–1706.

Smits, C., & Houtgast, T. (2007). Recognition of digits in different types of noise by normal-hearing and hearing-impaired listeners. *International Journal of Audiology*, *46*(3), pp.134–144.

Smits, C., Kapteyn, T., & Houtgast T. (2004). Development and validation of an automatic speech-in-noise screening test by telephone. *International Journal of Audiology* , 43, pp.15 – 28

Smits, C., Merkus, P. and Houtgast, T. (2006). How we do it: The Dutch functional hearing screening tests by telephone and internet. *Clinical Otolaryngology*, 31(5), pp.436-440.

Stach, Brad A. (2010). Clinical audiology: an introduction. Clifton Park, NY: Delmar Cengage Learning.

Swanepoel, D., Clark, J., Koekemoer, D., Hall III, J., Krumm, M., Ferrari, D., McPherson, B., Olusanya, B., Mars, M., Russo, I. & Barajas, J. (2010). Telehealth in audiology: The need and potential to reach underserved communities. *International Journal of Audiology*, 49(3), pp.195-202.

Swanepoel, D., De Sousa, K., Smits, C. & Moore, D. (2019). Mobile apps to detect hearing impairment: Opportunities and challenges. *WHO Bulletin*, In Press

Swanepoel, D., Myburgh, H., Howe, D., Mahomed, F. & Eikelboom, R. (2014). Smartphone hearing screening with integrated quality control and data management. *International Journal of Audiology*, 53(12), pp.841-849.

The Economist. (2015). *Planet of the phones.* Retrieved August 12, 2018, from http://www.economist.com/news/leaders/21645180-smartphone-ubiquitous-addictive-and-transformative-planet-phones

Watson, C., Kidd, G., Miller, J., Smits, C., & Humes, L. (2012). Telephone Screening Tests for Functionally Impaired Hearing: Current Use in Seven Countries and Development of a US Version. *Journal of The American Academy of Audiology*, 23(10), pp.757-767.

Windmill, I., & Freeman, B. (2013). Demand for Audiology Services: 30-Yr Projections and Impact on Academic Programs. *Journal of The American Academy Of Audiology*, 24(5), pp.407-416.

Wilson, B., Tucci, D., Merson, M., & O'Donoghue, G. (2017). Global hearing health care: new findings and perspectives. *The Lancet*, 390(10111), 2503-2515.

World Health Organization. (2013). *Millions of people in the world have hearing loss that can be treated or prevented*. Retrieved August 13, 2018, from http://www.who.int/pbd/deafness/news/Millionslivewithhearingloss.pdf?ua =1

World Health Organisation. (2018). *Deafness and hearing loss.* Retrieved August 12, 2018, from http://www.who.int/en/news-room/fact-sheets/detail/deafness-and-hearing-loss

Yousuf Hussein, S., Wet Swanepoel, D., Biagio de Jager, L., Myburgh, H. C., Eikelboom, R. H., & Hugo, J. (2015). Smartphone hearing screening in mHealth assisted community-based primary care. *Journal of Telemedicine and Telecare*, 22(7), 1–8.

Zokoll, M., Wagener, K., Brand, T., Buschermöhle, M., & Kollmeier, B. (2012). Internationally comparable screening tests for listening in noise in several European languages: The German digit triplet test as an optimization prototype. *International Journal of Audiology*, *51*(9), pp.697-707.

APPENDIXES

Appendix A: Permission from the Director of Student Affairs, University of Pretoria

Attention: Director of Student Affairs

RE: PERMISSION TO CONDUCT A RESEARCH STUDY WITH STUDENT PARTICIPANTS FROM THE UNIVERSITY OF PRETORIA

I, Kyla Eichhorn a final year audiology student at the Department of Speech-Language Pathology and Audiology, University of Pretoria would like to request your permission to invite participants from the university student body to participate in a research project that I am undertaking as a requirement for my undergraduate degree.

I am conducting my research project in the field of the Digits-in-Noise (DIN) smartphone test application. The DIN smartphone test application was developed and validated by researchers from the University of Pretoria. The DIN test has been verified across a limited number of electronic devices and my study will develop this work to validate across a range of devices and headphone versus earphone conditions. Thus, the aim of the current study is to determine the validity of the DIN test across various digital devices and evaluate the effect of earphones versus headphone conditions and evaluate the effect of sound file types on the test's reliability.

Participant candidacy: Normal hearing individuals above the age of 18 (male or female), that are first language English speakers or be very proficient in English as a second language.

Design and procedure: Testing will take place at the Department of Speech-Language Pathology and Audiology,University of Pretoria and will include the following:

1. Completing the ISO 389-1 checklist for otologically normal hearing individuals

2. Tympanometry
This includes placing a probe into the ear (one may expect to experience slight pressure in the ear canal). This measures the pressure of the middle ear, the mobility of the eardrum and the volume of the ear canal. This test determines whether the middle ear is functioning normally.

3. Hearing test
Participants will be asked to perform a hearing screening test. Using earphones, participants are required to respond to a soft tone by pushing a button. This test will

determine hearing sensitivity to ensure the participant meets the candidacy criteria. The test will take approximately 5 minutes.

4. DIN test

This will involve listening and identifying three digits in the presence of background noise which will vary in loudness. This test will be performed in six different conditions. The first three conditions use earphones, participants are requested to respond to a soft tone presented in both ears by typing the digits heard. The soft tone will be presented via the application on a high-end smartphone, low end smart phone and tablet. The next three conditions will then be re-conducted on all the digital devices using headphones. These tests will take approximately 20-30 minutes. Finally, participants will conduct the test another three times using different sound file types.

Ethical Considerations: Participation will only take place once students have consented to, and fully understand the terms of the study. All participants will be given an alpha-numeric code. Therefore, the personal information and information collected during this research will be kept confidential and only the researchers will have access to identifying information.

Risks and benefits: There are no risks associated with this study and confidentiality will be ensured. The information received may help us determine the effects of various devices on the SRT when considering performance on the DIN test and to establish normative data thereof. Thus, assisting in the advancement of knowledge in the field of audiology. Should you have any queries, concerns or wish to obtain additional information regarding any aspect of this study, feel free to contact me at any point. Thank you in advance for your time and cooperation.

Yours sincerely,

____

Kyla Eichhorn
Researcher
Tel: 0794417796
Email: kylaeichhorn@gmail.com

_________________________ _________________________

Prof. De Wet Swanepoel
Supervisor

Faheema Mohomed-Asmail
Supervisor

PERMISSION FOR THE USE OF PARTICIPANTS FROM THE UNIVERSITY OF PRETORIA

Herewith I, N R Madik__ give permission that the participants from the University of Pretoria may be used for the research project titled: Reliability of the South-African Digits-In-Noise test on various electronic devices using headphones and earphones.

Pending ethical clearance from the faculty.

Signature

05/12/2017

Date

Appendix B: Participant Informed Consent

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

INFORMED CONSENT – RESEARCH PROJECT

Dear Participant,

Thank you for considering participating in the research project entitled: ***Reliability of the Digits-In-Noise test on various digital devices, transducers and sound file types.*** I am conducting a study to determine whether the South African Digits-in-Noise test will yield the same results despite the digital device used to conduct the test as well as determine headphone versus earphone results and the effect of sound file types used. Therefore, determining its reliability across these different conditions.

Before you agree to take part in this study you should fully understand what will be required from you as a research participant. We ask that you read this form and ask questions should you have any before agreeing to participate in the study.

Volunteers: If you want to participate in this study you can be either male or female and should be above the age of 18 years with normal hearing thresholds. You must also be a first language English speaker or be proficient in English as a second language.

Procedures: Participation in the study will be conducted in two different phases on two different days. The assessment period of the first phase and second phase will be approximately 25 minutes each. If you agree to participate in this study, the assessment will include the following tests:

1. Completing the ISO 389-1 checklist for otologically normal hearing individuals

2. Tympanometry
This includes placing a probe into the ear (one may expect to experience slight pressure in the ear canal). This measures the pressure of the middle ear, the mobility of the eardrum and the volume of the ear canal. This test determines whether your middle ear is functioning normally

3. Hearing test
For this test you will wear earphones on your ears. You are required to respond to a soft tone by pushing a button. This will test your hearing sensitivity to ensure you meet the candidacy criteria.

4. South African Digit-in-Noise hearing test
This will involve listening and identifying three digits in the presence of background noise which will vary in loudness as the test proceeds. The first phase of the test will be performed in four different conditions. These conditions include the South-African Digits-in-Noise test that will be presented through earphones via a high-end smartphone, low-end smart phone a tablet. The next phase, which will occur on another day, will include conducting the test through headphones via a high-end smartphone, low end smart phone and tablet. The time between phase one and phase two should be approximately 5-10days.

Rights as a Volunteer: Your participation in this research is entirely voluntary. You have the right of withdrawing from the study at any time.

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

Risks and Benefits: There are no risks involved during this study and you will not be negatively influenced in any way. You will benefit from this study by obtaining a free hearing screening. If necessary, you will be referred for further medical or audiological intervention.

Sharing of results: Results obtained from this research study will be shared in the form of a scientific article and dissertation, which will be made available to the professionals in the field of Audiology. If you wish to have a copy of your results from these tests, I will make these available to you once the research is complete.

Data storage: Data will be stored at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for 15 years for research and archiving purposes.

Should you require any additional information, or clarification on the information stated above, please feel free to contact Kyla Eichhorn 0794417796. Should you wish to make use of these services and participate in this research project, kindly complete the informed consent form.

Thank you for your participation and assistance in this research project.

Researchers	**Research Supervisors**
Kyla Eichhorn	Prof De Wet Swanepoel & Dr Faheema Mohamed-Asmail

Consent to participate in this study

Informed consent

The research has been explained to me. I, __________________________ (name and surname) voluntarily consent to participate in the study titled: ***Reliability of the South-African Digits-In-Noise test on various electronic devices using headphones and earphones.*** I know that I may refuse to participate or stop my participation in the research at any time.

____________________	___________________________
Participant	Date
____________________	___________________________
Investigator	Date
____________________	___________________________
Witness	Date

Appendix C: Data Collection Sheet

Name: ______________________ **Date Phase 1:**_____________

DOB: _______________________ **Date Phase 2:**_____________

Subject Number: ____________

1. Tympanometry

	Right Ear	Left Ear
Type		
Middle Ear Pressure		
Static Compliance		
Ear Canal Volume		

2. Pure Tone Thresholds

Frequency	Right Ear	Left Ear
250Hz		
500Hz		
1000Hz		
2000Hz		
4000Hz		
6000Hz		
8000Hz		

3. SA DIN Test

Conditions	SNR Results	Time
Headphones + High-end smartphone		
Headphones + Low-end Smartphone		
Headphones + Tablet		
Earphones + High-end smartphone		
Earphones + low-end smartphone		
Earphones + Tablet		

Venue: _________________________

TOTAL TIME: __________________________

Appendix D: ISO 389-1 Questionnaire

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:

Appendix E: Ethical Clearance Form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

10 April 2018

Dear Ms Eichhorn

Project:	**Reliability of the South-African Digits-In-Noise test on various electronic devices using headphones and earphones**
Researcher:	**K Eichhorn**
Supervisor:	**Prof DCD Swanepoel and Dr F Mahomed**
Department:	**Speech-Language Pathology and Audiology**
Reference number:	**14006422 (GW201801120HS)**

Thank you for your response to the Committee's correspondence of 15 February 2018.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 9 April 2018. Data collection may therefore commence.

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

We wish you success with the project.

Sincerely

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

cc: Prof DCD Swanepoel and Dr F Mahomed (Supervisors)
Dr J van der Linde (HoD)