Maturation of speech-in-noise performance in children using binaural diotic and antiphasic digits-in-noise testing

by

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LIST OF ABBREVIATIONS

DIN:	Digits-in-noise
EAL:	English additional language
EFL:	English first language
LMIC:	Low and middle-income country
NIHL:	Noise-induced hearing loss
SNR:	Signal-to-noise ratio
SRT:	Speech reception threshold

FORMATTING

APA referencing style was used in this dissertation.

ABSTRACT

Digits-in-noise (DIN) tests have become very popular over the past 15 years for hearing loss detection. Several recent studies have highlighted the potential utility of digits-in-noise (DIN) as a school-aged hearing test. However, age may influence test performance in children. In addition, a new antiphasic stimulus paradigm has been introduced. This study determined the maturation of speech recognition for diotic and antiphasic DIN in children and evaluated DIN self-testing in young children. A cross-sectional, quantitative, quasi-experimental research design was used in this study. Participants with confirmed normal hearing were tested with a diotic and antiphasic DIN test. During the DIN test, arrangements of three spoken digits were presented in noise via headphones at varying signal-to-noise ratios (SNRs). The researcher entered each three-digit sequence the participant said on a smartphone keypad. Six hundred and twenty-one normal hearing (bilateral pure tone threshold of ≤ 20 dB HL at 1, 2, and 4kHz) children between the ages of 6-13 years with normal hearing were recruited in order to examine the comparative maturation of diotic and antiphasic performance. A further sample of 30 first grade (7-year-old) children with normal hearing were recruited to determine the validity of self-testing on a smartphone. Multiple regression analysis including age, gender, and English additional language (i.e. Person whose first language or home language is not English) showed only age to be a significant predictor for both diotic and antiphasic SRT ($p < 0.05$). Speech reception thresholds improved by 0.15 dB and 0.35 dB SNR per year for diotic and antiphasic SRT, respectively. Post hoc multiple age group comparisons using Bonferroni adjustment for multiple comparisons (by year) showed SRTs for young children (6 to 9 years old) differed significantly from older children (11 to 13 years old) ($p < 0.05$). There was no significant difference in SRT between age 10 and upward. Self- and facilitated testing in young children was significantly ($p > 0.05$) different for the antiphasic condition and demonstrated poor reliability in diotic and antiphasic conditions. Increasing age was significantly associated with improved SRT using diotic and antiphasic DIN. Beyond 10 years of age, SRT results of children became more adult-like. However, age effects were only significant up to 10 and 12 years for antiphasic and diotic SRT, respectively. Furthermore, between self- and facilitated testing, the SRT difference was not significant ($p > 0.05$).

Keywords: Age, children, speech-in-noise recognition, diotic, antiphasic, speech reception threshold.

1. INTRODUCTION

Approximately 49 million individuals in Sub-Saharan Africa have a disabling hearing loss (World Health Organization, 2019). An estimated 34 million children worldwide have a disabling hearing loss (World Health Organization, 2019). It is well known that unidentified childhood hearing loss is associated with poor academic achievement, increased dysfunction in aspects such as self-esteem, behaviour, energy, and socio-emotional ability and limited vocational outcomes (Bess, Dodd-Murphy,& Parker, 1998; Lieu, 2004; Stevenson, Kreppner, Pimperton, Worsfold, & Kennedy, 2015; Theunissen et al., 2014; Winiger, Alexander, & Diefendorf, 2016). Ideally, newborn infants should be screened after birth, but due to poor adherence to neonatal hearing screening (Swanepoel, 2009), loss to follow-up testing (Russ, Hanna, DesGeorges, & Forsman, 2010; Shulman et al., 2010), and progressive or acquired hearing loss during infancy and early childhood (Barreira-Nielsen et al., 2016), childhood hearing loss is not adequately assessed or managed, even in high-income countries. Children’s ability to learn in a noisy classroom is affected by their speech recognition abilities in noise. In addition, hearing loss can reduce speech-in-noise recognition abilities in children (Ching et al., 2017). Therefore, it is imperative to know how speech-in-noise recognition of normal hearing children matures with age. Noise-induced hearing loss (NIHL) concerns have also increased due to personal audio device usage amongst youths (Twardella et al., 2017; Vogel, Brug, Van der Ploeg, & Raat, 2011). Children as young as seven years old have been associated with permanent hearing loss due to personal audio usage (Cone, Wake, Tobin, Poulakis, & Rickards, 2010). School hearing screenings, therefore, offer a way to identify progressive hearing loss and NIHL.

Many low- and middle-income countries do not mandate hearing screenings for newborns and infants (Olusanya, 2012). However, even in countries where mandates exist, it is possible that infants with hearing loss may be missed. Periodic hearing screenings in schools are, therefore, often the first point of access for children not screened at birth (Van Kerschaver, Boudewyns, Declau, Van de Heyning, & Wuyts, 2012), and is a valuable strategy to identify late-onset and acquired childhood hearing loss. Due to the lack of resources, the prevention and treatment of a permanent hearing loss are not prioritised (World Health Organization, 2017). This underscores the increased need for cost-effective hearing health care to address disabling hearing losses (Fagan & Jacobs, 2009). Furthermore, a passed hearing screening (negative for hearing loss) does not guarantee that a child has unaffected hearing. Hearing screening programmes play an important role in early detection of hearing difficulty as well as monitoring hearing (World Health Organization, 2017). Current protocols for school-aged screening recommend pure tone audiometry (AAA, 2011). While pure tone testing is an accurate method for detection of peripheral hearing loss, it is reliant on trained personnel and expensive audiometric equipment that must be calibrated regularly to industry standards.

Children mostly listen to speech in acoustically demanding situations where there is a dependence on their ability to separate speech from noise and use of binaural cues (Koopmans, Goverts, & Smits, 2018). Besides good peripheral hearing, the maturation of cognitive factors such as working memory and attention, and auditory function (e.g. temporal processing) also play a role in the ability to accurately recognize speech in noise (Schoof, 2014; Neher, 2017). Speech recognition in noise is, therefore, a developmental process where performance improves with increasing age in childhood and the maturation of these processes may have an effect on results. Speech-in-noise testing has recently been proposed as a possible screening measure in children using a simple digits-in-noise (DIN) test (Denys et al., 2018; Koopmans et al., 2018). The DIN test uses a closed set of digits presented as triplets in speech-shaped masking noise to measure the speech reception threshold (SRT), expressed in dB signal-to-noise ratio (dB SNR), where 50% of the digit triplets can be recognized correctly (Smits, Goverts & Festen, 2013; Potgieter, Swanepoel, Myburgh, & Smits, 2017). This measure has a strong correlation with pure tone average thresholds and has been shown to have specificity and sensitivity above 90% to detect sensorineural hearing loss in adults (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016; Potgieter et al., 2017). Sentences are typically preferred for speech-in-noise assessment since it includes contextual cues and can have a central influence. However, the use of digits is debatably more valid since digits are more of a test of peripheral hearing and easily understood by persons with limited linguistic skills and multilingual environments (Smits et al., 2013). Especially within a multilingual context in countries like South Africa, English numerals are often most frequently used in most languages and amongst some of the first words learned (Branford & Claughton, 2002). Children's abilities to recognize speech in noise can reliably and accurately be assessed using the DIN, as digits are easily understood, even by listeners with low linguistic competence (Kaandorp et al., 2015). More recently, attention has been given to DIN assessment in children. Koopmans et al. (2018) and Moore et al. (2019) have shown that, when facilitated by a test administrator, the test can accurately be conducted in children as young as four years old. When unassisted, young children tend to perform poorly (Denys et al., 2018). Speech-in-noise tests are known for their robustness since they can be used without professionally calibrated equipment, as a self-test, and are less sensitive to ambient noise than audiometry (Jansen, Luts, Wagener, Frachet, & Wouters, 2010; Smits, Kapteyn, & Houtgast, 2004). Consequently, the DIN was developed as a self-screening for mobile (De Sousa, Swanepoel, Moore, & Smits, 2020; Potgieter et al., 2016), telephone (Smits et al., 2004) and internet platforms (Moore, Zobay, Mackinnon, Whitmer, & Akeroyd, 2017).

Worldwide, current mobile device use is estimated at 5 billion individuals, with smartphones accounting for more than half (Pew Research Center, 2019). It has been predicted that smartphone use will grow by 20 per cent between 2017 and 2025, demonstrating that three out of four phones will be a smartphone (GSMA, 2018). Due to rapidly increasing mobile internet use (Sanou, 2015), the first downloadable app-based version was released as South Africa’s national hearing test in 2016 (Potgieter et al., 2016). There are several versions of the DIN, differing in either language, test procedure or both Previous landline telephone and computer-based versions of DIN tests either sequentially tested each ear (Smits et al, 2004; Jansen et al, 2010; Watson et al, 2012) or used binaural diotic (NoSo) presentation (Potgieter et al, 2016), where identically phased speech is presented to both ears simultaneously in the presences of masking noise. Although the diotic binaural test version is highly time efficient with a typical test completed within three minutes (Potgieter et al., 2016, 2017), it lacks sensitivity to unilateral hearing loss since the results reflect primarily the performance of the better ear (De Sousa et al., 2020). Therefore, a listener with asymmetric or unilateral hearing loss may still pass the screening since they can adequately hear the signal presented to the better ear. Furthermore, suprathreshold tests like the DIN are insensitive to the attenuation caused by conductive hearing loss (De Sousa et al., 2020). The most common hearing loss in young children is conductive, related to otitis media (ASHA, 2019) and wax impaction (Butler, 2012). In a study by Hussain, Alghasham, and Raza, (2011), 88.2% of hearing-impaired children (5-15 years old) had conductive hearing loss (CHL). Middle ear issues increase the risk of medical and developmental consequences, including permanent hearing loss, social isolation, and academic disadvantage.

Recently, a DIN test with a new antiphasic (NoSπ) stimulus paradigm using speech with a 180° phase shift between the two ears (Smits et al, 2016; Koopmans et al, 2018), has been found to improve sensitivity to all main forms of hearing loss, including unilateral and CHL (De Sousa et al., 2020). The advantages of hearing with both ears are greater compared to hearing with only one ear. These advantages are attributed to the ability of the brain to amplify the sound, which stimulates both ears (Deun et al., 2009). When there is a difference in the phase of the signal between the ears, the auditory system lets a person hear sounds at a lower signal-to-noise (SNR) in the presence of competing background noise (Durlach, 1963). De Sousa et al. (2020) also found larger areas under the Receiver Operating Characteristic (ROC) curve for detection of hearing loss (> 25 dB HL) for antiphasic (0.94) than for diotic DIN (0.77). Thus, antiphasic SRT is a more sensitive measure for hearing loss detection. Recently, there has been a growing acknowledgement that pure-tone audiometry is a substandard illustrator of speech perception and suprathreshold, especially in environments that are noisy (De Sousa et al., 2020; Liberman, 2017).

This study investigated the maturation of diotic and antiphasic SRTs in children between 6 and 13 years of age. A secondary aim was to determine the validity of self-testing on a smartphone compared to facilitated testing in a subgroup of seven-year-old children.

2. METHODOLOGY

2.1. Research aims

To investigate the maturation of the diotic and antiphasic SRTs in children between 6 and 13 years of age.

Secondary Aim

To evaluate the self-test validity of speech recognition in noise in a subgroup of seven-year-old children

2.2. Research design

This study employed a cross-sectional, quantitative, quasi-experimental research design (Leedy & Ormrod, 2010), assembling a sample of participants at one point to assess the predictor and outcome variables simultaneously and determine any associations (Haynes & Johnson, 2009). In the case of this study, to investigate the maturation of the diotic and antiphasic SRTs in children within a fixed period. The tests were counterbalanced in order to counteract test order bias.

The secondary aim of the study used a comparative within-subjects design (Leedy & Ormrod, 2015) to compare diotic and antiphasic SRTs when the South African English DIN test was self-tested by the participant and facilitated by the researcher. Additionally, the secondary aim required the same participant to be measured on two independent variables (diotic and antiphasic) using a repeated measures design (Beins, 2009). The repeat-measures design was counterbalanced in order to counteract test order bias.

2.3. Ethical considerations

Ethical considerations are vital to address and protect the welfare and rights of the persons involved in the study (Leedy & Ormrod, 2010). The Faculty of Humanities Research Ethics Committee (Appendix A) was granted before data collection commenced.

Permission

The principals of four English-medium private schools in the City of Tshwane, South Africa granted permission (Appendix B1; B2; B3; B4) to permit the recruitment of students from the various schools for participation in the study.

Voluntary and informed consent

Informed consent (Appendix C) letters explaining the procedures, risks, and benefits of participation were compiled and provided to the parents. The letters were easy to understand, distinctly stated the title and objective of the study, and provided a clear description that the participants may abort testing at any time (Maxwell & Satake, 1997). After a simple explanation, participants were required to provide both verbal and written informed assent before the assessment commenced.

Confidentiality and right to privacy

All researchers must respect the privacy of the participants by keeping all information strictly confidential. Therefore, no identifying information will be used (Leedy & Ormrod, 2015). The parents were ensured that all their information would be kept strictly confidential and that only research clinicians would analyse the data. This was achieved by participants receiving a numeric code to ensure confidentiality. Only the research clinician knew the identity of participants. No identifying data were captured to ensure complete anonymity.

Protection from harm

Participants in the study should not be exposed to any risk that exceeds the normal risks of everyday living (Leedy & Ormrod, 2015). Researchers should protect participants from any unnecessary physical or psychological harm (Leedy & Ormrod, 2015). In this study, all participants were handled courteously and respectfully as well as protected with regards to gender, culture, and inability to self-advocate. The study contained no known associated medical risks or discomfort, as explained to the participant.

Benefits

Parents were informed that there are no direct benefits to their child by partaking in the study, but that the results of this study were for research purposes. Participants who were identified with hearing loss were referred to their closest hearing healthcare provider for further evaluation at their own discretion.

Plagiarism

Plagiarism is the act of using another's ideas or writings and passing it off as your work without proper acknowledgement (Brynard, Hanekom, & Brynard, 2014). All sources used in this study were appropriately cited in the text as well as in the reference list.

Release of findings

Participants were made aware that the information obtained in the study might be published in professional journals and used in future research.

2.4. Participants

Requirements for this study included normal bilateral hearing sensitivity (bilateral pure tone threshold of ≤ 20 dB HL at 1, 2, and 4kHz) via screening and normal middle ear functioning confirmed by normal audiometry, otoscopy, and tympanometry results. Purposive sampling was used to recruit 661 participants from four English private schools in the City of Tshwane, South Africa, and stratified according to age. However, only 621 met the inclusion criteria of normal hearing (bilateral PTA ≤ 20 dB HL at 1, 2, and 4kHz), outer and middle ear function (428 male and 193 female). Participants who failed testing were referred for further diagnostic assessment. These participants were from grades 1 to 7 ranging between the ages of 6 to 13 (Mean 9.6; SD 2.1) and were categorized into English first language (EFL) (n=556) and English additional language groups (EAL) (n=65). A sub-group of seven-year-olds (n=30), complying with the same selection criteria mentioned above, were selected to determine the validity of self-testing on a smartphone compared to facilitated testing of diotic and antiphasic SRT. These children were recruited within the seven-year-old participant group to partake in further testing for the secondary aim of 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 further evaluation at their own discretion.

2.5. Materials and apparatus

Table 1 provides an overview of the materials and apparatus used in the research study.

Table 1. Equipment

Equipment	Description
Welch Allyn PocketScope™ with reusable specula	An otoscope was used to examine the external ear canal and tympanic membrane for any abnormalities.
MAICO RO•SCAN® Pro Tympanometer	A tympanometer used to determine the participant's middle ear functioning to rule out any conductive component.
Type 4 screening audiometer	Data was collected using the Samsung Smartphone, which runs the hearScreen™ application with circumaural headphones (Sennheiser HD280 Pro, Connecticut, United States). The hearScreen™ identified normal hearing children. Prior to data collection, the circumaural headphones were calibrated according to prescribed standards (ISO 389-8 2008; ANSI/ASA S3.6-2010). The protocol defined a screening failure as the failure to detect 20 dB HL at one or more frequencies (1, 2, and 4kHz) in either ear.
Digits-in-noise test	The South African English DIN (hearZA) test application was loaded onto the Samsung smartphone. Participants self-administered the application and completed testing by entering their responses onto the smartphone (Samsung SM-J200H) with circumaural headphones (Sennheiser HD280 Pro).

2.6. Research procedures

Stimuli

The digits-in-noise test application ran on a smartphone (Samsung SM-J200H) with circumaural headphones (Sennheiser HD280 Pro). The DIN application was written in

Java version 1.8.0 and designed in Android Studio version 2.3.0, which is consistent with the original *hearZA* App. The DIN test used diotic and antiphasic South African English stimuli (SA DIN; De Sousa et al., 2018, 2020). The diotic test paradigm used a signal and masker with identical phases in both ears. Antiphasic stimuli present masking noise that is identical in both ears, but the digits are presented with a 180° phase shift between the two ears (De Sousa et al., 2020; Koopmans et al., 2018; Smits et al., 2016). A list of 120 unique digit (0 to 9) triplets were used (Potgieter et al., 2016). Digit triplets were presented with 500 ms inter-triplet silent interval. Consecutive digits were presented with a mean separation of 200ms (100ms jitter; Potgieter et al., 2016). The speech-shaped masking noise had the same spectrum as the long-term average speech spectrum of the digits without any silences (Potgieter et al., 2016; Smits et al., 2013). A fixed noise level of 70dB HL and varying speech level were used when triplets with negative SNRs were presented. However, to ensure a relatively constant overall level of the stimuli, the noise level varied, and the speech level was fixed once the SNRs became positive (Potgieter et al., 2016). When needed for facilitated testing, a smartphone keypad allowed the researcher to enter the response as verbalised by the child. Otherwise, for the retest of the subgroup of seven-years-olds (*n*=30), the children also self-registered their responses. Testing started at 0 dB SNR and followed a one-up, one-down staircase, to identify an SRT of 50% correct responses to all 3 digits (Potgieter et al, 2016; Potgieter et al, 2017), averaging the last 19 SNRs. The first three step-sizes were 4-dB, continuing in 2-dB steps for later trials.

Test procedures

Screening audiometry, tympanometry, and otoscopy were conducted on all children to ensure only those with normal hearing and outer and middle-ear appearance were included in the study sample. Tympanometry is an objective technique that evaluates middle ear function (Jacobson, 1981). Normal tympanometry results included: ear canal volume of 0.8 to 2.0 ml; compliance of 0.3 to 1.8 ml; and middle ear pressure of -50 to +50 daPa (Jerger, 1970). Participants who presented with abnormalities in outer or middle ears were excluded from the study and were referred for further evaluation. Participants with confirmed normal hearing were tested with the DIN test. The tests were conducted by the researcher in a quiet room to avoid noise disturbances. The diotic and antiphasic conditions were counterbalanced across participants in order to counteract test order bias. The researcher explained the procedure before testing, and the participants were instructed to listen to the digits and repeat them once they were heard. Whenever participants were uncertain, they were instructed to guess. The test operator entered the digits repeated by the participants on the smartphone. The response was only considered correct by the application if all the digits were entered correctly.

To determine the validity of self-testing compared to facilitated testing, an additional 30 children aged seven years were recruited. This subgroup met the same criteria of normal hearing, and normal outer and middle ear functioning. Four DIN tests were done, with a self-test and facilitated test in each condition (antiphasic and diotic). The DIN test procedure was counterbalanced for both diotic and antiphasic stimuli, and self- and facilitated- testing. Self-administered testing required participants to listen to the digit triplets and enter them on the smartphone keypad. Whenever they were uncertain of what they heard, they were instructed to type in what they thought they heard. In the facilitating testing, a researcher entered the child's verbal responses into a smartphone keypad. Otherwise, for retest of the subgroup of seven-years-olds (n=30), the children also self-registered their responses.

2.7. Data processing procedure

Data were captured on data collection sheets and prepared in Microsoft Excel™ (Microsoft Inc., Redmond, USA). The data was imported into the Statistical Package for the Social sciences Version 25 (IBM SPSS v25.0, Chicago, Illinois) for analysis.

2.8. Data analysis procedure

Raw data were captured onto a Microsoft Excel spreadsheet and analysed using statistical software (Statistical Package for the Social Sciences, IBM SPSS, v25. Chicago, Illinois). Descriptive statistics included means, standard deviations, and percentages. After inspecting skewness, kurtosis values and boxplots, multiple outliers were identified. Based on the standardized values for skewness and kurtosis, the distribution was negatively skewed. Unreliable measurements of the tests (reaching ceiling SRT) were excluded (n =16 diotic; n = 18 antiphasic). Multiple regression and one-way ANOVA using Bonferroni adjustment models were run.

Intraclass Correlation Coefficients (ICC) estimates and their 95% confidence intervals were calculated based on mean, absolute-agreement, and 2-way mixed-effects model to determine the level of validity between the facilitated and self-tested diotic and antiphasic SRT.

2.9. Reliability and validity

Reliability refers to the consistency with which a measuring instrument yields a specific result when the unit measured has not changed (Leedy & Ormrod, 2010). The validity of a measurement instrument is referred to as the extent to which the instrument measures what it is intended to measure (Leedy & Ormrod, 2010). Reliability and validity measures were ensured in the design of this study. Potgieter et al. (2016) validated the national hearing screening test for adults and deemed it as an accurate and valid tool. The test can indicate functional hearing ability with a sensitivity and specificity to detect a sensorineural hearing loss in the better ear of more than 25 dB HL (Potgieter et al., 2017). De Sousa et al. (2020) determined that the antiphasic DIN has the sensitivity to detect sensorineural hearing loss and conductive hearing loss, either symmetric or asymmetric. Furthermore, specific data was used to determine the reliability of self-testing in children 7-years and younger.

3. SPEECH RECOGNITION IN NOISE USING BINAURAL DIOTIC AND ANTIPHASIC DIGITS-IN-NOISE IN CHILDREN: MATURATION AND SELF-TEST VALIDITY

Authors: Jenique Wolmarans, Cas Smits, Faheema Mahomed Asmail, Karina C. De Sousa, David R. Moore, De Wet Swanepoel
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This article was edited in accordance with the editorial specifications required by the journal and may differ from the editorial style of the rest of this document.

3.1. Abstract

Background: Several recent studies have highlighted the potential utility of digits-in-noise (DIN) as a school-aged hearing test. However, results have been mixed as to whether young children can yield reliable results and self-administer DIN.

Purpose: This study determined normative data for diotic and antiphasic DIN in children and evaluated DIN self-testing in young children.

Research design: A cross-sectional, quantitative, quasi-experimental research design was used. This design was chosen because there is no control group, no random selection, and no active manipulation (Campbell & Cook, 1979) and the researcher measures the outcome in the participants at the same point in time (Setia, 2016). Participants with confirmed normal hearing were tested with the diotic and antiphasic DIN test. During the DIN test, arrangements of three spoken digits were presented in noise via headphones at varying signal-to-noise ratios (SNRs). The researcher entered each three-digit sequence the participant said on a keypad.

Study sample: Six hundred and twenty-one (428 male and 193 female) normal hearing children (bilateral pure tone threshold of ≤ 20 dB HL at 1, 2, and 4kHz) were recruited from four English private schools in the City of Tshwane, South Africa, and stratified according to age. These participants ranged between the ages of 6 to 13. A sub-group of seven-year-olds (n=30), complying with the same selection criteria.

Data collection and analysis: Once normal hearing was confirmed with screening audiometry, DIN testing was completed via headphones and a smartphone. Diotic and antiphasic SRT data were analyzed and compared for each age group tested. Multiple regression and one-way ANOVA models using Bonferroni adjustment were run to determine the effect of age on SRT. Intraclass Correlation Coefficients (ICC) estimates determine the level of validity between the facilitated and self-tested diotic and antiphasic SRT.

Results: Age was a significant predictor, of both diotic and antiphasic SRT ($p < 0.05$). Speech reception thresholds improved by 0.15 dB and 0.35 dB SNR per year for diotic and antiphasic SRT, respectively. SRTs for younger children (6 to 9-years of age) to be significantly different ($p < 0.05$) from older children (11 to 13 years of age). There was no significant difference in SRT between age 10 and older. Self- and facilitated testing in young children was significantly (p < 0.05) different for the antiphasic condition and self-testing demonstrated poor validity in diotic and antiphasic conditions.

Conclusions: Increasing age was significantly associated with improved SRT using diotic and antiphasic DIN. Beyond 10 years of age, SRTs became more adult-like. Self-testing in young children introduces more variability and higher SRT scores than facilitated testing.

Keywords: Age, children, speech-in-noise recognition, diotic, antiphasic, speech reception threshold.

Abbreviations: DIN = Digits-in-noise; EAL = English additional language; EFL = English first language; HL = hearing loss; LMIC = Low and middle-income country; NIHL = Noise-induced hearing loss; SNR = Signal-to-noise ratio; SRT = Speech reception threshold

3.2. Introduction

An estimated 34 million children worldwide have a disabling hearing loss (World Health Organization, 2019). It is well known that unidentified childhood hearing loss is associated with poor academic achievement, increased dysfunction in self-esteem, behaviour and energy, decreased socio-emotional ability, and limited vocational outcomes (Bess et al, 1998; Lieu, 2004; Theunissen et al, 2014; Stevenson et al, 2015; Winiger et al, 2016). Ideally, newborn infants should be screened for hearing after birth. However, due to poor adherence to neonatal hearing screening (Swanepoel, 2009), loss to follow-up testing (Russ et al, 2010; Shulman et al, 2010), and progressive or acquired hearing loss during infancy and early childhood (Barreira-Nielsen et al, 2016), hearing throughout childhood is not adequately assessed or managed, even in high income countries. Noise-induced hearing loss (NIHL) concerns have also increased due to personal audio device usage amongst youths (Vogel et al, 2011; Twardella et al, 2017). Children as young as 7 years old have been associated with permanent hearing loss due to personal audio usage (Cone et al, 2010). School hearing screenings, therefore, offer a way to identify progressive hearing loss and NIHL.

In low- and middle-income countries (LMICs), there are limited healthcare mandates available to conduct hearing screening in newborns and infants (Olusanya, 2012). Periodic hearing screenings in schools are, therefore, often the first point of access for children not screened at birth (Van Kerschaver et al, 2012). However, even in countries where mandates exist, it is possible that infants with hearing loss may be missed. School-age hearing screening is a valuable strategy to identify late onset and acquired childhood hearing loss. Current protocols for school-aged screening recommend pure tone audiometry (AAA, 2011). While pure tone testing is an accurate method for detection of peripheral hearing loss, it is reliant on expensive audiometric equipment, calibrated to industry standards, and trained personnel.

Children mostly listen to speech in acoustically demanding situations where there is a dependence on their ability to separate speech from noise, using binaural and other cues (Koopmans et al, 2018). Cognitive factors such as working memory and attention, and auditory function (e.g. temporal processing), also play a role in the ability to recognize speech in noise (Schoof, 2014; Neher, 2017). Speech-in-noise testing has recently been proposed as a possible screening measure in children using a simple digits-in-noise (DIN) test (Denys et al, 2018; Koopmans et al, 2018). The DIN test uses a closed set of digits presented as triplets in speech-shaped masking noise to measure the speech reception threshold (SRT), expressed in dB signal-to-noise ratio (dB SNR), where 50% of the digit triplets can be recognized correctly (Smits et al, 2013; Potgieter et al, 2017). This measure correlates highly with pure tone average thresholds and has been shown to have specificity and sensitivity above 90% to detect sensorineural hearing loss in adults (Potgieter et al, 2016; Potgieter et al, 2017). Children's abilities to recognize speech in noise can reliably and accurately be assessed using the DIN, as digits are easily understood, even by listeners with low linguistic competence (Kaandorp et al, 2015). More recently, attention has been given to DIN assessment in children. Koopmans et al (2018) and Moore et al (2019) have shown that, when facilitated by a test administrator, the test can accurately be conducted in children as young as four years old. When unassisted, young children tend to perform poorly (Denys et al, 2018). Speech-in-noise tests are known for their robustness since they can be used without calibrated equipment, as a self-test, and are less sensitive to ambient noise than audiometry (Smits et al, 2004; Jansen et al, 2010). Consequently, the DIN was developed as a self-screening for mobile (Potgieter et al, 2016; De Sousa et al, 2020), telephone (Smits et al, 2004), and internet platforms (Moore et al, 2017).

Due to rapidly increasing mobile internet use (Sanou, 2015), the first downloadable app-based version was released as South Africa's national hearing test in 2016 (Potgieter et al, 2016). Previous landline telephone or computerized versions of DIN tests either used monaural presentation (each ear sequentially tested) or binaural presentation. This South African version implemented a test paradigm, where binaurally identical speech (i.e., diotic) was presented in the presence of speech-weighted masking noise (Potgieter et al, 2016). Although the diotic binaural DIN version is highly time efficient with a typical test completed within three minutes (Potgieter et al, 2016; Potgieter et al, 2017), it lacks sensitivity to unilateral hearing loss since the results reflect primarily the performance of the better ear (De Sousa et al, 2020). Furthermore, suprathreshold tests like the DIN are insensitive to the attenuation caused by conductive hearing loss (De Sousa et al, 2020). The most common hearing loss in young children is conductive, related to otitis media (ASHA, 2019) and wax impaction (Butler, 2012). In a study by Hussain et al (2011), 88.2% of hearing-impaired children (5-15 years old) had conductive hearing loss (CHL). Middle ear issues increase the risk of medical and developmental consequences including permanent hearing loss, social isolation, and academic disadvantage.

Antiphasic DIN, using speech with a 180° phase shift between the two ears (Smits et al, 2016; Koopmans et al, 2018), has recently been found to improve sensitivity to all main forms of hearing loss, including unilateral and CHL (De Sousa et al, 2020). De Sousa et al (2020) also found larger areas under the Receiver Operating Characteristic (ROC) curve for detection of hearing loss (> 25 dB HL) for antiphasic (0.94) than for diotic DIN (0.77). Thus, antiphasic SRT is a more sensitive measure for hearing loss detection.

This study investigated the maturation of diotic and antiphasic SRTs in children between 6 and 13 years of age. A secondary aim was to determine the validity of self-testing on a smartphone compared to facilitated testing in a subgroup of seven-year-old children.

3.3. Method

Institutional review board approval was obtained prior to data collection. All caregivers/parents provided consent and children provided assent for inclusion in the study.

Participants

Six hundred and twenty-one participants (428 male and 193 female) were purposively sampled from four English private schools in the City of Tshwane, South Africa, and stratified according to age. These participants were from grades 1 to 7 ranging between the ages of 6 to 13 (Mean 9.6; SD 2.1) and were categorized into English first language (EFL) (*n*=556) and English additional language groups (EAL) (*n*=65). Requirements for this study included normal bilateral hearing sensitivity (bilateral pure tone threshold of ≤ 20 dB HL at 1, 2, and 4kHz) and normal middle ear functioning confirmed by screening audiometry, otoscopy, and tympanometry results. A sub-group of seven-year-olds (*n*=30), complying with the same selection criteria, were selected to determine the validity of self-testing on a smartphone compared to facilitated testing of diotic and antiphasic SRT.

Material and apparatus

A Welch Allyn PocketScope™ was used to examine the ear canal and tympanic membrane for any abnormalities. A calibrated tympanometer (MAICO ERO•SCAN® Pro) was used to determine the participant's middle ear functioning to rule out any conductive component.

A type 4 screening audiometer (hearScreen™, hearX group, Pretoria, South Africa) connected to calibrated circumaural headphones (Sennheiser HD280 Pro, Connecticut, United States) was used to identify normal hearing children. Prior to data collection, the circumaural headphones were calibrated according to prescribed standards (ISO 389-8 2008; ANSI/ASA S3.6-2010). According to The American-Speech-Language-Hearing Association Guidelines for Audiological Screening, the recommended protocol for hearing screening in children uses a 20 dB HL screening level and includes the frequencies 1000, 2000, and 4000 Hz (ASHA, 1997). The protocol defined a screening failure as the failure to detect 20 dB HL at one or more frequencies (1, 2, and 4kHz) in either ear.

The digits-in-noise test application ran on a smartphone (Samsung SM-J200H) with circumaural headphones (Sennheiser HD280 Pro). The DIN application was written in Java version 1.8.0 and designed in Android Studio version 2.3.0, which is consistent with the original *hearZA* App. The DIN test used diotic and antiphasic South African English stimuli (De Sousa et al, 2018; De Sousa et al, 2020). The diotic test paradigm used a signal and masker with identical phases in both ears. Antiphasic stimuli present masking noise that is identical in both ears, but the digits are presented with a 180° phase shift between the two ears (Smits et al, 2016; Koopmans et al, 2018; De Sousa et al, 2020). A list of 120 unique digit (0 to 9) triplets were used (Potgieter et al, 2016). Digit triplets were presented with 500 ms inter-triplet silent interval. Consecutive digits were presented with a mean separation of 200ms (100ms jitter; Potgieter et al, 2016). The speech-shaped masking noise had the same spectrum as the long-term average speech spectrum of the digits without any silences (Smits et al, 2013; Potgieter et al, 2016). A fixed noise level of 70dB and varying speech level were used when triplets with negative SNRs were presented. However, to ensure a relatively constant overall level of the stimuli, the noise level varied, and the speech level was fixed once the SNRs became positive (Potgieter et al, 2016). When needed for facilitated testing, a smartphone keypad allowed the researcher to enter the response as verbalized by the child. Otherwise, for retest of the subgroup of seven-years-olds (*n*=30), the children also self-registered their responses. Testing started at 0 dB SNR and followed a one-up, one-down staircase, to identify an SRT of 50% correct responses to all 3 digits (Potgieter et al, 2016; Potgieter et al, 2017), averaging the last 19 SNRs. The first three step-sizes were 4-dB, continuing in 2-dB steps for later trials.

Procedures

Screening audiometry, tympanometry, and otoscopy were conducted on all children to ensure only those with normal hearing and outer and middle-ear appearance were included in the study sample. Tympanometry is an objective technique which evaluates middle ear function (Jacobson, 1981). Normal tympanometry results included: ear canal volume of 0.8 to 2.0 ml; compliance of 0.3 to 1.8 ml; and middle ear pressure of -50 to +50 daPa (Jerger, 1970). Abnormalities in outer or middle ear results were excluded from the study and the children referred for further evaluation.

Participants with confirmed normal hearing were tested with the DIN test. The DIN used the same procedure as described in De Sousa et al. (2020). The researcher conducted the tests at the different schools in a quiet room to avoid noise disturbances and minimize possible distractions. The diotic and antiphasic conditions were counterbalanced across participants in order to counteract test order bias. The researcher explained the procedure before testing, and the participants were instructed to listen to the digits and repeat them once they were heard. Whenever participants were uncertain, they were instructed to guess. The test operator entered the digits repeated by the participants on the smartphone. The response was only considered correct by the application if all the digits were entered correctly.

To address the secondary aim, an additional 30 children aged seven years were recruited. This subgroup met the same criteria of normal hearing, and normal outer and middle ear functioning. The DIN test procedure was counterbalanced for both diotic and antiphasic stimuli, and self- and facilitated- testing. The participants were instructed to self-administer the tests by listening to the digit triplets and entering them into the phone. Whenever they were uncertain of what they heard, they were instructed to type in what they think they heard. The facilitated test was administered by the researcher as above.

Data analysis

Raw data were captured onto a Microsoft Excel spreadsheet and analyzed using statistical software (Statistical Package for the Social Sciences, IBM SPSS, v25. Chicago, Illinois). Descriptive statistics included means, standard deviations, and percentages. After inspecting skewness, kurtosis values, and boxplots, multiple outliers were identified. Based on the standardized values for skewness and kurtosis, the distribution was negatively skewed. Unreliable measurements of the tests (reaching ceiling SRT) were excluded (n =16 diotic; n = 18 antiphasic). Multiple regression and one-way ANOVA models using Bonferroni adjustment were run. Intraclass Correlation Coefficients (ICC) estimates and their 95% confidence intervals were calculated based on mean, absolute-agreement, and 2-way mixed-effects model to determine the level of validity between the facilitated and self-tested diotic and antiphasic SRT.

3.4. Results

Maturation of SRT

Table 1. Distribution of the average Diotic SRT across age groups, standard deviation of the mean (SD), Range, and 90th percentile range (5th to 95th percentiles)

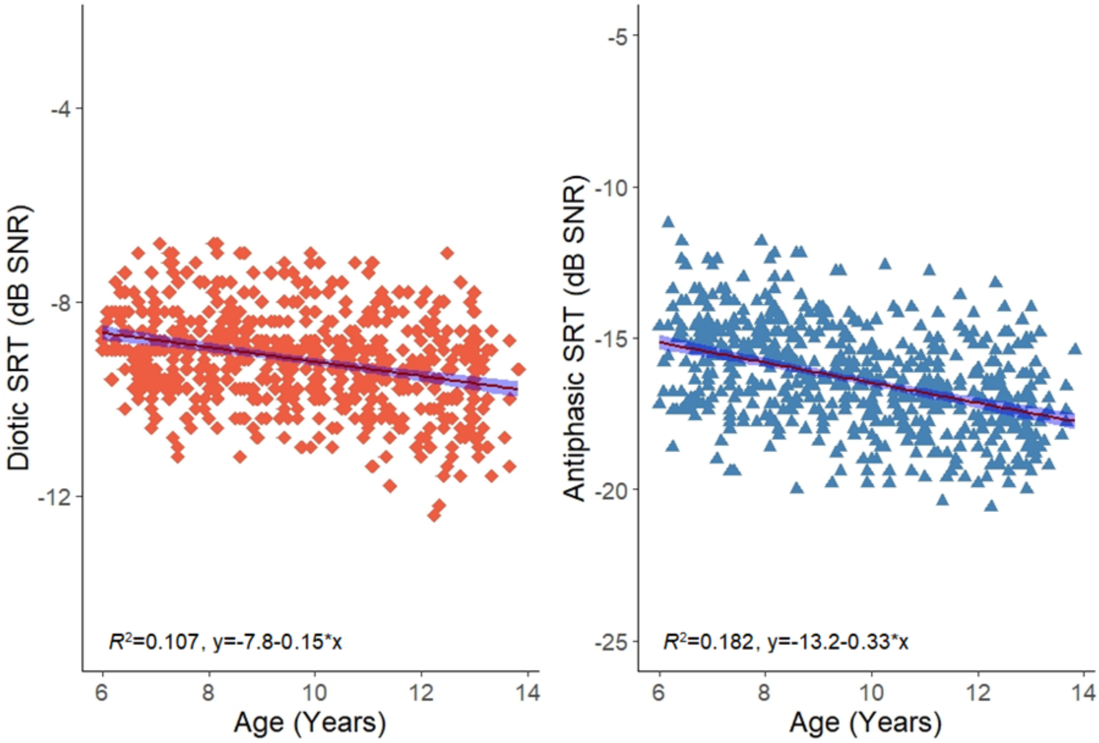
Age [years]	*N*	Mean (SD) [dB SNR]	Minimum [dB SNR]	Maximum [dB SNR]	5th to 95th percentiles
6.00-6.99	74	-8.8 (0.8)	-10.6	-7.0	-10.2 to -7.5
7.00-7.99	82	-8.9 (1.0)	-11.2	-6.8	-10.6 to -7.2
8.00-8.99	92	-9.0 (0.9)	-11.2	-6.8	-10.5 to -7.0
9.00-9.99	87	-9.1 (0.9)	-11.0	-7.0	-10.4 to -7.4
10.00-10.99	75	-9.2 (0.9)	-11.0	-7.2	-10.6 to -7.6
11.00-11.99	78	-9.4 (1.0)	-11.8	-7.2	-11.0 to -7.8
12.00-12.99	83	-9.7 (1.1)	-12.4	-7.0	-11.6 to -8.0
13.00-13.99	34	-9.8 (1.0)	-11.6	-7.8	-11.5 to -8.1
Total	605	-9.2 (1.0)	-12.4	-6.8	-10.8 to -7.5

Table 2. Distribution of the average antiphasic SRT across age groups, standard deviation of the mean (SD), Range, 90th percentile range (5th to 95th percentiles)

Age [years]	*N*	Mean (SD) [dB SNR]	Minimum [dB SNR]	Maximum [dB SNR]	5th to 95th percentiles
6.00-6.99	79	-15.4 (1.6)	-18.6	-11.2	-17.4 to -12.4
7.00-7.99	81	-15.6 (1.5)	-19.4	-11.8	-18.4 to -13.0
8.00-8.99	93	-15.7 (1.6)	-20.0	-12.2	-18.0 to -12.8
9.00-9.99	87	-16.3 (1.5)	-19.8	-12.8	-19.2 to -14.1
10.00-10.99	72	-17.0 (1.3)	-19.8	-14.0	-19.1 to -14.3
11.00-11.99	74	-17.0 (1.4)	-20.4	-13.6	-19.6 to -14.5
12.00-12.99	83	-17.3 (1.4)	-20.6	-14.0	-19.8 to -14.8
13.00-13.99	34	-17.5 (1.4)	-19.4	-14.0	-19.3 to -14.6
Total	603	-16.4 (1.6)	-20.6	-11.2	-19.0 to -13.6

Of the 661 participants tested, 621 met the inclusion criteria of normal hearing (bilateral pure tone threshold of ≤ 20 dB HL at 1, 2, and 4kHz) of whom 89.5% were EFL speakers, and 68.9% were male. Participants ranged from 6 to 13 years, with an average age of 9.6 years (2.01 SD). The distribution of diotic and antiphasic DIN SRTs are presented in Table 1 and 2, respectively.

Figure 1: Correlation of diotic and antiphasic SRTs across age [n= 601 (diotic) and 599 (antiphasic)]. Solid lines are regression lines fitted to diotic and antiphasic SRT. The smoothed areas are the 95% confidence intervals. SRT; speech reception threshold, SNR; signal-to-noise ratio.



Multiple regression analysis was used to investigate whether age, gender, and EAL predicted diotic and antiphasic SRT. As seen in figure 1, there was a negative association between age and SRT in both the diotic and antiphasic conditions. That is, younger children tended to have higher (i.e., poorer) SRTs than other children. Only age significantly (p < 0.001) predicted diotic (F[3,601]=23.756, adj. R^2 =0.10) and antiphasic SRT (F[3,599]=49.598, adj. R^2 =0.20). Every one-year increase in age was associated with a 0.15 dB SNR (95% CI -0.188 to -0.116) and 0.35 dB SNR (95% CI -0.404 to -0.291) improvement in diotic and antiphasic SRT respectively (Figure 1). Furthermore, linear regressions were done across different ages to determine where antiphasic and diotic SRT plateaued. Age significantly (p < 0.001) predicted antiphasic SRT up to 9.9 years (F[1,337]=14.175, adj. R2 =0.038) and diotic SRT up to 11.9 years

(F[1,488]=21.764, adj. R2 = 0.041). However, from 10 and 12 years onward age was not a significant predictor for antiphasic (p=0.062) and diotic (p=0.194) SRT, respectively.

Validity of self-testing

Table 3. Post hoc multiple comparisons of significant (p < 0.05) diotic and antiphasic SRTs across ages. Mean difference, standard error (SE), Confidence Interval (CI)

(I) Age Categories [years]		Diotic		Antiphasic	
		Mean Difference (I-J) [dB SNR]	SE (95% CI) [dB SNR]	Mean Difference (I-J) [dB SNR]	SE (95% CI) [dB SNR]
6-6.9	9-9.9			.87*	0.23 (0.172 to 1.568)
	10-10.9			1.56*	0.24 (0.827 to 2.289)
	11-11.9	.62*	0.15 (0.159 to 1.081)	1.52*	0.24 (0.797 to 2.289)
	12-12.9	.86*	0.14 (0.409 to 1.317)	1.85*	0.23 (1.144 to 2.556)
	13-13.9	.97*	0,19 (0.386 to 1.563)	2.03*	0.30 (1.113 to 2.955)
7-7.9	9-9.9			.75*	0.23 (0.054 to 1.441)
	10-10.9			1.44*	0.24 (0.708 to 2.163)
	11-11.9	.52*	0.15 (0.069 to 0.968)	1.40*	0.24 (0.678 to 2.122)
	12-12.9	.76*	0.15 (0.319 to 1.204)	1.73*	0.23 (1.026 to 2.429)
	13-13.9	.87*	0.19 (0.293 to 1.452)	1.91*	0.30 (0.994 to 2.29)
8-8.9	10-10.9			1.29*	0.23 (0.586 to 1.996)
	11-11.9	.48*	0.14 (0.039 to 0.913)	1.26*	0.23 (0.556 to 1.955)
	12-12.9	.72*	0.14 (0.289 to 1.149)	1.58*	0.22 (0.905 to 2.261)
	13-13.9	.83*	0.19 (0.260 to 1.400)	1.77*	0.30 (0.867 to 2.667)
9-9.9	12-12.9	.60*	0.14 (0.164 to 1.036)	.98*	0.22 (0.291 to 1.669)
	13-13.9	.71*	0.19 (0.137 to 1.285)	1.16*	0.30 (0.256 to 2.072)

* The mean difference is significant at the 0.05 level.

Table 4. Distribution of the average diotic and antiphasic SRT across the seven-year-old sub-group (*n*=30).

	n	Facilitated test mean (SD) [dB SNR]	Self-test mean (SD) [dB SNR]	Mean diff (SD) - Facilitated vs self-test [dB SNR]	Intraclass Correlation Coefficients (ICC*)*	95% CI
Diotic	30	-8.9 (1.2)	-7.6 (5.9)	1.4 (5.6)	0.242	-0.545 to 0.634
Antiphasic	30	-15 (3.2)	-13.2 (6.5)	1.8 (5.8)	0.507	0.004 to 0.761
Excluding outlier (n=1)*						
Diotic	29	-9.0 (1.1)	-8.6 (1.6)	0.43 (1.6)	0.240	-0.569 to 0.638
Antiphasic	29	-15.0 (3.3)	-14.2 (3.8)	0.83 (2.2)	0.047	-0.911 to 0.539

* *Outlier is more than 1.5 times the interquartile range*

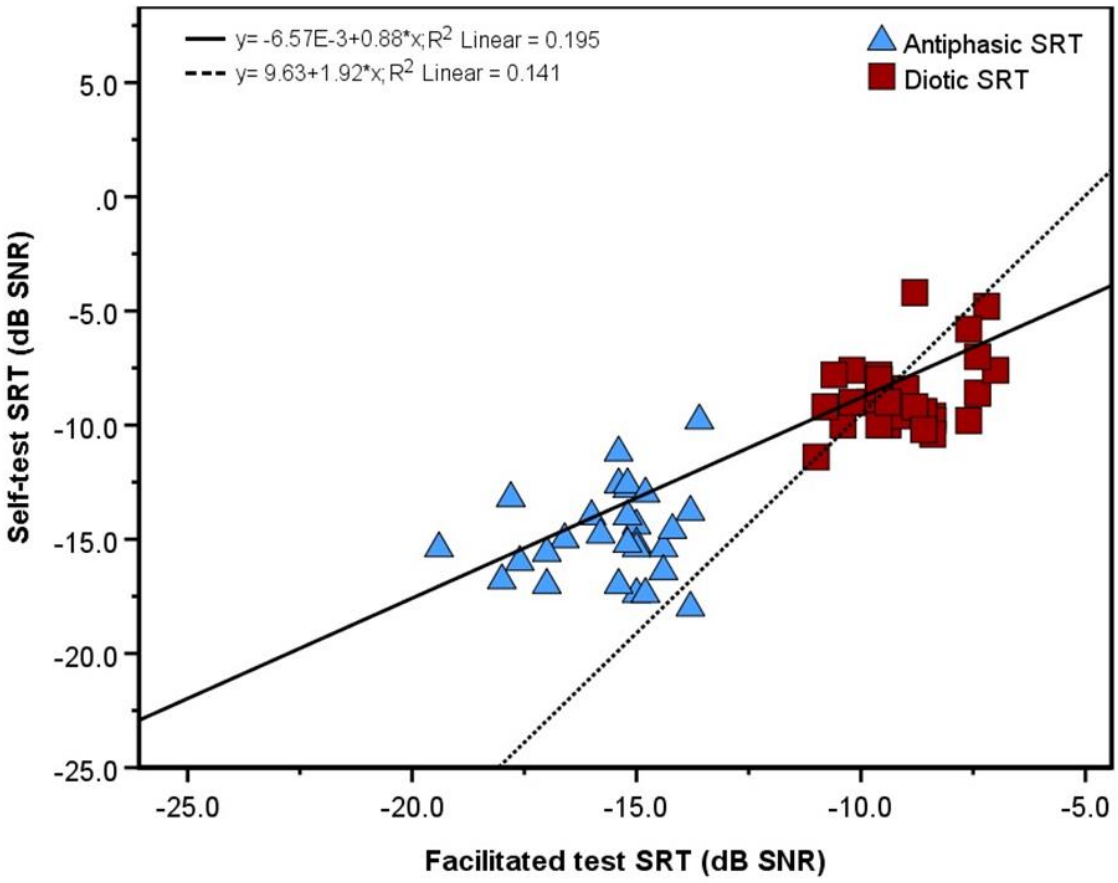


Figure 2: Diotic and antiphasic SRT according to self-test and facilitated test. SRT; speech reception threshold. One outlier outside the scale is not shown.

Table 3 shows the mean diotic and antiphasic SRTs for self-test vs. facilitated test. Figure 2 shows the self-test SRT against the facilitated SRT for diotic and antiphasic stimuli. The facilitated SRTs were, on average, better (lower) than the self-test SRTs (Table 4). Intraclass Correlation Coefficients (ICC) results were used to investigate the SRT agreement between a facilitated and self-tested diotic and antiphasic SRT. One outlier that deviated more than 3 standard deviations from one hinge of the box was found, and results are reflected with and without the outlier. The agreement between the two diotic tests were poor, with ICC of 0.242 (95% CI, -0.545 to 0.634) and 0.240 (95% CI, -0.569 to 0.638) with and without the outlier respectively. Similarly, between facilitated and self-tested antiphasic DIN, SRTs showed poor ICC of 0.507 (95% CI, 0.004 to 0.761) and .047 (95% CI, -0.911 to 0.539), with and without the outlier, respectively.

3.5. Discussion

Diotic and antiphasic SRTs in the present study demonstrated an age effect for children between 6 and 13 years of age, with an improvement of 0.15 dB SNR and 0.35 dB SNR per year in diotic and antiphasic SRT respectively. Koopmans et al (2018) used exponential fits to describe their data. An average improvement of 0.25 dB SNR and 0.46 dB SNR per year for children between 6 and 13 years can be derived from the reported functions, which is a slightly stronger age effect than reported in the current study. Recently, Denys et al, (2018) reported that a unilateral stimulus setup showed an improvement of 0.2 dB per year of the SRT is seen between 9 and 16 years of age. In general, these findings are consistent with those reported previously, suggesting that children's SRT results improve with age and reach adult-like performance by the age of no less than 10 years (Hall et al, 2004; Buss et al, 2006; Stuart, 2008; Van Deun et al, 2010; Holder et al, 2016; Koopmans et al, 2018).

In a study by De Sousa et al. (2020), adult hearing sensitivity categories of excellent (0-15 dB HL) and minimal (16-25 dB HL) yielded mean diotic SRTs of -11.1 dB and -9.7 dB respectively. Similarly, Potgieter et al. (2018), yielded binaural mean diotic SRT of -10.2 dB in normal hearing adults. Young children in the current study had mean diotic SRT of -8.9 dB SNR for 6- and 9-years old and -9.5 dB SNR for 10- and 13-years old. The results of these children were statistically poorer than the adult SRT results (De Sousa et al. 2020; Potgieter et al. 2018). De Sousa et al. (2020) also reported mean antiphasic SRTs of -18.4 dB SNR for their excellent (0-15 dB HL) hearing sensitivity and -16.7 dB SNR for minimal (16-25 dB HL) hearing sensitivity respectively. In comparison, the current study found mean antiphasic SRT results of -15.8 dB between 6- and 9-years old and -17.1 dB SNR between 10- and 13-years old. When comparing normal hearing participants, the present study's results, and those of Koopmans et al. (2018), De Sousa et al. (2020), Potgieter et al. (2018) demonstrate that young children have lower average SRTs than adults in diotic and antiphasic conditions. To date, however, De Sousa et al. (2020) is the only study with antiphasic adult SRT results that could be used to compare with the results present study.

The cause of the increase in SRT with age is likely due to either auditory, nonauditory factors (attention and memory), or a combination of the two (Moore et al, 2011; Koopmans et al, 2018). Koopmans et al, (2018) found that binaural unmasking improves with age. As such, children had adult-like binaural unmasking after 10 years of age. The binaural unmasking is the difference in SRT between diotic and antiphasic, which involves central auditory processing and improves speech intelligibility in binaural conditions (Hirsh, 1948). Like the present study, participants in De Sousa et al. (2020) had 6-8 dB better antiphasic than diotic SRTs. Maturation of auditory pathways and binaural processing, as well as the maturation effects of auditory perception, has been linked to this increase in SRT with age (Eggermont & Ponton, 2003. Buss et al., 2016) showing that the ability to recognize speech in noise also takes longer to mature in children. The present study supports the idea that young children need a more favourable SNR in difficult and demanding listening conditions as their ability to benefit from binaural cues and to isolate speech from noise is still developing. Although perceptual hearing abilities mature well into adolescence, different auditory abilities become adult-like at different ages (Sanes & Woolley, 2011). For both diotic and antiphasic DIN tests, children typically have lower SRT scores and release from masking than adults. The DIN test is often regarded as a simple test, but attention and memory might still play a limited role in children's speech recognition abilities role (Moore et al, 2011). In tests like the DIN, selective attention determines which sounds are 'listened' to, while the remaining sounds that are unattended are 'ignored' (Fritz et al, 2007). Selective attention is difficult with speech as it usually occurs with competing background noise (Shinn-Cunningham & Best, 2008). Children with normal hearing thresholds with difficulties in one or more of these areas may still fail the test (Denys et al, 2018).

In addition to the developmental effects that recognition of speech-in-noise yields, it is much worse for children with hearing loss. Consequently, children with hearing loss require greater listening effort in adverse listening environments and favourable SNR than normal hearing children (Hicks & Tharpe, 2002). The present study shows that the digits material in the SA DIN test is familiar to children down to the age of 6 years and that they possess the auditory memory skills for a three-digit span. In their version of the DIN, Smits et al. (2013) showed that the DIN depends minimally on top-down processing, e.g., linguistic skills. These results are in agreement with results reported by Kaandorp et al. (2015) demonstrating that the DIN test only requires minimal linguistic skills and that the effect of non-native language is small. Therefore, it is important to consider that the participants in this study were recruited from mainstream private schools and that they do not have any obvious cognitive deficits or severe academic underachievement.

The second study objective evaluated the level of validity between the facilitated and self-tested diotic and antiphasic SRT. Koopmans et al. (2018) used binaural diotic or antiphasic stimuli with age groups of 4–6years (-7.9 dB SNR), 7–9 years (-8.8 dB SNR), and 10–12 years (-9.7 dB SNR). Their study tested a similar range of ages (4–12 years) and found that even the 4-year-olds could reliably perform the DIN. In both studies, facilitated testing required children to verbally report back the digits that they heard to the researcher. Both studies found that young children had worse SRTs of 3 to 7dB compared to older children and adults. There was a much larger difference between children and adults when antiphasic stimuli were used. The results reported here are consistent with other evidence that the performance of the DIN is influenced by children's increasing ability to perform the task with increasing age, as well as by the type of the stimulus (either diotic or antiphasic). In another study, Denys et al. (2018) reported in children between age 9 to 16 years who self-administered the DIN test and found that these older children could also do a diotic test unassisted. Clinically, the present study indicates that DIN self-testing using a smartphone in young children (7 years of age and most likely younger) may be too unreliable for screening purposes.

Conclusion

Young children need a more favourable signal-to-noise ratio (SNR) than adults since speech recognition abilities only develop well into adolescence. Age-dependent normative data for children were established for the DIN test in diotic and antiphasic conditions. This study indicated that using the DIN test as a screening tool in young children requires age-specific norms. Self-testing in children 7-years and younger is probably too unreliable for screening purposes.

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Declaration of conflicts of interest

The 5th and last author has a relationship with the *hearX™ Group (Pty) Ltd*, which includes equity, consulting, and potential royalties. The authors report no other conflicts of interest.

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DISCUSSION AND CONCLUSION

4.1. Discussion of results

Since its release in 2016, more than 36 000 individuals took the smartphone DIN test (De Sousa et al., 2018). The application has also been made available on internet platforms that allow the test to be completed on smartphones, tablets, and computers. Although this test was developed for adult users, a large sample of 4,2% of the 30321 persons tested from 3 March 2016 to 14 August 2017, were under 15 years of age (De Sousa et al., 2018). The test uptake amongst the younger population indicates that the South African DIN (SA DIN; De Sousa et al., 2018, 2020) identifies an important target audience that could be reached. This study used the SRT results of binaural diotic and antiphasic digits-in-noise to investigate the maturation and self-test validity in children.

The DIN correlates well with pure-tone audiometry as its speech material is generally understood and can be used in populations with various languages and dialects. The audiogram's shortcomings are a major reason that speech in noise should be used as a diagnostic tool as it detects specific problems with speech hearing and suprathreshold performance in noise. The very simple procedure and speech material of the DIN makes it a good first test of sensory processing of speech in noise in children's hearing. Diotic and antiphasic SRTs in the present study demonstrated an age effect for children between 6 and 13 years of age, with an improvement of 0.15 dB SNR and 0.35 dB SNR per year in diotic and antiphasic SRT respectively. Recently, Denys et al, (2018) reported that a unilateral stimulus setup showed an improvement of 0.2 dB per year of the SRT is seen between 9 and 16 years of age. In general, these findings are consistent with those reported previously, suggesting that children's SRT results improve with age and reach adult-like performance by the age of no less than 10 years (Buss, Hall, & Grose, 2006; Hall, Buss, Grose, & Dev, 2004; Holder, Sheffield, & Gifford, 2016; Koopmans et al, 2018; Stuart, 2008; Van Deun, van Wieringen, & Wouters, 2010).

In a study done by De Sousa et al. (2020), adult hearing sensitivity categories of excellent (0-15 dB HL) and minimal (16-25 dB HL) yielded mean diotic SRTs of -11.1 dB and -9.7 dB respectively. Similarly, Potgieter et al. (2018), yielded binaural mean diotic SRT of -10.4 dB in normal hearing adults. Young children in the current study had mean diotic SRT of (-8.9 dB SNR) for 6- and 9-years old and (9.5 dB SNR) for 10- and 13-years old (9.5 dB SNR). The results of these children were poorer than the adult SRT results (De Sousa et al., 2020; Potgieter et al., 2018). De Sousa et al. (2020) also reported mean antiphasic SRTs of -18.4 dB SNR for their excellent (0-15 dB HL) hearing sensitivity and -16.7 dB SNR for minimal (16-25 dB HL) hearing sensitivity, respectively. In comparison, the current study found mean antiphasic SRT results of -15.8 dB between 6- and 9-years old and -17.1 dB SNR between 10- and 13-years old. When comparing normal hearing participants, the present study's results, and those of Koopmans et al. (2018), De Sousa et al. (2020), Potgieter et al. (2018) demonstrate that young children have lower average SRTs than adults in diotic and antiphasic conditions. Various studies reveal that auditory processing skills in children, develop gradually (Elliott,1979; Hall, Grose, Buss, & Dev, 2002; Holder et al, 2016; Stuart, 2008; Van Deun et al, 2010). To date, however, De Sousa et al. (2020) is the only study with antiphasic adult SRT results that could be used to compare with the results present study.

The cause of this increase in SRT with age is likely due to either auditory factors, nonauditory factors (attention and memory), or a combination of the two (Moore, Cowan, Riley, Edmondson-Jones, & Ferguson, 2011; Koopmans et al, 2018). Koopmans et al, (2018) found that binaural unmasking improves with age. As such, children had adult-like binaural unmasking after 10 years of age. The binaural unmasking is the difference in SRT between diotic and antiphasic, which involves central auditory processing and improves speech intelligibility in binaural conditions (Hirsh, 1948). Like the present study, participants in De Sousa et al. (2020) had 6-8 dB better antiphasic than diotic SRTs. It is possible that the observed improvement in SRT is due to the maturation of auditory pathways and binaural processing, as well as the maturation effects of auditory perception, has been linked to this increase in SRT with age (Eggermont & Ponton, 2003). Furthermore, linguistic and cognitive skills, working memory, and attention takes place simultaneously and may also play a role (Elliot 1979). Buss, Leibold, & Hall (2016) show that the ability to recognize speech in noise also takes longer to mature in children. The present study supports the idea that young children need a more favourable SNR in difficult and demanding listening conditions as their ability to benefit from binaural cues and to isolate speech from noise is still developing. Although perceptual hearing abilities mature well into adolescence, different auditory abilities become adult-like at different ages (Sanes & Woolley, 2011). For both diotic and antiphasic DIN tests, children typically have lower SRT scores and release from masking than adults. The DIN test is often regarded as a simple test, but attention and memory might still play a limited role (Moore, Cowan, Riley, Edmondson-Jones, & Ferguson, 2011). In tests like the DIN, selective attention determines which sounds are ‘listened’ to, while the remaining sounds that are unattended to are ‘ignored’ (Fritz, Elhilali, David, & Shamma, 2007). Selective attention is difficult with speech as it usually occurs with competing background noise (Shinn-Cunningham & Best, 2008). Children with normal hearing thresholds with difficulties in one or more of these areas may still fail the test (Denys et al., 2018). However, the exclusion of children with unreliable measurements in order to filter out children who performed poorly as a result of inattention, we cannot completely rule out the effects of attention. For example, as a result of lost attention, a few children without a hearing loss failed either the diotic or antiphasic condition (whichever was tested second), even though the tests were counterbalanced.

The use of digits as stimuli yields an important advantage in that they are amongst the first words a person acquires when learning a new language. The present study shows that the digits material in the SA DIN test is familiar to children down to the age of 6 years and that they possess the auditory memory skills for a three-digit span. Smits et al., (2013) showed that the DIN depends minimally on top-down processing, e.g., linguistic skills. These results are in agreement with results reported by Kaandorp, De Groot, Festen, Smits, & Goverts. (2015), demonstrating that the DIN test only requires minimal linguistic skills and that the effect of non-native language is small. Moore et al. (2011) found a significant relation between measures of cognition and DIN SRT in older adults. On the other hand, Talarico et al. (2017) found that children with higher cognitive abilities did not outperform children with lower cognitive abilities on speech recognition tasks in speech shaped noise. Therefore, it is important to note that the participants in this study were recruited from mainstream private schools and that they do not have any obvious cognitive deficits or severe academic underachievement.

The second study objective evaluated the level of validity between the facilitated and self-tested diotic and antiphasic SRT. Koopmans et al. (2018) used binaural diotic or antiphasic stimuli with age groups of 4–6years (-7.9 dB SNR), 7–9 years (-8.8 dB SNR), and 10–12 years (-9.7 dB SNR). These values agree with the present studie's results indicating that reliable SRT results can be obtained in school-age children. Koopmans et al. (2018) tested a similar age examined here and found that even the 4-year-olds could reliably perform the DIN. Like in the current study's facilitated testing condition, with stimulus presented binaurally, children had to verbally report back the digits that they heard to the researcher. They found that young children had worse SRTs of 3 to 7dB compared to adults. There was a much larger difference between children and adults when antiphasic stimuli (180° phase shift) was used. Similarly, we also used antiphasic stimuli and found similar elevated SRTs in young children and improvement of the SRT with age. These results are consistent with the evidence that the DIN test is influenced by age in children as well as the type of the stimulus (either diotic or antiphasic). In another study, Denys et al. (2018) reported on children between age 9 to 16 years who self-administered the DIN test and found that young children could also do a diotic test unassisted. Although a small number of young children in this study could yield adult-like SRT results, the present study indicates that DIN self-testing using a smartphone in young children (7 years of age and younger) may be too unreliable for screening purposes.

4.2. Clinical implications

By measuring the age-dependent SRT results for a substantial group (n = 621) of normal hearing children between 6 and 13 years of age, we were able to determine age dependant normative date (95% percentile and mean) for diotic and antiphasic test conditions. The current study and Koopmans et al. (2018) have demonstrated that the smartphone DIN test can be used in children as young as 4 to 6 years of age. Since school-aged screening programs, where the DIN is used, has already been successfully implemented (Denys et al., 2018), the DIN test may be a means of early identification in those populations. Preventative care for hearing loss and early detection facilitated by routine hearing screening could produce a dramatic reduction in the cost of untreated hearing loss (World Health Organization, 2017).

The audiogram's shortcomings are a major reason that the DIN test should be used as a diagnostic tool as it detects specific problems with speech hearing and suprathreshold performance in noise. Although the difference between conductive- or sensorineural hearing loss could not be determined with binaural DIN test, a follow up diagnostic audiometry can identify either unilateral or bilateral hearing loss for individuals who failed the DIN test. When considering the large quantity of children who completed the *hearZA* test between 3 March 2016 to 14 August 2017 (De Sousa et al., 2018), the DIN test has the potential to reach many young children in countries where few resources are available. The cloud-based data platform of the smartphone DIN test also provides the opportunity for early intervention and direct referrals. Consequently, the consequences of undetected hearing loss could, therefore, be prevented by facilitating the DIN test as a standard screening tool for most clinical populations.

4.3. Critical evaluation

Strengths of the study

This study was the first to investigate the influence of maturation on the results of the South African smartphone DIN test in children aged 6 to 13 years. The study had a large sample (*n*=621), allowing the opportunity to accurately make inferences about the test performance and to investigate the influence of maturation in normal hearing children. This DIN test highlights the opportunity for earlier hearing loss detection and intervention when using it as a screening tool in school-aged children. The fact that the DIN test is a smartphone application and easy to use, it enables the possibility of home-based screening by caregivers.

Furthermore, the test environment of this study is representative of real-life situations with ambient noise and reverberation that are representative of the environment where users would perform this test. Lastly, in countries like South Africa with various languages, English digits are amongst the first words learned as a child. Thus, using the DIN test for screening is a major strength of this study.

Limitations of the study

The most significant limitation of this study is that the participants were recruited from mainstream private schools in Pretoria. This raises the concern that data are not fully representative of the general population. Unfortunately, it is sometimes challenging to conduct research on children who attend their local public schools as additional permission from the Department of Education is needed, which has proven to be difficult. Additionally, these schools are widely distributed and challenging to access.

Another limitation is that participants were required to perform the smartphone DIN test throughout the day, and therefore, children who were tested by the end of the school day were susceptible to fatigue. As a result, their fatigue could have influenced the results due to the lack of concentration.

Lastly, this study utilized screening audiometry and did not determine the actual pure tone audiometry thresholds against which the SRT results could be correlated. Furthermore, only children with normal hearing were included in this study. As a result, the effect of unilateral or asymmetric hearing loss on the DIN test was not recorded.

4.4. Future research

All participants with a hearing loss of any degree were excluded from the current study. Future research is needed to understand how various degrees of hearing loss in children affects their performance on the DIN test. This is important as children with a hearing loss are an important target audience for this application. As such, this test provides the potential for implementation of regular and compulsory school-aged hearing screening as it is a very simple and user-friendly test.

It is also important to note that a limited sample of EAL (10.5%; 65/621 listeners) was collected for this study. Data on this group of listeners should be expanded, as well as develop DIN test in other language variants to make it accessible to larger population groups.

Lastly, the underlying causes of the impaired speech understanding in noise, including, but not limited to, auditory processing disorder (APD) and noise-induced hearing loss, should also be investigated. Information like this provides the opportunity to fine-tune the pass or fail criteria for DIN in children.

4.5. Conclusion

Young children need a more favourable signal-to-noise ratio (SNR) than adults since speech recognition abilities only develop well into adolescence. Age-dependent normative data for children were established for the DIN test in diotic and antiphasic conditions. This study indicated that the DIN test is a valuable screening tool in young children, however, age-specific norms should be considered. Self-testing in children 7-years and younger is probably too unreliable for screening purposes. Consequently, producing widespread access to the smartphone DIN test platform provides the opportunity for early identification, intervention, and monitoring of hearing loss and speech recognition in noise difficulties in school-aged children.

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6. APPANDICES

Appendix A: Faculty of Humanities Ethical Clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

20 March 2019

Dear Ms Wolmarans

Project:	**Speech Reception Threshold (SRT) age specific normative data for the DIN test in children**
Researcher:	**J Wolmarans**
Supervisor:	**Prof D Swanepoel, Dr F Mahomed and Ms KC Swanepoel**
Department:	**Speech-Language Pathology and Audiology**
Reference number:	**15204261 (HUM020/0119)**

Thank you for your response to the Committee's correspondence.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 20 March 2019. 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: PGHumanities@up.ac.za

cc: Prof D Swanepoel, Dr M Mahomed and Ms KC Swanepoel (Supervisors) Dr J van der Linde (HoD)

Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Research Ethics Committee Members: Prof MME Schoeman (Deputy Dean); Prof KL Harris; Mr A Bizos; Dr L Blokland; Dr K Booyens; Dr A-M de Beer; Ms A dos Santos; Dr R Fasselt; Ms KT Govinder Andrew; Dr E Johnson; Dr W Kelleher; Mr A Mohamed; Dr C Puttergill; Dr D Reyburn; Dr M Soer; Prof E Taljard; Prof V Thebe; Ms B Tsebe; Ms D Mokalapa

Appendix B: Letter to the principle

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Principal,

Speech Reception Threshold (SRT) age specific normative data for the DIN test in children

I am a student completing my master's degree in Audiology at the University of Pretoria's Department of Speech-Language Pathology and Audiology. As part of my study I am required to screen the hearing of learners at a primary school. I would like to offer this hearing screening service to learners at your school free of charge. These services will take approximately 15 to 20 minutes and will be provided to learners from Grade 1 to 7 between the ages 6 to 13 years. The screening will take place during school hours. Furthermore, we require that you act on behalf of me (the researcher) and approach participants parents/caregivers to obtain informed consent to conduct the screening (consent form *attached*).Informed assent will also be obtained from the learners before any tests are performed (assent form *attached*). If a learner does not pass the screening, the parents will receive a referral letter for further testing at their own discretion. Each learner who passes the screening will also be tested using the Digits-In-Noise test that will give an indication of how well they perceive speech in the presence of noise. This will thus assist in determining age specific normative data for the Digits in Noise (DIN) test in children.

All information will be kept strictly confidential and will be used for research purposes only. Please note that should a parent/guardian or learner wish to withdraw from the research project at any time they may do so without consequences.

Information and results obtained from the hearing screening will be stored for 15 years at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for research purposes.

I trust that you will find the above in order. Should you have any related enquiries, you are welcome to contact the University of Pretoria's Department of Speech-Language Pathology and Audiology. If you are willing to participate, please fill in the consent form provided below.

Sincerely,

____

Jenique Wolmarans

Researcher

____

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. De Sousa

Research Supervisors

Consent form:

I__________________________(principal) of ______________________________(school), hereby provide consent for hearing screening services to be conducted at this school.

____

Signature

____

Date

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix B1: Signed letter from the principle

Information and results obtained from the hearing screening will be stored for 15 years at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for research purposes.

I trust that you will find the above in order. Should you have any related enquiries, you are welcome to contact the University of Pretoria's Department of Speech-Language Pathology and Audiology. If you are willing to participate, please fill in the consent form provided below.

Sincerely

Jenique Wolmarans
Researcher

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. De Sousa
Research Supervisors

Consent form:

I Mrs M. Gorst-Allman (principal) of St Paulus Pre+ Primary (school), hereby provide consent for hearing screening services to be conducted at this school.

M Gorst-Allman
Signature

2019.03.19
Date

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix B2: Signed letter from the principle

Information and results obtained from the hearing screening will be stored for 15 years at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for research purposes.

I trust that you will find the above in order. Should you have any related enquiries, you are welcome to contact the University of Pretoria's Department of Speech-Language Pathology and Audiology. If you are willing to participate, please fill in the consent form provided below.

Sincerely,

Jenique Wolmarans

Researcher

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. De Sousa

Research Supervisors

Consent form:

I Mark George Whitelaw (principal) of Waterkloof House Prep School (school), hereby provide consent for hearing screening services to be conducted at this school.

Signature

Date 11·03·2019

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix B3: Signed letter from the principle

Information and results obtained from the hearing screening will be stored for 15 years at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for research purposes.

I trust that you will find the above in order. Should you have any related enquiries, you are welcome to contact the University of Pretoria's Department of Speech-Language Pathology and Audiology. If you are willing to participate, please fill in the consent form provided below.

Sincerely, *J. Wolmarans*

Jenique Wolmarans

Researcher

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. De Sousa

Research Supervisors

Consent form:

I *M. I. AREFF* (principal) of *TSHWANE MUSLIM School* (school), hereby provide consent for hearing screening services to be conducted at this school.

Signature

31 JULY 2019

Date

Appendix B4: Signed letter from the principle

Consent form:

I, Sharon Brown (Name) the principal of Anchor Christian Academy (School) hereby give permission for the above-mentioned hearing screening to take place at my primary school.

Signature ____________________

Date: 3/5/2019

ANCHOR CHRISTIAN ACADEMY
PO BOX 32063
TOTIUSDAL
0134
082 392 2154

Appendix C: Informed consent to parents

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Parent/Guardian,

Speech Reception Threshold (SRT) age specific normative data for the DIN test in children

A masters student from the University of Pretoria's Department of Speech-Language Pathology and Audiology, is providing a hearing screening service free of charge. This service is being provided at our primary school. The hearing screening will take approximately 15 to 20 minutes and will be performed during school hours. In the case that your child does not pass the screening assessment, a referral letter will be provided for further assessment and/or intervention. Each learner who passes the screening will also be tested using the Digits-In-Noise test that will give an indication of how well they perceive speech in the presence of noise. This will assist in determining age specific normative data for the DIN test in children.

Any personal information will be kept strictly confidential and will and results obtained will be used for research purposes only. It is also important to note that these tests are completely voluntary and if you or your child wishes to withdraw from the research project at any time, they may do so. Data will be stored at the Department of Speech-Language Pathology and Audiology at the University of Pretoria for 15 years for research purposes.

Should you wish for your child to receive these services, please complete the form below:

Kind Regards,

____

Jenique Wolmarans

Researcher

____

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. K De Sousa

Research Supervisors

…………………………………………………………………………………………………..

Consent form for hearing screening

I, ____ (name and surname), hereby grant permission that hearing tests may be conducted on my child, (name) __________________ Gr.___ Home language___________________ and I acknowledge that the information will be used for research purposes as specified above.

Does your child have a history of ear infections? Yes/No

Are you concerned about your child's hearing? Yes/No

____

Signature of Parent/Guardian

Date ______________________

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix D: Informed assent to children

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

In order to obtain assent from the participants the following information will be provided to the participants verbally:

My name is Jenique. I am trying to learn more about and your hearing.

1.) I will be testing how well your ears can hear.

2.) The test does not cause any pain or and will not hurt you in any way.

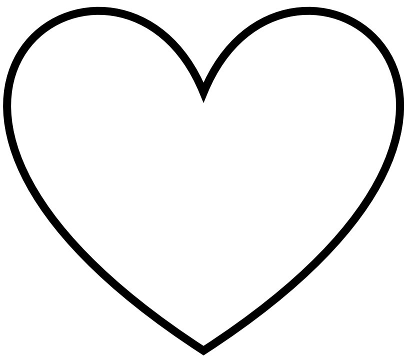
3.) I am going to do two tests.

4.) In the first test, you must listen to the sounds and raise your hand when you hear it.

5.) In the second test, you will hear numbers and you must tell me the numbers you hear.

6.) If you want the test to stop at any time just tell me.

7.) If you want me to test your ears, please color in the heart or sign your name at the bottom.



Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix E: Data collection form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Data Collection Form

Name:	
Code number:	
Date of Birth:	
Age:	
First Language:	
Second Language:	
School:	
Date of testing:	
Tester:	

Tympanometry:

	Right Ear	Left Ear
Ear Canal Volume		
Compliance		
Pressure		
TYPE		

hearScreen™:

	1000 Hz	2000 Hz	4000 Hz	Overall
Right	Pass/Refer	Pass/Refer	Pass/Refer	Pass/Refer
Left	Pass/Refer	Pass/Refer	Pass/Refer	Pass/Refer

Retest:

	1000 Hz	2000 Hz	4000 Hz	Overall
Right	Pass/Refer	Pass/Refer	Pass/Refer	Pass/Refer
Left	Pass/Refer	Pass/Refer	Pass/Refer	Pass/Refer

If Pass on *hearScreen*™:

Digit-In-Noise Test:

Signal-to-Noise Ratio	Diotic =
	Dichotic =
BMLD	

Overall results:

Pass	Refer

Appendix F: Pass letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Parent/Guardian,

Thank you for providing consent so that __________________'s hearing could be screened. The results obtained from the hearing screening indicate that currently there is no concern with your child's hearing and no further tests are needed. We do recommend however that your child's hearing should be screened at least once a year.

Should you require any additional information contact the Department of Speech-Language Pathology and Audiology, University of Pretoria.

Kind Regards,

Jenique Wolmarans

Researchers

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. Karina De Sousa

Research Supervisors

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix G: Referral letter

APPENDIX F

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Parent/Guardian,

Your child, ___________ 's hearing was screened on ___/___/_____. According to the results that we obtained; your child should be referred for further assessment. We would like to refer you to:

An Audiologist for full audiometric testing.

Should you require any additional information, please contact the Department of Speech-Language Pathology and Audiology, University of Pretoria.

Kind Regards,

____

Jenique Wolmarans

Researcher

____

Prof. De Wet Swanepoel, Dr. Faheema Mahomed-Asmail, Mrs. K de Sousa

Research Supervisors

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Appendix H: Proof of article submission to an accredited journal

Gmail Jenique Wolmarans <jenique25@gmail.com>

Journal of the American Academy of Audiology - Manuscript ID 19-107

Journal of the American Academy of Audiology <onbehalfof@manuscriptcentral.com> Mon, Dec 2, 2019 at 3:36 AM
Reply-To: gary.jacobson@vumc.org
To: jenique25@gmail.com

01-Dec-2019

Dear Miss Wolmarans:

Your manuscript entitled "Speech recognition in noise using binaural diotic and antiphasic digits-in-noise in children: maturation and self-test reliability" has been successfully submitted online and is presently being given full consideration for publication in the Journal of the American Academy of Audiology.

Your manuscript ID is 19-107.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at https://mc.manuscriptcentral.com/jaaa and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Center after logging in to https://mc.manuscriptcentral.com/jaaa.

Thank you for submitting your manuscript to the Journal of the American Academy of Audiology.

Sincerely,
Journal of the American Academy of Audiology Editorial Office