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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

# Performance and test-retest reliability of the digits-in-noise test used in the sound field

Lisa Brown

(14188202)

In fulfilment of the requirements for the degree **MA Audiology** in the Department of Speech Language Pathology and Audiology, Faculty of Humanities, University of Pretoria

**Supervisors:**

Prof. De Wet Swanepoel

Dr Faheema Mahomed-Asmail

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## ABSTRACT

There are approximately 1.7 billion smartphone downloads of health surveillance applications, which have become vital in modern day living (Economist, 2016). The smartphone Digits-in-Noise (DIN) test was developed with South African English digits and was released and marketed in 2016 as a smartphone application allowing for an accessible hearing screening solution (Potgieter et al., 2016). Typically, the test is completed with coupling to headphones/earphones. However, due to several limitations, such as the lack of availability or inability to utilise headphones/earphones, performing tests with earphones/headphones may not always be possible. Therefore, this study aimed to determine if the results obtained via earphones would be comparable to those obtained in the sound field via various transducers.

The study employed a cross-sectional, quasi-experimental research design. Fifty normal hearing participants (bilateral pure tone thresholds 0.5 – 8kHz ≤ 15dB HL) between the ages of 18 to 25 years (mean 20; SD ±1.93) were recruited. The study consisted of two test sessions over two days and used a repeated measure design where the conditions were counterbalanced using a Latin square setup. The first test session compared the SRTs of the smartphone DIN test across Samsung Fame Lite earphones, two smartphone speakers and two external loudspeakers in a sound booth. Test session two determined the test-retest reliability of the above conditions.

Results of this study indicated that there was no significant difference ($p > 0.05$) between the SRTs across the four different loudspeakers and earphones. It also demonstrated that the test-retest differences across the various loudspeakers was not significant ($p > 0.05$). Findings indicate that test-retest results in the sound field using various transducers is reliable.

This study demonstrated that a smartphone version of the DIN test can be utilised in the sound field using various transducers with equivalent results compared to an earphone condition. Therefore, the smartphone DIN test can be implemented in any practice which has access to a controlled testing environment for screening and rehabilitation purposes. A limitation of the current study is that the smartphone DIN test is designed for users to utilise the application in a home environment where ambient noise and reverberation is not controlled. Therefore, a future research priority is to conduct the testing in a home environment. Based on the findings of this study, it is expected that the smartphone DIN test performed through the sound field will be a promising tool in a home environment if the noise and reverberation is low.

**Keywords:** Digits-in-Noise, sound field, headphones, earphones, smartphone, speech-in-noise, signal-to-noise ratio, speech reception threshold

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## LIST OF ABBREVIATIONS

CI – Cochlear Implant

daPa – Dekapascal

dB HL – Decibel hearing level

DIN – Digits-in-Noise

HA – Hearing Aid

Hz – Hertz

ISO – International Organisation for Standardisation

LMIC – Low- and middle-income countries

ml – Millilitres

SNR – Signal-to-Noise Ratio

SRT –Speech Reception Threshold

# CHAPTER 1: INTRODUCTION

Approximately 49 million individuals residing in Sub-Saharan Africa have a disabling hearing loss, which is considered the fourth leading disabling condition globally (WHO, 2018). It is estimated that 50% of hearing losses could be prevented and the remainder thereof treated (WHO, 2014; WHO, 2018). However, the prevention and treatment of a permanent disabling hearing loss in low- and middle-income countries (LMICs), such as South Africa, are not prioritized due to a lack of resources (WHO, 2014). These include a shortage of trained healthcare personnel as there is a currently one audiologist for every one million individuals in Sub–Saharan Africa (Fagan & Jacobs, 2009; WHO, 2014). Furthermore, the distribution of these services is not equally spread around Sub-Saharan Africa, and the availability of audiological equipment is poor due to constrained resources (Fagan & Jacobs, 2009; Malwafu, Ensink, Kuper & Fagen, 2017; Swanepoel, Störbeck & Friedland, 2009). Thus, individuals with a disabling hearing loss are sometimes unable to seek audiological services (Fagen & Jacobs, 2009). This urges the increased need for hearing health care that is cost-effective to address disabling hearing losses (Fagan & Jacobs, 2009).

The greatest handicap associated with a disabling hearing loss is the difficulty to understand speech in the presence of background noise (Kramer, Kapteyn & Festen, 1998; Smits, Kapteyn, & Houtgast, 2004). Background noise can cause severe problems with speech recognition and perception which may result in an inability to interpret speech sounds (Darwin, 2008). This, in turn, can give rise to societal and psychological consequences which may lead to depression and anxiety which all contributes to a reduced quality of life (Davis et al., 2016). Therefore, it is necessary to assess speech-in-noise recognition abilities in individuals (Taylor, 2003).

Speech-in-noise tests are valuable indicators of real-life communication difficulties as opposed to pure tone and speech audiometry in quiet (Taylor, 2003). There are two main types of speech-in-noise tests available, the fixed and adaptive signal-to-noise ratio (SNR) tests (Taylor, 2003). Fixed SNR tests are speech-in-noise tests where the SNR is fixed at a certain level which is established prior to testing by the clinician and, a percentage is measured based on this SNR (Taylor, 2003). These tests provide a straightforward percentage score related to the hearing aid benefit and are only used in the sound field (Taylor, 2003; Smits, 2017). However, due to the subjective establishment of the fixed SNR, it is a challenging task to identify where to maintain the SNR as this could underestimate or overestimate the benefit of the hearing aids (Taylor, 2003). In contrast, the adaptive SNR test measures the SNR itself as the intensity and noise varies (Smits, 2017). One advantage of this test is that it has the capability of diagnosing a SNR hearing loss (Smits & Hougast, 2005). This is important as a SNR loss of as little as 2.5 dB corresponds to sentence unintelligibility of approximately 45% in challenging listening environments (Smits & Hougast, 2005). Furthermore, these tests can be used to verify hearing aid performance and demonstrate that an individual’s ability to listen to speech in the presence of background noise will be better aided compared to unaided (Taylor, 2003). Although adaptive SNR tests can be used in the sound field, they are mainly used with earphones/headphones (Taylor, 2003).

A straightforward and quick adaptive speech-in-noise self-test performed on a telephone, namely the National Hearing Test, was developed in 2003 (Smits, Merkus & Hougast, 2005). This self-administered telephone screening test was developed to improve detection rates because hearing loss has been underdiagnosed and untreated globally (Smits, Merkus & Hougast, 2006; Potgieter, Swanepoel, Myburgh, Hopper & Smits, 2016). The test also serves as a tool to increase awareness of hearing impairments as many individuals have misconceptions of their hearing abilities or deny a hearing impairment (Smits & Hougast, 2005). The National Hearing Test is an automatic screening test that uses a closed response set of digit-triplets as speech material (Smits et al., 2006). This test allows individuals to perform the test over a telephone, thereby accessing a large population (Koole, Nagtegaal, Homans, Hofman, Baatenburg der Jong & Goedegebure, 2016). The National Hearing Test measures an individual’s ability to understand speech in the presence of background noise by varying the SNR (Smits et al., 2006; Watson et al., 2012). This screening test can discriminate between individuals with normal hearing compared to those with a SNR loss (Smits & Hougast, 2005).

This telephone-based digit-triplet speech in noise screening has been implemented in many developed countries and can be an affordable option in LMICs, however; access to landlines are problematic (Jansen et al., 2010; Potgieter, Swanepoel, Myburgh & Smits, 2018; Watson et al., 2012). In South Africa, less than 10% of households have access to landline telephones while nearly 80% of households have access to smartphones (Statistics South Africa, 2013; Ericsson, 2015). Furthermore, health surveillance utilizing smartphones has taken a significant foothold with estimates of 1.7

billion downloads in 2017 and global revenues of $21.5 billion in 2018 (Economist, 2016). This urged the development of a smartphone-based application which would allow for widespread access to hearing screening in rural and urban areas and across different socio-economic strata (Potgieter et al., 2016). As a result, a smartphone DIN application using South African English was developed and validated (Potgieter et al., 2016; Potgieter et al., 2018).

The smartphone DIN test uses a combination of three digits which are presented in English in the presence of speech weighted masking-noise (Potgieter et al., 2016). Digits are familiar spoken words and have a low linguistic demand and a closed-set pattern (Potgieter et al., 2016; Potgieter et al., 2018). Similar to the telephone-based speech-in-noise test, it measures the SNR at which an individual identifies 50% of the digits correctly (Potgieter et al., 2016). The smartphone DIN test has several advantages including its broadband quality signals (30Hz to 20 000Hz), as compared to the telephone bandwidth which is limited to approximately 300Hz to 3400Hz (Potgieter et al., 2018). Furthermore, the test uses a binaural paradigm (Potgieter et al., 2016; Potgieter et al., 2018), which has shown to benefit binaural listeners by 1.4 dB compared to monaural listeners (De Sousa, Swanepoel, Moore & Smits, In Press). It is also a good predictor of understanding speech-in-noise which is a primary complaint of hearing-impaired individuals (Healy, Yoho & Wang, 2013; Potgieter et al., 2016; Potgieter et al., 2018). The smartphone DIN test has demonstrated a high uptake, particularly those who self-report a hearing loss or who failed the test, therefore reaching an important target market (De Sousa et al., In Press).

The smartphone DIN test was successfully developed and validated as a smartphone-based hearing test via a smartphone application that can be administered using standard and clinical headphones (Potgieter et al., 2016). However, an alternative way of listening to an auditory signal is through the sound field (Kallinen & Ravaja, 2004). Sound field audiometry is the condition in which auditory stimuli is presented through a loudspeaker which is delivered at a distance to the subject (Kallinen & Ravaja, 2004; Rochlin, 1993). This is different to headphones/earphones, under which circumstances the auditory signal and the subject are closer to one another, and additional signals from the surrounding environment are attenuated (Kallinen & Ravaja, 2004; Rochlin, 1993). In sound field conditions, the interaction between the test stimuli, room acoustics and psychoacoustic perception in the listener becomes critical (Rochlin, 1993). Sound field testing is often used to evaluate the need as well as the degree of the benefit of hearing aids and to assess speech discrimination testing in noise (Rochlin, 1993). An underlying assumption is that the thresholds obtained from a loudspeaker through the sound field will correlate with those obtained through headphones/earphones (Rochlin, 1993). However, the thresholds of the listener will be affected by the calibration of the sound field signals, the characteristics of the stimuli used for testing and the position of the loudspeaker (Rochlin, 1993).

Accurate and reliable DIN testing in the sound field using a smartphone may be important for national screening programmes and home-based test applications. For example, in South Africa, earphones/headphones may not be readily available to all those who own a smartphone, as South Africa is a LMIC which is characterised with high unemployment rates and poor economic circumstances (Bakari, 2017). Therefore, if no earphones/headphones are available, the alternative method of performing the smartphone DIN test would be using the smartphone speaker itself. Although mobile phones are responsible for over three-quarters of the web traffic in South-Africa (72%), the internet is largely used through laptops (17%) and tablets (5%) (Qwerty, 2017). The advantage of electronic equipment, such as smartphones, laptops, and tablets, is that they have built-in speakers and can connect wired or wireless to external loudspeakers. Therefore, this is another avenue where it can be utilised.

It may also benefit individuals, such as children, who have tactile sensitivity issues and those who have bilateral structural abnormalities in their ear canals such as bilateral atresia, where the placement of earphones/headphones is not possible. Furthermore, it may also be useful for home-based clinical measures of the performance of hearing aids as speech in noise tests are great objective outcome measures of amplification devices performance in a realistic environment (Mendel, 2009).

The goal of speech in noise testing is to maximise the validity and reliability of speech understanding in hearing aid users (Mendel, 2009). To perform a speech in noise test, as an objective measure for hearing aid users, a test must have considerable standardised norms to document the validity and reliability of the test and should be performed in the sound field (Mendel, 2009). Therefore, as the smartphone DIN application has been validated, it can objectively be used to measure hearing aid performance for personal use. In addition to hearing aids, speech recognition in noise and quiet is an important part of the clinical routine for cochlear implant (CI) users (de Graaff, Huysmans, Merkus, Goverts & Smits, 2018). Stimuli used for speech recognition tests for CI users are usually sentences, mono-syllabic words or digits which are presented via the sound field (de Graaff et al., 2018). During the intensive rehabilitation programme of CI users (three to six months post implantation), speech recognition tests are assessed approximately six times during this period (de Graaff et al., 2018). However, due to financial issues and lack of transportation in LMICs, the ability to visit these centres is not always possible (Hughes, Goehring, Buadhuin, Diaz, Sanford, Harpster & Valente, 2012). Visits to CI centres to perform these assessments are crucial as the inability to attend these follow-up visits may result in poorer outcomes and the possibility of the non-use of the device (Hughes et al., 2012). Therefore, the ability to perform these speech recognition tests for CI users in the comfort of an individual's home is vital to avoid any potential negative outcomes. Furthermore, performing the smartphone DIN test can be advantageous in tele-audiology models in terms of screening and rehabilitation purposes to access underserved populations where hearing health care services are lacking in availability (Swanepoel et al., 2010). In addition to the circumstances mentioned above, even though the smartphone DIN test has seen a high uptake, it could increase considerably if the test could be performed in the sound field (De Sousa et al., In Press; Culling et al., 2005).

The smartphone DIN application has not been assessed in sound field conditions to date. The aim of the study, therefore, was to compare the smartphone DIN test presented through various sound field transducers and smartphone coupling with earphones. Furthermore, the study also aimed to determine the test-retest reliability of the smartphone DIN application in the sound field across various transducers.

# CHAPTER 2: METHODOLOGY

## 2.1 Research Aims

To compare the performance and test-retest reliability of the smartphone DIN test across various sound field transducers.

## 2.2 Research design

This study employed a cross-sectional, quantitative, quasi-experimental research design (Leedy & Ormrod, 2010). To achieve the research aim, quantitative descriptive data was collected cross-sectionally from 50 participants in a sound booth. The tests were counterbalanced using a Latin square to control the variation of the five listening conditions and avoid first-order carryover effects.

## 2.3 Research participants

Convenience sampling was used to recruit 50 participants with normal pure tone thresholds (≤ 15 dB HL at 250Hz to 8000Hz bilaterally) and Type A tympanograms. Participants were recruited from the Department of Speech-Language Pathology and Audiology, University of Pretoria along with volunteers outside the department, such as friends and family members. The Director of Student affairs of the University of Pretoria provided informed consent (Appendix A) to recruit students. All participants had otologically normal ear health and history as determined by the International Organisation for Standardisation (ISO) 389-1 questionnaire (Appendix B). The age of all participants ranged from 18 to 25 years (otologically normal in accordance with the ISO 389-1) with a mean age of 20 years (±1.93 SD). A percentage of 92% of participants were female and 8% male. English first-language distribution was 58% with 42% Afrikaans first-language speakers who were proficient in English, which was self-determined by participants from a rating score of 1 to 10 (Potgieter et al., 2017). Only those with a rating of 7 or higher were included in the study.

Participants that presented with a conductive component or had a hearing loss of any degree were excluded from the study and were referred for necessary intervention.

## 2.4 Research Equipment and Apparatus

Table 1 provides an overview of the equipment that was included in the research study.

**Table 1: Equipment used for data collection**

| ***Test*** | ***Equipment*** | ***Use*** |
|---|---|---|
| *ISO Checklist* | ISO 389-1 checklist for otologically normal hearing | To determine if normal otological requirements were met |
| *Otoscopy* | Welch Allyn Pocket set Otoscope | To examine the external auditory canal |
| *Tympanometry* | 226 Hz probe tone (GSI Tympstar, Grason-Stadler) tympanometer calibrated according to the SANS 10154-1/2 10182. Eden, Prairie, MN, USA. | To determine the overall functioning of the middle ear |
| *Hearing assessment* | Grason Stadler GSI 61 clinical audiometer calibrated according to the SANS 10154-1/2 10182 standards utilizing the Telephonics TDH-50P audiometric earphones | To determine the hearing sensitivity of participants (bilateral pure tone thresholds ≤ 15 dB at 250Hz to 8000Hz) |
| *South Africa Digits-in-Noise application* | • Samsung Galaxy S4 smartphone<br>• Samsung J2 smartphone<br>• Samsung Fame Lite cell phone earphones<br>• Jam Classic wireless Bluetooth speaker<br>• Philips Docking Entertainment System | To investigate the effect of earphones and loudspeakers on the SRT. |

## 2.5 Research Procedures

Before the research project commenced, clearance from the Faculty of Humanities, Research Ethics Committee, University of Pretoria, was obtained (Appendix C). Participants were required to provide informed consent (Appendix D) before data collection commenced. To achieve the research aim and secondary objective, the research procedure consisted of two test sessions that took take place on two separate days (Figure 1).

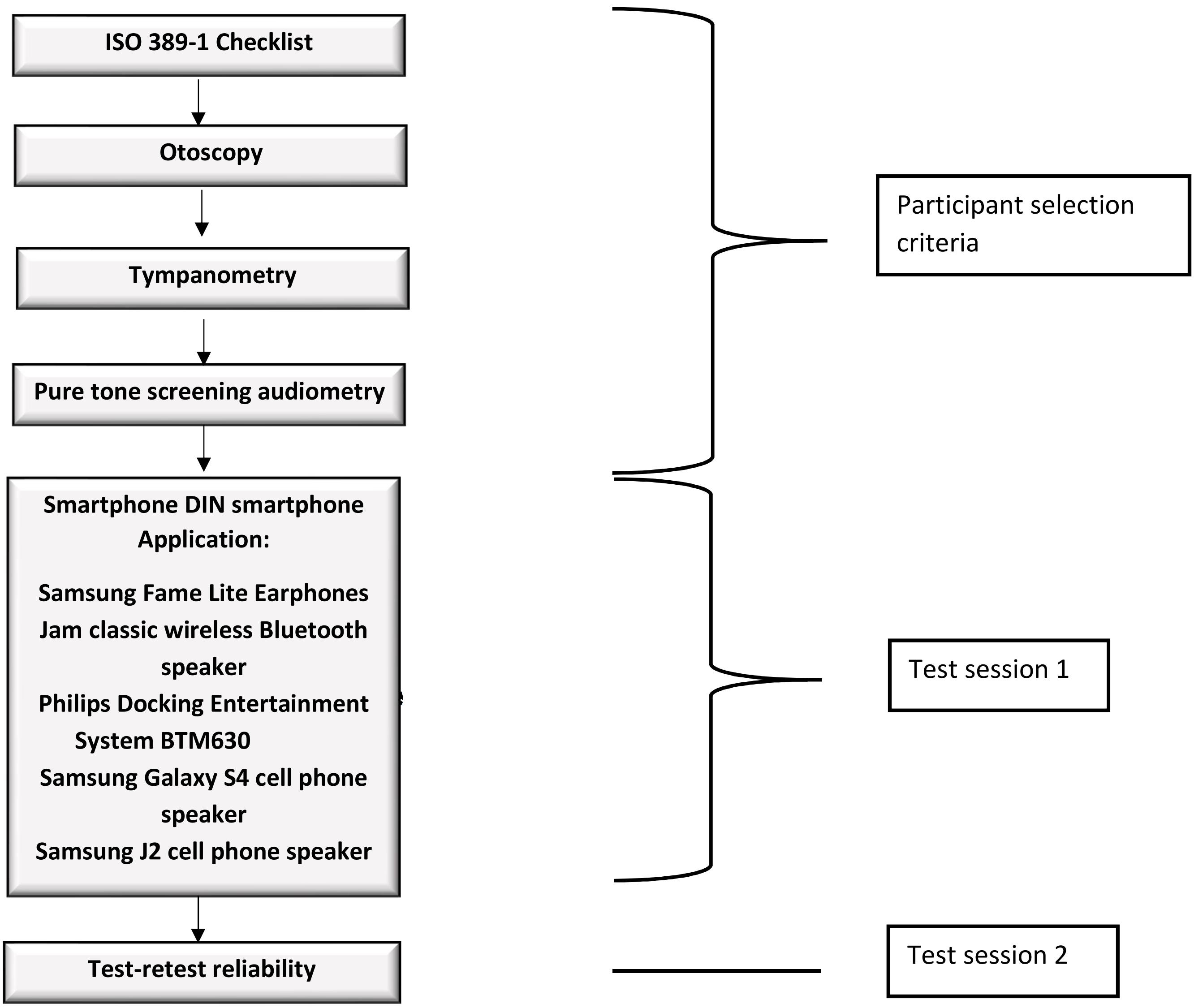


**Figure 1: Summary of the research procedure**

### 2.5.1 Test session 1: Participant selection criteria and smartphone DIN testing

Test session 1 took place on the same day and testing consisted of the following:

- ISO 389-1 checklist for otologically normal hearing individuals
- Otoscopy
- Tympanometry
- Pure tone screening audiometry
- Smartphone Digits-in-Noise test

Tympanometry and pure tone audiometry was conducted on all participants to ensure accurate hearing thresholds. All testing took place at the Department of Speech-Language Pathology and Audiology, University of Pretoria and was recorded on the data collection sheet (Appendix E).

### *ISO 389-1 checklist for otologically normal hearing individuals*

This checklist was used to determine whether otologically normal candidacy criteria was met in terms of having a normal state of ear health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canal, and who has had no history of excessive exposure to noise, potential ototoxic drugs, or family hearing loss (International Standard, 1998). The checklist was filled out before the testing commenced.

### *Otoscopy*

Otoscopy was performed to examine the external ear canal and the tympanic membrane to identify any external ear canal pathologies.

### *Tympanometry*

Tympanometry resulted in a pressure change in the ear canal via a probe to measure the pressure in the middle ear, the mobility of the eardrum and the volume of the ear canal. All participants had Type A tympanograms indicating an ear canal volume between 0.8 – 2.0 ml, compliance 0.3ml – 1.8ml and middle ear pressure -100 daPa to +50 daPa (Stach, 2008). This was performed to identify any middle ear pathologies. If any middle ear pathology were present, these participants were excluded from the study as the smartphone DIN test is insensitive to detect a conductive hearing loss (Smits & Hougast, 2005).

### *Pure tone screening audiometry*

Pure tone screening audiometry was conducted by presenting pure tones via Telephonics TDH-50P audiometric supra-aural headphones. Participants were placed in a sound booth with headphones placed on participant's ears and were required to press the response button every-time they heard the tone. The initial starting intensity was 25dB HL at 1000Hz in their right ear. A positive response was recorded if the participant heard the tone and the intensity would decrease by 10 dB HL. If a response was obtained at 15dB HL, this was considered a pass and the test proceeded to the lower frequencies (250 – 500Hz), after which proceeded into the higher frequencies (2000 – 8000Hz). This was conducted to ensure participants had hearing thresholds of 15 dB HL at each frequency. If a participant had a threshold above 15 dB HL at any frequency, they were excluded from the study.

***Smartphone Digits-in-Noise test***

The smartphone DIN application was conducted using a research Android OS application of the hearZA app (De Sousa et al., In Press) using diotic (in-phase) stimulus paradigm. This test contains 120 unique digit triplets (eg., 4-7-2) which are South-African English mono- and bi-syllabic digits ranging from numbers 1-9 (Potgieter et al., 2016). This test involves listening and identifying three digits (which are selected randomly from the 120 unique digit triplets) in the presence of background noise (Potgieter et al., 2016).

The participants' name, surname, year of birth, code and home language was entered in the application before testing commenced. If English was not a listener's home language, a rating scale appeared to rate English-speaking competence out of a score of 1 to 10 (Potgieter et al., 2016). Furthermore, a three-step tutorial screen opened that instructed the participant on how to use the application. After which, the participant was required to adjust the intensity to a comfortable hearing level. Thereafter, the participant was required to press the "Start Test" button for the testing to begin. Digit triplets were presented to both ears simultaneously and a pop-up keypad appeared afterward to allow the participants to enter the numbers they heard. The digit triplets are presented in both a negative and positive SNR (Potgieter et al., 2016). When the SNR is negative, the background noise remains fixed and the speech intensity varies, however, when the SNR is positive, the speech intensity is fixed, and the background noise varies (Potgieter et al., 2016). This occurs for the overall level of the signal to remain constant. The SNR varies as a response to their response. The application utilised a 4 dB adaptive procedure for the first three digit-triplets if all three were identified correctly, followed by a 2 dB adaptive procedure for the remaining digit triplets. Afterward, the SNR was calculated as an average of the SNR's presented (Potgieter et al., 2016).

This test was performed in a sound booth through earphones, two smartphone speakers and two loudspeakers. When participants performed the test with the smartphones, participants held the phone in front of them at eye and ear level. When performed through the external speakers, participants sat one meter away from the external loudspeakers facing the loudspeakers. The tests were counterbalanced using a Latin square to control the variation of the five listening conditions and avoid first-order carryover effects.

### 2.5.2 Test session 2: Test-retest reliability

This retest reliability was conducted to compute the correspondence between the two sets of scores obtained using either the same loudspeaker or the same smartphone speaker. Test session 2 ranged between five to ten days after test session 1. It involved retesting the smartphone DIN test by conducting the test on earphones, and to avoid fatigue, only on one of the two external speakers and one of the two smartphone speakers. The retests were counterbalanced using a Latin square.

## 2.6 Ethical Considerations

Ethical considerations are vital to address and protect the rights and welfare of the participants that are involved in the study (Leedy & Ormrod, 2010). Ethical approval of this study was obtained from the research committee at the Faculty of Humanities, at the University of Pretoria (Appendix C).

### 2.6.1 Informed consent

Informed consent is important as participants should have knowledge regarding the nature of the study and their level of involvement in the study and therefore should be obtained from all participants (Leedy & Ormrod, 2010).

Permission to recruit participants from the University of Pretoria student body was obtained from the Director of student affairs of the University of Pretoria (Appendix A).

A participant information letter and informed consent (Appendix D) was provided to all participants and testing commenced once the participants signed the informed consent form. All participants were aware that their participation was voluntary, and they could withdraw from the study at any time.

### 2.6.2 Possible risks and benefits from research

There were no risks involved in participating in the study. There were also no direct benefits to the participants, however, testing served as a hearing screening for all participants, and if needed, were referred to the Hearing Aid Clinic, University of Pretoria, for further assessment.

### 2.6.3 Confidentiality

According to Leedy and Omrod (2010), the privacy of participants should be respected. This is achieved by keeping the nature and quality of the participant’s performance strictly confidential. Participants were informed that all information would be kept confidential and only researchers would have access to such information. This was achieved by participant's receiving a numeric code to ensure confidentiality. This was explained verbally and is noted in the participant information letter. This code was used during data analysis and was only known to the researcher and the supervisors. The data will be stored for 15 years for research purposes.

### 2.7 Data analysis

Data was retrieved from the research Android OS application and was coded into MS Excel 2013 and analysed using Statistical Package of the Social Science (SPSS v25.0; Armonk, New York). Descriptive statistical measures were used to analyse the average SNR mean and standard deviations of all conditions in the test and retest phase of the study. The different SNR's values were normally distributed as assessed by Shapiro Wilk's normality test ($p>0.05$). Therefore, a parametric analysis was used to analyse data. Repeated measures analysis of variances (ANOVA) was conducted to compare the effect of loudspeakers on the SNR. All pairwise comparisons run reported 95% confidence intervals and *p*-values were Bonferroni-adjusted. A paired sample t-test was used to determine whether there was a statistically significant mean difference between the SNR's in the initial test compared to the retest ($p<0.05$).

## CHAPTER 3: RESEARCH ARTICLE

**Title:** Performance and test-retest reliability of the digits-in-noise test used in the sound field

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Authors: Lisa Brown, De Wet Swanepoel, Faheema Mahomed-Asmail, Karina De Sousa

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

### 3.1 Abstract

**Purpose:** This study compared the speech reception thresholds (SRTs) and test-retest reliability of the smartphone digits-in-noise (DIN) test coupled to various sound field transducers.

**Method:** Fifty normal hearing participants (bilateral pure tone thresholds 0.5 – 8kHz ≤ 15dB HL) between the ages of 18 to 25 years (mean 20; SD ±1.93) were recruited. The study used a repeated measure counterbalanced Latin square design to compare the SRTs of the smartphone DIN test recorded with earphones, two smartphone speakers and two external loudspeakers in a sound booth. Test-retest reliability across sound field conditions was also determined.

**Results:** Mean SRTs across earphone and different sound field transducers ranged from -11.3 (0.8 SD) to -11.7 (1.2 SD). SRTs across the four different loudspeaker transducers and earphones were not significant ($p$ > 0.05) for both the initial test and retest.

**Conclusion:** The smartphone DIN test is reliable and can be conducted using various sound field transducers. This could allow home-based testing without earphones, with special application to aided performance for speech-in-noise testing.

### 3.2 Introduction

Hearing impairment is the fourth leading cause of disabling conditions globally (WHO, 2018). Approximately 466 million individuals live with disabling hearing loss where the majority of these individuals reside in low and middle-income countries (WHO, 2018). It is expected that the number of people with disabling hearing loss will increase with annual population-growth due to increasing life expectancy and dropping mortality rates (WHO, 2018). This increasing incidence has raised global awareness to reduce disabilities and handicaps such as hearing impairments.

Approximately 50% of hearing impairments could be prevented, and the remainder treated effectively (WHO, 2014; WHO, 2018). However, the prevention and treatment of permanent disabling hearing loss in low and middle-income countries are not prioritized in public health systems (WHO 2014). Typically, other health problems are favoured above hearing loss due to a lack of resources, such as trained health personnel and educational facilities (WHO, 2014; Wilson, Tucci, Merson & O'Donoghue, 2017). The inability to prevent or treat a hearing loss gives rise to societal and psychological consequences (Davis et al., 2016), due to communication exclusion resulting in increased feelings of loneliness, isolation and frustration (WHO, 2018; Davis et al., 2016). This may lead to depression and anxiety which all contributes to a reduced quality of life (Davis et al., 2016).

One of the most significant consequences and greatest handicap associated with a permanent disabling hearing loss is difficulty understanding speech-in-noise (Kramer, Kapteyn & Festen, 1998; Smits, Kapteyn & Houtgast, 2004). Tests to assess speech-in-noise recognition are valuable indicators of real-life communication difficulties as opposed to pure tone and speech audiometry in quiet (Taylor, 2003). A rapidly conducted speech-in-noise test using a closed response set of randomised digit triplets was developed by Smits et al. (2004). It measures an individual's ability to understand speech in the presence of background noise by varying the ratio between speech and noise levels (i.e. signal to noise ratio; SNR) (Smits et al., 2004; Smits et al., 2006; Rashid, Leense, de Laat & Dreschler, 2017). This self-administered screening test was developed to improve detection rates of underdiagnosed and untreated hearing loss globally (Smits et al., 2006; Potgieter, Swanepoel, Myburgh, Hopper & Smits, 2016). A telephone-based DIN screening test was successfully implemented in many high-income countries and access to such a test could provide an affordable option in low- and middle-income countries (LMICs) (Jansen, Luts, Wagener, Frachet & Wouters, 2010; Watson, Kidd, Miller, Smits & Humes, 2012; Potgieter, Swanepoel, Myburgh & Smits, 2018).

Unfortunately, in LMICs, landline telephones are usually unavailable. For example, in South Africa, less than 10% of households have access to landline telephones compared to an estimated 80% of households with access to smartphones (Statistics South Africa, 2013; Ericsson, 2015). The mobile revolution, in contrast, has seen cellular phones become part of everyday life in LMICs but the poorer audio call quality makes this inappropriate for a telephone test (Smits et al., 2004). Therefore, an alternative set-up is to use a smartphone application. Health surveillance utilizing smartphones has taken a significant foothold with estimates of 1.7 billion downloads by 2017 and global revenues of $21.5 billion in 2018 (Economist, 2016). As a result, a smartphone-based application that allows for widespread access to hearing screening in rural and urban areas and across different socio-economic strata was recently developed and validated (Potgieter et al., 2016; Potgieter et al., 2018). This test was released and marketed as South Africa's national hearing test allowing for an accessible hearing screening solution (De Sousa, Swanepoel, Moore & Smits, In Press).

Since smartphones can be coupled with different headphones, the influence of several types and quality of headphones was investigated (Potgieter et al., 2016). The test was found to be reliable across devices and different earphone and headphones without significant differences in results (Potgieter et al., 2016). The recommended procedure for a DIN test is coupling with earphones or headphones since an earlier study indicated that the SRTs recorded with headphones were better compared to loudspeakers (Smits et al., 2006). This difference was assumed to arise from poor listening conditions when using loudspeakers and the attentiveness of the listener when using headphones (Smits et al., 2006).

Listening to an auditory signal through the sound field differs from listening through earphones where a subject is more isolated from the surroundings, with more control on the distance to the acoustic signal (Kallinen & Ravaja, 2007). In sound field conditions, the interaction between the test stimuli, room acoustics and psychoacoustic perception in the listener becomes critical (Rochlin, 1993). Sound field testing is often used to evaluate the need and the degree of the benefit of hearing aids and to assess speech discrimination testing in noise (Rochlin, 1993).

Accurate and reliable DIN testing in the sound field using a smartphone may be important for national screening programmes and home-based test applications. For example, in LMICs, earphones or headphones may not be readily available to all those who own a smartphone as these countries are characterised with high unemployment rates and poor economic circumstances (Agarwal, 2017). Therefore, the alternative method of performing the smartphone DIN test would be the smartphone speaker itself. Also, although mobile phones are responsible for over half of the web traffic globally (52.2%); it is also largely accessed through laptops and tablets (Statista, 2018). Furthermore, most electronic equipment, such as smartphones, laptops, and tablets, have built-in speakers or can easily be coupled wired or wireless to external speakers (Leesen & Drechsler, 2013). Therefore, the speakers of these devices are another avenue through which the test could be performed.

Individuals such as children, who have tactile sensitivity issues or those with structural abnormalities such as atresia, barring placement of earphones, would also benefit from access to sound field test paradigms. Speech-in-noise tests are essential objective measures to maximise the validity and reliability of a listener's speech understanding with hearing aids or cochlear implants (Mendel, 2009). In clinical monitoring, newly implanted cochlear implant users require appointments to a centre between eight to ten visits a year with assessment of their speech recognition abilities nearly six times in the first three to six months post-implantation (Hughes, Goehring, Buadhuin, Diaz, Sanford, Harpster & Valente, 2012; de Graaff, Huysmans, Merkus, Goverts & Smits, 2018). Transportation to these centres can be financially and resource intensive, especially in LMICs, keeping patients from these visits. The DIN test in the sound field would, therefore, be convenient as a home-based clinical measure for hearing device performance over time. Furthermore, performing the smartphone DIN test through the sound field in tele-audiology models for screening and rehabilitation purposes would be beneficial to access underserved populations where hearing health care services are lacking in availability (Swanepoel et al., 2010).

The smartphone application of the DIN test has not been assessed in sound field conditions for accuracy and reliability. The aim of this study, therefore, was to evaluate the performance and reliability of the smartphone DIN application across various sound field transducers.

### 3.3 Materials and methods

Institutional review board approval was obtained prior to data collection which took place across two test sessions, ranging five to ten days apart. The first test session compared the smartphone DIN across a variety of loudspeakers compared to the coupling with the earphone condition. The second test session assessed the test-retest reliability of the earphone condition and the various sound field transducers.

### 3.3.1 Participants

A convenience sample of fifty participants (both male and female) aged 18 to 25 years (mean 20; SD ±1.93) were recruited for this study. Participants had pure tone thresholds <15 dB HL across 250 Hz to 8000Hz bilaterally and were otologically normal as assessed by the ISO 389-1 checklist for otologically normal hearing. Furthermore, participants were English home-language speakers, or, had good English proficiency. Participants rated their English competence on a scale of 1 to 10 (Potgieter et al., 2017). Only those with a rating of 7 or higher were considered to have good proficiency and were included in the study sample.

### 3.3.2 Equipment

*3.3.2.1 Hearing screening equipment*

Test procedures included the ISO 389-1 checklist for otologically normal hearing, otoscopy, tympanometry, hearing screening, and the smartphone DIN test. 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 for tympanometry. The Tympstar was calibrated according to the SANS 10154-1/2 10182.

Hearing screening was conducted using the Grason Stadler GSI 61 clinical audiometer calibrated according to the SANS 10154-1/2 10182 standards utilizing the Telephonics TDH-50P audiometric earphones.

*3.3.2.2 Smartphone DIN test*

The smartphone DIN research application (Android OS) using South African English digits (Potgieter et al., 2016; Potgieter et al., 2018) was performed with a binaural diotic (in-phase) stimulus paradigm. The application contains 120 unique digit triplets (e.g., 4-7-2) consisting of English mono- and bi-syllabic digits from 0-9 (Potgieter et al., 2016). This test involves listening and identifying digit-triplets randomly presented from the list of 120 triplets in the presence of broadband speech-shaped noise (Potgieter et al., 2016; Potgieter et al., 2018). The smartphone DIN test measures the signal-to-noise (SNR) ratio at which an individual identifies 50% of the digits correctly in the presence of changing levels of masking noise (Potgieter et al., 2016; Potgieter et al., 2018). The test used an up and down adaptive procedure, going down in 4 dB steps for the first three responses when triplets were entered correctly, thereafter, continuing in 2 dB steps. Each test uses 23-digit triplets and averages the last 19 responses to determine the SRT in dB SNR.

The smartphone DIN test was presented in five different conditions, varying between high- and low-end smartphones and loudspeakers. These included the 1) Samsung Fame Lite smartphone earphones coupled to the Samsung S4 smartphone and the speakers of the high end smartphone and loudspeaker, namely the 2) Samsung S4 smartphone and 3) Philips Docking Entertainment System BTM630 and the low end smartphone and speaker, namely the 4) Samsung S4 smartphone and 5) Jam Classic wireless Bluetooth speaker.

### 3.3.3 Procedure

Data was collected at the Department of Speech-Language Pathology and Audiology, University of Pretoria, in a sound booth. All participants underwent hearing screening to establish normal hearing thresholds (<15 dB HL at 250 Hz – 8000Hz). Thereafter, participants completed the ISO 389-1 checklist to determine otologically normal criteria. After all inclusionary criteria were met, participants completed the DIN test in five test setups. Participants performed the smartphone DIN with earphones, two smartphone speakers and two external loudspeakers after which the SNRs of the DIN tests were compared across test conditions. Participants were seated one meter away from the external loudspeakers in the booth facing the loudspeaker. The participant held the smartphone speakers at eye and ear level in front of them (Figure 2). The tests were counterbalanced using a Latin square to control the variation of the five listening conditions and avoid first-order carryover effects.

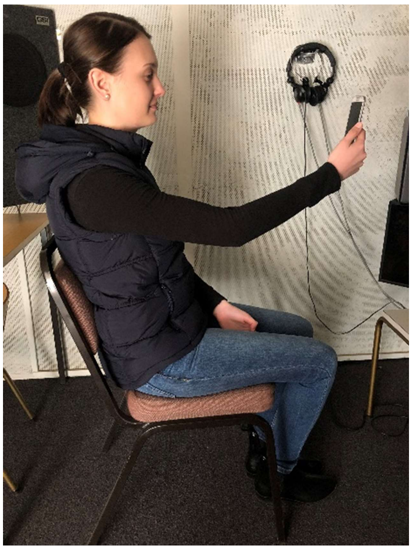

**Figure 2. Position of participant and smartphone during testing with smartphone speaker**

The second test session took place between five to ten days after the first test session. It involved retesting the smartphone DIN test through the sound field with three of the five conditions to avoid fatigue of the participant. The Samsung Fame Lite earphones were retested on all participants whereas only one of the smartphone speakers and one of the external loudspeakers were retested per participant.

### 3.3.4 Data analysis

Data was retrieved from the research Android OS application and was coded into MS Excel 2013 and analysed using Statistical Package of the Social Science (SPSS v25.0; Armonk, New York). Descriptive statistical measures were used to analyse the average SRT and standard deviations of all conditions in the test and retest phase of the study. The different values were normally distributed as assessed by Shapiro Wilk's normality test ($p > 0.05$). Therefore, a parametric analysis was used to analyse data. Repeated measures analysis of variances (ANOVA) was conducted to compare the effect of loudspeakers on the SRT. All pairwise comparisons run reported 95% confidence intervals, and *p*-values were Bonferroni-adjusted. A paired sample t-test was used to determine whether there was a statistically significant mean difference between the SNR's in the initial test compared to the retest ($p < 0.05$).

### 3.4 Results

A total of 50 adults were included in the study with a mean age of 20 years (±1.93 SD; Range 18 to 24 years). English first-language distribution was 58% and 42% Afrikaans first-language with good English-speaking competence.

Mean SRTs across the earphones, and four different loudspeaker transducers (Table 2), ranged from -11.3 dB SNR (0.8 SD) to -11.7 dB SNR (1.2 SD). A repeated measures ANOVA comparing the SRTs across the earphone and four-different loudspeakers demonstrated no significant difference between conditions ($F$ [4, 196] = 1.902, $p > 0.05$).

**Table 2. Speech Reception Thresholds across transducer types for the initial test and retest conditions.**

| Condition | **n** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| **Initial test** | | | | | |
| *Earphones* | 50 | -11.4 | 0.8 | -13.2 | -9.8 |
| *Smartphone Speaker (HE)* | 50 | -11.3 | 1.2 | -14.0 | -8.2 |
| *Smartphone Speaker (LE)* | 50 | -11.7 | 1.0 | -14.0 | -10 |
| *Loudspeaker (HE)* | 50 | -11.3 | 1.0 | -14.2 | -9.4 |
| *Loudspeaker (LE)* | 50 | -11.5 | 0.8 | -13.4 | -9.8 |
| **Retest** | | | | | |
| *Earphones* | 50 | -11.3 | 1.0 | -13.6 | -9.0 |
| *Smartphone Speaker (HE)* | 24 | -11.3 | 1.3 | -13.4 | -8.6 |
| *Smartphone Speaker (LE)* | 26 | -11.5 | 1.4 | -15.6 | -9.6 |
| *Loudspeaker (HE)* | 25 | -11.2 | 0.7 | -13.0 | -10.4 |
| *Loudspeaker (LE)* | 25 | -11.5 | 0.8 | -13.0 | -10.0 |

HE = Higher end device; LE = Lower end device; Earphones = Samsung Fame Lite earphones; Smartphone speaker (HE) = Samsung S4; Smartphone Speaker (LE) = Samsung J2; Loudspeaker (HE) = Philips Docking Entertainment System BTM630 Bluetooth USB and SD card slots; Loudspeaker (LE) = Jam Classic wireless Bluetooth speaker; n = Number of participants; SD = Standard Deviation

SRTs were not statistically significant ($p$ > 0.05) across all test retest transducer conditions. Mean test-retest differences ranged from -0.1 (1.0 SD) to 0.2 (1.4 SD) (Table 3).

**Table 3. Test-retest difference between the SNR means, SD, minimum, and maximum of the earphone and four speaker types.**

| Conditions | n | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| *Earphones* | 50 | -0.1 | 1.2 | 0.1 | 0.8 |
| *Smartphone Speaker (HE)* | 24 | 0.2 | 1.2 | 0.6 | 0.4 |
| *Smartphone Speaker (LE)* | 26 | -0.1 | 1.4 | 1.2 | 0.4 |
| *Loudspeaker (HE)* | 25 | 0.2 | 1.0 | 1.2 | 1.0 |
| *Loudspeaker (LE)* | 25 | 0.1 | 1.0 | 0.4 | 0.2 |

Earphones = Samsung Fame Lite earphones; Smartphone speaker (HE) = Samsung S4 speaker; Smartphone speaker (LE) = Samsung J2 speaker; Loudspeaker (HE) = Philips Docking Entertainment System BTM630 Bluetooth USB and SD card slots; Loudspeaker (LE) = Jam Classic wireless Bluetooth speaker; SD = Standard deviation; n = Number of participants

### 3.5 Discussion

To confirm accurate SRTs with the smartphone DIN test, various types of sound field transducers would have to agree across test conditions and have agreement between test and retest (Margolis et al., 2007). Mean SRTs across loudspeakers when compared to earphones was not significantly different and no significant differences across test-retest comparisons were found ($p$ > 0.05). Therefore, the smartphone DIN application can be administered using smartphone speakers and external loudspeakers in a low reverberated room with the same accuracy and reliability as in the earphone conditions. These results agree with a study conducted on an online DIN test, namely *Earcheck*, where different transducer types did not show a main effect on the results (Leesen & Dreschler, 2013).

In contrast, Smits et al. (2006) found a significant difference in SRT score of 1.1 dB between headphones compared to loudspeakers using the Dutch National Hearing Test. In the current study, there was no significant improvement in average SRT for the earphone condition (0.1 dB SNR). A probable reason for the Smits et al. (2006) result was that the sound field testing was not conducted in a sound booth but rather in a home environment (Smits et al., 2006). Therefore, possible ambient noise and reverberation in the environment, as well as distractions of the listener could have interfered with the results (Culling et al., 2005; Smits et al., 2006). Furthermore, the smartphone DIN test utilised broadband quality signals which range from 30Hz to 20 000Hz compared to the restricted bandwidth used with the Dutch National Hearing test (Smits et al., 2004; Potgieter et al., 2016; Potgieter et al., 2018). Previous studies on other speech-in-noise tests yielded results that differ in a home environment when compared to a controlled environment ranging on average from 1 dB to 1.45 dB poorer when compared to the SRT's obtained in a controlled environment (Culling et al., 2005; Leesen & Dreschler, 2013).

The average SRT across the loudspeakers in the current study (-11.5 dB SNR) was approximately 0.9 dB SNR better than the average mean of the normative diotic smartphone DIN test (-10.6 dB SNR) using earphones in normal hearing individuals (Potgieter et al., 2016). This difference may result from the adaptive procedure that was utilised in the current study where the first three digit-triplets, if identified correctly, used a 4 dB step size as opposed to a 2 dB step size by Potgieter et al. (2016).

Furthermore, the reliability of the test was derived from the mean differences between the SRTs in the initial test and retest, which ranged from -0.1 dB (1.0 SD) to 0.2 dB (1.4 SD) across all four speakers. The average retest SRT for earphones was small (0.1 dB SNR) compared to the smartphone speakers and external loudspeakers. Furthermore, no significant difference was noted in the test and re-test measures, taken on different days, of the DIN test ($p > 0.05$). This indicates that the DIN test can be performed reliably with various types of sound field transducers.

One limitation of the current study is that it was conducted in a controlled environment in a sound booth. The use of the application for screening and rehabilitation purposes, however, would typically be administered in a home environment which is not controlled. Earlier studies have suggested that the results of speech-in-noise tests presented through the sound field will be affected by the environment (Culling et al., 2005; Smits et al., 2006; Leesen & Dreschler, 2013). Furthermore, poorer speech recognition results were obtained via the sound field in home environments compared to a sound booth for CI users due to the prominent factors of background noise and room reverberation (Goehring et al., 2012; Hughes et al., 2012). In contrary, de Graaff et al. (2018) demonstrated that self-assessed speech recognition in noise tests in a home environment had no significant effect on results, suggesting that self-administered tests at home could be reliable. Thus, for the smartphone DIN test to be a useful home-based clinical tool, it should be tested in various home environments in a future investigation.

The current study indicates that the smartphone DIN test can be used in the sound field for screening and rehabilitation purposes such as monitoring amplification devices in clinics that have access to a sound booth. However, the problem of room noise can be overcome by properly instructing listeners on appropriate test environments. Therefore, based on these results, it is expected that the smartphone DIN test performed in the sound field could be a promising tool for home-based assessments.

# CHAPTER 4: DISCUSSION AND CONCLUSION

## 4.1 Summary and discussion of results

The smartphone DIN test has seen a significant uptake with more than 36 000 tests taken since its release in 2016 (De Sousa et al., In Press). Capitalizing on this current trend, the application has also been made available online as a web-based screening test, allowing test completion on smartphones, tablets and computers. Typically, the test is completed by coupling different earphones or headphones which do not influence the SNR results (Potgieter et al., 2016). However, due to several limitations, for example, the lack of availability of headphones or the anatomic structure of a person's ear, the use of headphones/earphones may not always be possible or available. Thus, individuals may need to use loudspeakers which could influence the results as there are many different qualities and types available. The current study evaluated whether the type and quality of different loudspeakers would influence the results when compared to the validated use of earphones.

The average SRT for earphones and external loudspeakers were similar (-11.4 dB SNR) and differed by 0.1 dB SNR across the smartphone speakers (-11.5 dB SNR). Overall, the average SRT across the loudspeakers was low (-11.5 dB SNR) and the difference between the loudspeakers and earphones was not significant ($p > 0.05$). Test-retest was performed to assess a possible test-retest difference in SRT results. The reliability of the test was obtained from the mean differences between the SRTs of the loudspeakers during the initial testing and retesting which ranged from -0.1 dB (1.0 SD) to 0.2 dB (1.4 SD). The average retest SRT for earphones and sound field transducers was small (0.1 dB SNR). Furthermore, no significant difference was noted in the test re-test measures of the smartphone DIN test ($p > 0.05$). These results indicate that the smartphone DIN test can be performed reliably across various types of sound field transducers in a low reverberated room.

The average mean SNR for the diotic smartphone DIN test in normal hearing individuals is -10.6 dB SNR (Potgieter et al., 2016). In the current study, the average mean across the various loudspeakers was approximately 0.8 dB better than the SNR in the normative data (Potgieter et al., 2016). This difference may result from the different adaptive procedure that was utilised in the current study as compared to Potgieter et al. (2016) study. In the current study, the first three digit triplets utilised a 4 dB adaptive procedure if all three-digit triplets were correctly identified, which was followed by the 2 dB adaptive procedure for the remaining 20 digit-triplets. Whereas, Potgieter et al. (2016) study utilised the 2 dB adaptive procedure from the beginning of testing.

The current study indicates that the smartphone DIN test is reliable across various transducer types. This agrees with the previous study of Leesen and Dreschler. (2013) where different transducer types, including laptop speakers, did not influence the results of the computer-based DIN test, *Earcheck*. However, the results of the current study are different to those reported by Smits et al. (2006) where the SRT results differed when the tests were presented through the sound field compared to earphones (Smits et al., 2006). The estimated average SRT for participants who used headphones was 1.1 dB better than for loudspeakers (Smits et al., 2006). In the current study however, the improvement of the SRT for the earphone condition was small (0.1 dB SNR). The poorer results obtained in Smits et al. (2006) study in the sound field could be attributed to the fact that the testing was performed in a home environment making the environment vulnerable to poorer testing condition. Ambient noise and reverberation present in a room could contribute to the poorer testing conditions in addition to the distractions of the listeners which may all result in poorer results (Culling et al., 2005; Smits et al., 2006).

Previous studies have indicated that SRTs obtained in a home environment range on average from 1 dB – 1.45 dB poorer when compared to the SRTs obtained in a controlled environment (Culling et al., 2005; Leesen & Dreschler, 2013). Furthermore, poorer speech recognition results were obtained via the sound field in home environments compared to a sound booth for CI users due to the prominent factors of background noise and room reverberation (Goehring et al., 2012; Hughes et al., 2012). In contrast, de Graaff et al. (2018) demonstrated that self-assessed speech recognition in noise tests in a home environment had no significant effect on results, therefore, making it possible to perform self-administered tests at home. In addition, a study that compared the use of speech-in-noise tests demonstrated results that were similar in a domestic and controlled environment (Culling et al., 2005). However, this home environment was simulated and therefore, similar for all the participants (Leesen & Dreschler, 2013).

The current study demonstrates that the smartphone DIN test is reliable in the sound field in a sound booth across various transducers. In addition, is expected that the smartphone DIN test performed through the sound field will be a promising tool in a home environment with comparable results to the current study if the noise and reverberation is low.

### 4.2 Clinical implications and recommendations

The current study has demonstrated that the smartphone DIN test is possible through the sound field in clinical settings whom have access to a sound booth. This is important as many individuals who cannot use headphones/earphones, such as in the case of bilateral atresia, can now perform this test during a clinical assessment. Furthermore, this test can now be expanded in the clinical setup to perform the test on hearing aid and/or CI users to measure the amplification devices' performance.

However, an important advantage of administering the smartphone DIN test in the sound field is to perform the test as a measure of the performance of amplification devices in the comfort of one's home. In the current study, the smartphone DIN test was performed in a sound booth; however, the smartphone DIN test is an application designed for the use of individuals at home. Therefore, for the smartphone DIN test to be a useful home-based clinical tool, it should be tested in a home environment and results should be comparable to the current study. This would be important as earlier studies have reported that presenting speech-in-noise tests through the sound field will be affected by the environment (Culling et al., 2005; Smits et al., 2006; Leesen & Dreschler, 2013). This difference in results could be attributed to ambient noise and room reverberation (Goehring et al., 2012; Hughes et al., 2012). However, in contrast, the de Graaff et al. (2018) study demonstrated that self-assessed speech recognition in noise tests in a home environment had no significant effect on results when assessing the performance of CI, therefore making it possible to perform self-administered tests at home. This can be made possible if the environment is quiet and has a minimum amount of ambient noise present.

The smartphone DIN test through the sound field may be advantageous in a tele-audiology set-up where a lack of availability and significant barriers, such as transportation and funding, to access audiological services are problematic (Stephens, 2013). As clinical measures of amplification devices are vital to maximise the validity and reliability of hearing aids and/or CI, home-based validation is important to ensure correct amplification is provided to hearing aid and/or CI users (Mendel, 2009). A proposed solution for this dilemma may be an amplification monitoring programme to be carried out at home for hearing aid and/or CI users so that audiological services can be provided to these individuals (Figure 3).

#### *4.2.1 Amplification monitoring programme*

An amplification monitoring programme can be carried out as part of a tele-audiology set-up. An audiologist can fit and programme an amplification device at a remote site after which the hearing aid and/or CI user can utilise the application to monitor their amplification benefit. A baseline measurement can be obtained with the smartphone DIN test of the performance of the amplification device on the day of programming the device. The application can provide reminders that may initially be scheduled weekly on the hearing aid user's smartphone to monitor his/her hearing aid or CI using the application through the sound field. Thereafter, the application could provide more intermittent reminders that may be monthly for example. If any shifts from the baseline are observed, a visit to their audiologist for the necessary changes to be made on the amplification device may be achieved. This proposed conceptual model for a future monitoring program is illustrated in Figure 3.

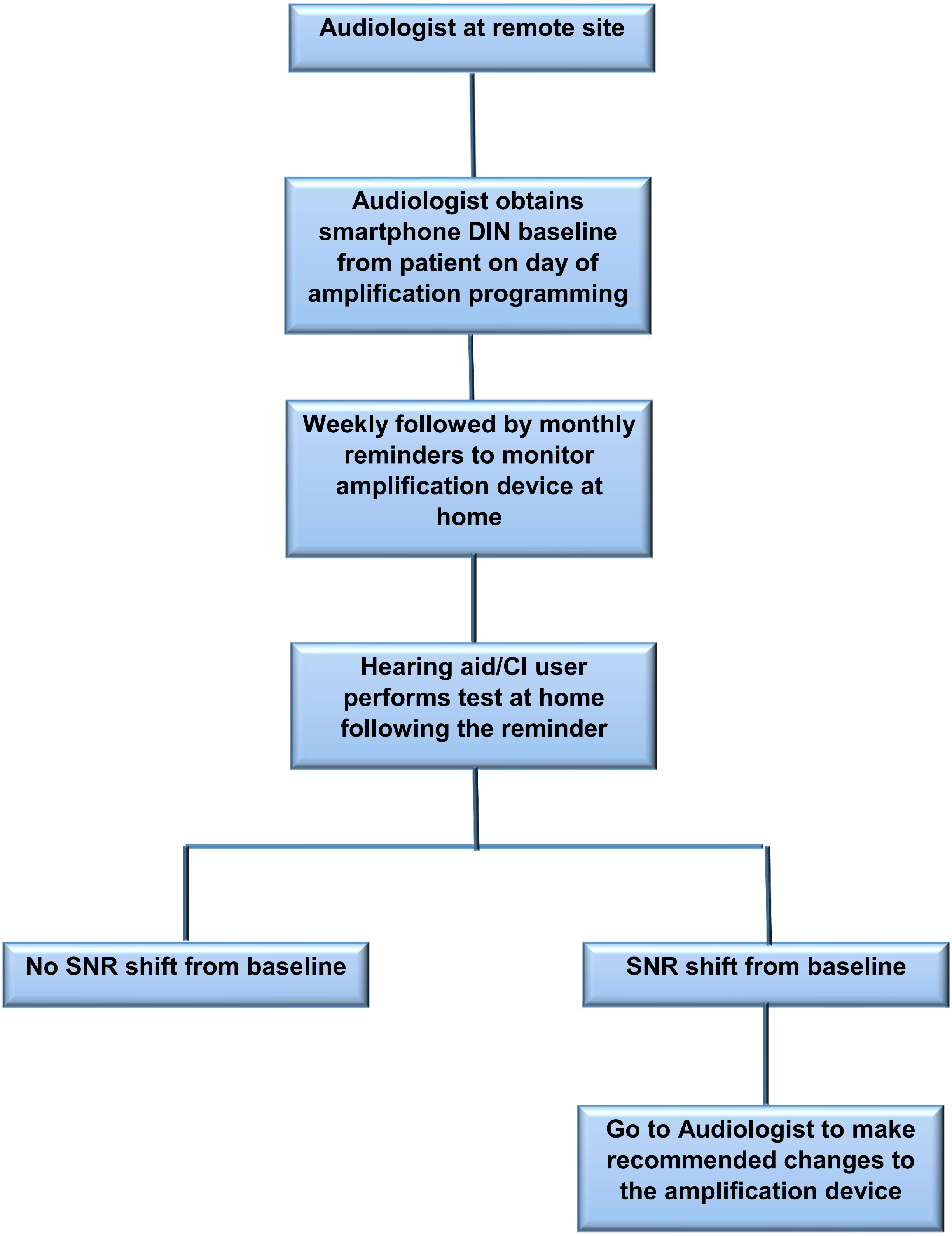


**Figure 3 Conceptual model for a monitoring programme**

### 4.3 Critical Evaluation

It is important to critically evaluate the research project to interpret the findings in terms of their strengths and limitations. These are mentioned below:

***Strengths of the study:***

- This study was the first to investigate the smartphone DIN test in combination with a variety of sound field transducers. This can result in the increase of individuals to use the smartphone application for those who cannot utilise headphones/earphones. Furthermore, it enables the possibility of home-based clinical measures of the performance of amplification devices.
- The research tests were counterbalanced using a Latin square to control the variation of the five listening conditions and avoid first-order carryover effects.
- The extraneous factors, such as the noise levels and the placement of the sound field transducers, of the research study were controlled.
- Various sound field transducers were utilised including lower and higher end smartphone speakers and external loudspeakers. This indicates that the smartphone DIN test is not influenced by the various types and quality of loudspeakers.
- The smartphone DIN application was reliable across various sound field transducers in a sound booth.
- Retesting was performed across the loudspeakers and earphone condition which deemed the results of the smartphone DIN test reliable across all transducers.

***Limitations of the study:***

- The current study was conducted in a sound booth with little to no reverberation. This is a limitation as the test environment that users would usually perform the test will likely be in a home environment where ambient noise and reverberation may be present. Therefore, it is likely that the results obtained in this study would be enhanced when compared to a home environment. Thus, it is important for future investigations to conduct testing in a home environment.
- Participants had to perform the smartphone DIN test five times in one day, and therefore, were vulnerable to fatigue. This could have caused a lack of concentration from the participants towards the end of testing, and as a result, could have influenced results.

- The retest of the smartphone DIN test was only conducted on the earphone condition and one smartphone and one external loudspeaker. Therefore, all sound field transducers were not retested on all participants, thus, this could possibly influence the retest results.

### 4.4 Future Research

The following recommendations are based on the critical evaluations of the research project:

- All participants with a hearing loss of any degree were excluded from this current study. Future studies should include various degrees of hearing loss to determine if results could be affected in the sound field based on different degrees and types of hearing losses. This is important as individuals with a hearing loss are an important target audience for this application (De Sousa et al., In Press).
- Performing the test in a home environment, where the environment is not controlled, to represent an environment where individuals would use the test. This is important as the smartphone DIN test is not intended for the use in a sound booth for individuals, but rather at home. Therefore, it will be important to note if the results obtained in a home environment will be comparable to the results obtained in this study.
- Performing the smartphone DIN test through the sound field will be beneficial for hearing aid and/or CI users to monitor the performance of their amplification devices over time. Therefore, future research should include hearing aid and CI users to determine whether there will be an effect of the SNR results through the sound field with hearing aids and CI.

## 4.5 Conclusion

Performing the smartphone DIN test through the sound field can increase the uptake of the application for hearing screening as it can be made available for individuals who cannot utilise headphones/earphones and to make home-based amplification monitoring possible. The current study demonstrated that the smartphone DIN test can be performed through the sound field in a low reverberated room with low noise levels reliably, and in effect, making the application accessible through the sound field. However, the potential SNR differences for the smartphone DIN test in a controlled environment compared to a home environment needs to be investigated to determine whether this may influence results.

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# APPENDICES

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

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

**Faculty of Humanities**
Department of Speech-Language Pathology and Audiology

**Attention: Director of Student Affairs**

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

I, Lisa Brown, am a final year audiology student at the Department of Speech-Language Pathology and Audiology at the University of Pretoria. I 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 postgraduate degree.

I am conducting a research project entitled: ***Test retest reliability and performance of the SA DIN test in the sound field.*** This research project will be conducted in the field of the South African Digits-in-Noise (SA DIN) smartphone test application. The SA DIN smartphone test application was developed and validated by researchers from the University of Pretoria. The SA DIN test has been validated on some headphone and earphones, however, this application has not been assessed in sound field conditions. I wish to investigate and compare the use of earphones versus the variability of different speakers in sound field testing when using the SA DIN application and to determine the test-retest reliability of these different speakers.

**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. Participation in the study will be conducted in two test sessions on two different days. The assessment period of the first test session will be approximately 30 minutes and the second phase will be approximately 10 minutes. The assessment will include the following tests:

1. Otoscopy and Tympanometry

The first test in this evaluation is otoscopy and tympanometry. Otoscopy will be performed to identify if there are any external ear pathologies. This will be followed by tympanometry where a probe tip (rubber tip) will be placed into the ear and the ear will feel a bit of pressure. This measures the pressure in the middle ear, the mobility of the eardrum and the volume of the ear canal. This determines whether the participant’s middle ear is functioning normally.

2. Pure tone screening audiometry

Participants will be asked to perform a hearing screening test. Using headphones, 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.

3. South African Digits in noise test:

This will involve listening and identifying three digits in the presence of background noise which will vary in loudness as the test proceeds. This test will be conducted in two test sessions on two different days. The first test session will be performed in five different conditions. These conditions include the Digits in Noise test that will be presented through two different commercial loudspeakers, two different smartphone loudspeakers and earphone condition all presented in an “office-like” environment. The second test session, which will occur 5 to 10 days following test session 1 will include retesting the earphone and two of the speaker conditions mentioned above.

**Ethical Considerations:** The participant will only participate after they have given the consent. All information about the participant and information collected during this research will be kept confidential and only the researchers will have access to such information. Participants will be given a numeric code to ensure anonymity. This code will be used during data analysis and the code will only be known to the researcher and the supervisors. Confidentiality will be guaranteed. The data collected will be stored for 15 years for research purposes.

**Risks and benefits:** There are no risks of participating as the participant will not be harmed in anyway. There will be no direct benefits to the participants.

The data collected will be able to help us determine if the SA DIN smartphone application in the sound field will yield the same or different results when using earphones. Thus assisting in advancing the knowledge in this 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,

Lisa Brown
Researcher
Tel: 084 897 2803
Email: brownlisa2468@gmail.com

Prof. De Wet Swanepoel
Supervisor

Dr Faheema Mohomed-Asmail
Supervisor

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

I, NRM MADIBA give permission that students from the University of Pretoria may be contacted and used as participants for the research project titled: Test retest reliability and performance of the SA DIN test in the sound field – pending ethical clearance from the faculty.

Signature

13/12/2017

Date

# Appendix B: 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 C: Ethical clearance form: Faculty of Humanities

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

28 February 2018

Dear Ms Brown

| | |
|---|---|
| **Project:** | **Test retest reliability and performance of the SA DIN test in the sound field** |
| **Researcher:** | **L Brown** |
| **Supervisors:** | **Prof DCDW Swanepoel and Dr F Mahomed-Asmail** |
| **Department:** | **Speech-Language Pathology and Audiology** |
| **Reference Number:** | **14188202 (GW20180116HS)** |

Thank you for the application that was submitted for ethical consideration.

I am pleased to inform you that the above application was **approved** by the **Research Ethics Committee** at an ad hoc held on 28 February. Data collection may therefore commence.

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

We wish you success with the project.

Sincerely

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

cc: Prof DCDW Swanepoel and Dr GF Mahomed-Asmail (Supervisors)
Dr J van der Linde (HoD)

## Appendix D: Participant information letter and Informed consent

# INFORMED CONSENT – RESEARCH PROJECT

Dear Participant,

Thank you for considering participating in the research project entitled***: Test retest reliability and performance of the SA DIN test in the sound field.*** I am conducting my research project on the South Africa Digits-in-Noise (SA DIN) application in the sound field. The South-African Digits in Noise test has been validated on some headphone and earphones, however, this application has not been assessed in sound field conditions. Sound field refers to the condition in which the acoustic signal is presented through a loud speaker that is delivered at a distance to the listener. I wish to investigate and compare the use of earphones versus the variability of different speakers in sound field testing when using the South African Digit-in-Noise application and to determine the test-retest reliability.

Before you agree to take part in this study you should fully understand what is involved. We ask that you read this form and ask questions should you have any questions before agreeing to participate in the study.

**Volunteers:** 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.

**Procedures:** Participation in the study will be conducted in two test sessions on two different days. The assessment period of the first phase will be approximately 20 minutes and the second phase will be approximately 10 minutes. If you agree to participate in this study, the assessment will include the following tests:

1. Otoscopy and Tympanometry

The first test in this evaluation is otoscopy and tympanometry. Otoscopy will be performed to identify if there are any external ear pathologies. This will be followed by tympanometry where a probe tip (rubber tip) will be placed into the ear and the ear will feel a bit of pressure. This measures the pressure in the middle ear, the mobility of the eardrum and the volume of the ear canal. This determines whether your middle ear is functioning normally.

2. Pure tone audiometry

For this test you will place 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.

3. 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 test session will be performed in five different conditions. These conditions include the South-African Digits-in-Noise test that will be presented through two different commercial loudspeakers, two different smartphone loudspeakers and earphone condition all presented in a sound booth. The next phase, which will occur 5 to 10 days after the first phase, will include retesting two of the speaker conditions mentioned above.

**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 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 Lisa Brown, 084 897 2803.

Should you wish to make use of these services and participate in this research project, kindly complete the informed consent form.

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

Lisa Brown
Researcher

Prof. Swanepoel
Supervisor

Dr. Faheema Mohamed-Asmail
Supervisor

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

**Faculty of Humanities**
Department of Speech-Language Pathology and Audiology

**Consent to participate in this study**

| **Participant information number** | |
|---|---|

The research has been explained to me. I, ________________________ (name and surname) voluntarily consent to participate in the study titled: ***Test retest reliability and performance of the SA DIN test in the sound field.*** 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 E: Data collection sheet

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

**Faculty of Humanities**
Department of Speech-Language Pathology and Audiology

Name___________________ Date _______________________

DOB____________________ Native Language ____________

Subject number: _____________

## *Phase I – Testing Phase*

**TYMPANOMETRY**

| | **Left ear** | **Right ear** |
|---|---|---|
| Type | | |
| Middle ear pressure (daPa) | | |
| Static Compliance (ml) | | |
| Ear canal volume (ml) | | |
| **VENUE** | | |
| **TIME** | | |

**PURE TONE THRESHOLDS:**

| | **Left ear (dB)** | **Right ear (dB)** |
|---|---|---|
| 250Hz | | |
| 500Hz | | |
| 1000Hz | | |
| 2000Hz | | |
| 4000Hz | | |
| 8000Hz | | |
| **VENUE** | | |
| **TIME** | | |

**SA DIN SMARTPHONE TEST**

| **CONDITIONS** | **SNR RESULTS** | **TIME** |
|---|---|---|
| Earphones | | |
| Samsung Galaxy s4 | | |
| Samsung J2 | | |
| Jam Classic | | |
| Philips | | |
| **VENUE** | | |

**TOTAL TIME =**

***Phase II – Test-retest reliability***

| **CONDITIONS** | **SNR RESULTS** | **TIME** |
|---|---|---|
| Samsung Galaxy s4 | | |
| Samsung J2 | | |
| Jam Classic | | |
| Philips | | |
| **VENUE** | | |

**TOTAL TIME:**

## **Additional comments:**

## Appendix F: Submission confirmation of article to the American Journal of Audiology

The American Journal of Audiology

Home

Author

Review

# Submission Confirmation

Print

## Thank you for your submission

**Submitted to**
The American Journal of Audiology

**Manuscript ID**
AJA-HEAL18-18-0161

**Title**
Performance and reliability of a smartphone digits-in-noise test in the sound field

**Authors**
Brown, Lisa
Swanepoel, De Wet
Mahomed-Asmail, Faheema
Swanepoel, Karina

**Date Submitted**
23-Oct-2018

Author Dashboard