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# Are listening difficulties in children related to speech recognition in noise and binaural intelligibility level difference?

**by**

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**Dissertation submitted in fulfilment of the requirements for the degree MA (Audiology) in the Department of Speech-Language Pathology and Audiology.**

**UNIVERSITY OF PRETORIA**

**FACULTY OF HUMANITIES**

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## LIST OF ABBREVIATIONS

**APD:** Auditory Processing Disorder

**BILD:** Binaural Intelligibility Level Difference

**BMLD:** Binaural Masking Level Difference

**CHAPPS:** Children's Auditory Processing Performance Scale

**dB:** Decibel

**DIN:** Digits-in-noise

**ECLiPS:** Evaluation of Children's Listening and Processing Skills

**LiD:** Listening difficulties

**SNR:** Signal-to-noise ratio

**SPSS:** Statistical package of the social sciences

**SRT:** Speech Reception Threshold

## FORMATTING

APA referencing style was used in this dissertation.

## ABSTRACT

In both clinical practice and the literature, parent reports and poor speech recognition in noise performance are commonly associated with listening difficulty (LiD). However, the relationship between these reports and skills is unclear. This study investigated the relationship between questionnaire measures of LiD and psychoacoustic measures of speech recognition in noise. Four hundred and forty-six typically developing, normal-hearing (pure-tone thresholds ≤ 20 dB HL) school children (73.8% male), 6-13 years old, were recruited. Diotic and antiphasic speech reception thresholds (SRTs), and the difference between them, the digits in noise binaural intelligibility level difference (DIN-BILD), were determined using the South African English DIN. Parents completed the Evaluation of Children's Listening and Processing Skills questionnaire (ECLiPS) (246/446) and teachers the Children's Auditory Processing Performance Scale (CHAPPS) (429/446) questionnaires to identify children with possible LiD. The ECLiPS classified 36/246 (14.6%), and the CHAPPS 103/429 (23.1%) children with LiD by questionnaire published criteria. Both questionnaires were obtained for 229 participants, of which 3.1% (7/229) were classified with LiD based on both CHAPPS and ECLiPS scores. There was no significant relationship between the DIN-BILD or speech recognition in noise (antiphasic and diotic conditions) and ECLiPS or CHAPPS total scores across the 246 ECLiPS and 429 CHAPPS participants. Age had a significant effect on BILD, SRTs and CHAPPS total score. LID, determined by total scores on parent and teacher questionnaires, was not predictive of BILD or poor speech recognition in noise. LiD is a heterogeneous construct for which a DIN test could inform abilities but not identify the condition.

**Keywords:** digits-in-noise; BILD; LiD; children; ECLiPS; CHAPPS; smartphone hearing screening.

# 1. INTRODUCTION

A listening difficulty (LiD) is defined as a difficulty understanding speech in noisy environments or difficulty following instructions or questions in the presence of background noise (Pienkowski, 2017; Moore, 2012). LiD often occurs with hearing loss, although in a small cohort of children, may appear without the presence of peripheral hearing loss determined through conventional pure-tone audiograms (Pienkowski, 2017; Moore, 2012; Rudner & Lunner, 2014). A review of one large paediatric audiology service (Nottingham, UK) found that approximately 5% of 2,924 children had normal audiograms but reported with LiD (Hind et al., 2011). These children may receive additional testing for auditory processing disorder (APD), although very few appear to receive a diagnosis of APD (Moore et al., 2018). APD is defined as a difficulty in perceptual processing of auditory stimuli in the central nervous system. This is demonstrated through poor performance in skills such as sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals (ASHA, 1996; Bellis, 2003; Chermak & Musiek, 1997; American Academy of Audiology, 2010). Many professionals have proposed that APD involves LiD, caused by impaired processing in the central auditory system (Moore, 2012).

In a separate lab study, Ferguson and colleagues (2011) reported that caregiver-reported difficulty hearing speech in noise was the most common complaint of a small group of children diagnosed with APD (13/19 = 68%). Kumar and colleagues (2007) indicated that 4000 patients with ages unspecified are seen yearly at their clinic. Ten percent of these patients had complaints of hearing loss, although a normal audiogram was present and consequently were typically discharged without treatment (Kumar, Furrat, & Roy, 2007).

Aside from hearing loss, otitis media has been shown to cause persistent listening deficits in terms of binaural interaction and functional listening ability once hearing returned to normal (PTA < 25 dB HL) (Graydon et al., 2017).

Although hearing loss not reflected on the audiogram, for example, extended high-frequency hearing loss (Hunter et al., 1996) may contribute to such observations. Another possible underlying cause for LiD may be cochlear synaptopathy which is a partial loss of the inner hair cells (Pienkowski, 2017). Children are often exposed to excessive intensity and duration of noise such as concerts, school events and through headphone use (Keith et al. 2011; Taljaard et al. 2013; Carter et al. 2014). This puts children at risk of developing noise-induced synaptopathy (Pienkowski, 2017). Impaired cognition (e.g. language, memory, attention) (Moore et al., 2010), leading to reduced academic and auditory test performance, is now an accepted, major contributor to LiD. A LiD may affect children's academic performance owing to the decreased perception of speech in noise typical of school environments (Hind et al., 2011). Listening takes up approximately 40-50% of communication (Bingol, Mart, Celik, & Yildiz, 2014) in classrooms that generally have high noise levels. Children with LiD will find classroom environments, especially challenging (Bingol et al., 2014).

Conventional hearing assessments using pure tone audiometry, do not fully reflect hearing ability, or speech perception (Rudner & Lunner, 2014) which is why children with LiD may be missed when presenting with a normal audiogram (Pienkowski, 2016). Currently, no single test serves as a gold standard to diagnose LiD (Drake et al., 2006). There are, however, screening tools such as the Children's Auditory Processing Performance Scale (CHAPPS), which compares the child's listening ability to the listening ability of age-related peers (Smoski, Brunt, & Tannahill, 1998). Another tool that has become available more recently is the Evaluation of Children's Listening and Processing Skills (ECLiPS). This test allows for a comprehensive profile of listening, communication, cognitive and language difficulties to be determined while gathering information about everyday listening abilities of the child (Barry, Tomlin, Moore, & Dillon, 2015). Completed by parents, statements in this tool are based on behaviours commonly observed (Barry, Tomlin, Moore, & Dillon, 2015) and so it is essential that this tool, as well as the CHAPPS, are completed by individuals who have a good knowledge of the child. However, as these tools are completed only through observations, they are only suitable for screening and not for making a definitive diagnosis of LiD or speech recognition in noise disorder (Barry & Moore, 2015). Instead, the information obtained could be used to supplement more objective results to identify LiD (Barry & Moore, 2015).

The use of simple speech perception in noise tests, like the digits-in-noise (DIN) test, has been suggested to detect LiD in children (Denys, et al., 2018; Koopmans, Goverts, & Smits, 2018; Moore et al., 2019). This test measures speech perception in noise and involves linguistic and cognitive demand (Moore et al., 2014). The signal-to-noise ratio (SNR) where the listener can correctly recognize 50% of three successive digits presented in background noise is measured by the DIN test. The DIN test makes use of simple digits from 0 to 9, enabling children from as young as four years to be able to take the test (Kaandorp et al., 2016). An additional advantage of the DIN test is that it requires minimal language proficiency making it relevant in a global context as many different countries use various languages in addition to English (Kaandorp et al., 2016). The DIN test is currently telephone and computer-based in multiple languages for countries such as the Netherlands, France, Australia, Germany, the United Kingdom, Poland, Switzerland and the United States (Smits et al., 2004; Folmer et al., 2017; Jansen et al., 2010; Smits, Merkus, & Houtgast, 2006; Watson et al., 2012; Zokoll, Wagener, Brand, Buschermöhle, & Kollmeier, 2012).

DIN tests also do not make use of equipment that requires calibration (Jansen et al., 2010). Studies also suggest the DIN can detect slight deteriorations in hearing over time (Denys et al., 2018). DIN tests have been demonstrated to have high sensitivity and specificity when identifying normal-hearing and hearing-impaired individuals (Watson et al. 2012; Jansen et al. 2013, 2014; Koole et al. 2016; Folmer et al. 2017) due to high correlations to pure tone audiogram results (Smits et al. 2004, 2013; Jansen et al. 2010, 2013; Watson et al. 2012; Vlaming et al. 2014; Koole et al. 2016). It has been proposed that DIN tests may be more sensitive to pathology beyond the peripheral hearing system (Denys et al., 2018). DIN tests could provide a more accurate representation of human communication. They may be assessing auditory processing difficulties which are difficulties in the perceptual processing of auditory information by the central nervous system (Denys et al., 2018).

DeBonis (2015) also highlighted the value of DIN testing in a protocol to identify children with LiD.

More recently a validated smartphone-based DIN test was released as the national hearing screening test of South Africa in 2016, and as the official hearing screening App of the World Health Organization in 2019 (Potgieter et al., 2016; Potgieter, Swanepoel, & Smits, 2018; Swanepoel, De Sousa, Smits, & Moore, 2019). This smartphone platform allows for improved access (Potgieter et al., 2018), improved quality of service delivery, effectiveness as well as the efficiency of health care (Swanepoel et al., 2010). This is achieved through the smartphone platforms being affordable, mobile as well as the high penetration of smartphones (Swanepoel, De Sousa, Smits, & Moore, 2019; STATSSA General Household Survey, 2013). Several other advantages include that the smartphone-based DIN test can be done without a test administrator (Denys et al., 2018), the digital nature of the platform ensures high fidelity signals can be delivered to determine robust SRT's, rapid testing within 3 minutes, and geolocation allowing for location-based referrals for follow-up (Potgieter et al., 2016; Potgieter, Swanepoel, & Smits, 2018; Swanepoel, De Sousa, Smits, & Moore, 2019).

Since the DIN test measures speech perception in noise, providing a more functional indication of hearing ability than pure tone audiometry, and some linguistic and cognitive demand, it has been proposed that DIN tests may be more sensitive to pathology beyond the peripheral hearing system, sometimes called auditory processing disorders (Denys et al., 2018). It has been highlighted that there may be value, including DIN testing in a protocol to identify children with LiD (DeBonis, 2015). Recently, the use of binaural phase reversed (antiphasic) digits was introduced as a method of increasing sensitivity of the DIN test to various types of hearing loss via smartphones (Swanepoel, De Sousa, Smits, & Moore, 2019). Using an antiphasic stimulus condition has demonstrated that the antiphasic advantage in DIN decreases as the severity of the hearing loss increases due to timing cue deterioration (Wilson et al. 1994). This is due to asynchronous neural firing at higher auditory centres (Jerger et al. 1984; Welsh et al. 2004; Vannson et al. 2017). By completing both a standard diotic and antiphasic DIN test, binaural intelligibility level difference

(BILD) can be determined. BILD is a psychoacoustic effect based on the classic binaural masking level difference (BMLD) (Hirsh, 1948; Licklider, 1948). BMLD is the difference in threshold for detection of a low-frequency tone presented simultaneously with a masking noise in each ear, between the stimuli being identical in the two ears ($N_oS_o$), and a 180-degree phase difference between the ears of either the masker ($N_\pi So$) or the tone ($N_oS_\pi$). BILD is a speech version of BMLD where, typically, a word is substituted for the tone. Both speech intelligibility and speech detection thresholds improve when the word is shifted from interaural in-phase ($N_oS_o$) to 180 degrees out-of-phase ($N_oS_\pi$), relative to a masking noise that remains identical in the two ears (Johansson & Arlinger, 2002). BILD is thus an indirect measure of the ability to understand speech-in-noise, relying on both accurate coding of interaural phase in the auditory brainstem (Palmer, Jiang, & McAlpine, 2000; Gilbert, Shackleton, Krumbholz, & Palmer, 2015), and decoding and identification of speech in the auditory cortex. Because it is a “derived” (Moore and Ferguson, 2014) or “subtraction” (Dillon et al., 2014) measure of auditory perception, BILD may also be less reliant on the cognitive aspects of a task than the contributing, individual speech-in-noise measures ($N_oS_o$, $N_oS_\pi$).

The hypothesis that BILD may be an indicator of an impaired auditory system underlying LiD, specifically speech recognition in noise difficulties, is based on two premises. First, that the measure reflects binaural temporal integration in the brainstem, at microsecond resolution (Joris et al., 1998) and, second, that cognitive cancellation, as outlined above, eliminates the possibility of top-down cortical influences, including attention, linguistic and efferent effects, on the observed performance of the children.

This study hypothesised that there is a relation between DIN-BILD, SRT on DIN and parent/teacher reports of LiD.

# 2. METHODOLOGY

## 2.1. Research Objectives

To determine if a relationship exists between LiDs, as determined by the ECLiPS and the CHAPPS, in young children and their Binaural Intelligibility Level Difference (BILD) using a diotic and antiphasic digits-in-noise test paradigm.

## 2.2. Research design

This study was quantitative and made use of a correlational, cross-sectional, within-subject design to determine if there was a correlation between the DIN BILD and LiD in children as determined by both the ECLiPS and the CHAPPS questionnaire. Each participant's data was collected once-off at a single point in time. Therefore, the study made use of a cross-sectional design, which collects all data needed once off (Leedy & Ormrod, 2015). This study was cross-sectional as the population was divided into cross-sections, namely into different age groups which were then sampled and compared.

## 2.3. Research ethics

Once ethical clearance was granted by the Research Ethics committee of Department of Speech-Language Pathology and Audiology and Research Ethics Community, and, the Faculty of Humanities at the University of Pretoria, data collection commenced. Data collection commenced once written consent was obtained from the principal of the school (Appendix B), teachers who participated in filling out the questionnaire (Appendix C) parents/guardians of the learners (Appendix D), as well as assent from the participants (Appendix E).

Ethical considerations are classified into four categories. These categories are protection from harm, voluntary and informed participation, the right to privacy and honesty with professional colleagues (Leedy & Ormrod, 2015). The ethical considerations for this research study were as follows:

### 2.3.1. Protection from Harm

Researchers should not expose participants to any form of physical or psychological harm (Leedy & Ormrod, 2015). In this study, the participants were treated with respect and were provided with information about the study objectives.

Teachers, parents of the participants and the participants were provided with information letters as well as verbal information explaining that they may withdraw from the study at any point without negative consequences (Appendix C, D and E).

### 2.3.2. Voluntary and Informed Consent

Research participants should be provided with information about the study and the procedures required to collect data (Leedy & Ormrod, 2015). Participants must be given a choice as to whether or not they wish to participate before data can be collected (Leedy & Ormrod, 2015). In this study, written consent was required from the principal of the school (Appendix B) where data collection occurred. Written consent was also then required from the teachers (Appendix C) before they could participate. Written consent was required from parents before their children could be considered as participants (Appendix D). Lastly, written assent was required from the participants (Appendix E) before data collection could commence.

### 2.3.3. Right to Privacy

Researchers must always keep information regarding the participants and their results confidential (Leedy & Ormrod, 2015). Confidentiality was maintained by using unique arbitrary coded numbers or pseudonyms (Leedy & Ormrod, 2015). In this study, each participant was given a unique arbitrary code number to be used instead of the participant's name. Only the researcher was aware of the participants' identity and all reports presenting the information used these unique arbitrary coded numbers to ensure participant identity was kept confidential. Datasheets with participant information were only accessed by the researchers. They will be stored at the Department of Speech-Language Pathology and Audiology of the University of Pretoria for 15 years for research and archiving purposes.

### 2.3.4. Honesty with Professional Colleagues

Research findings must be represented honestly and entirely, with no misinterpretations or misleading information (Leedy & Ormrod, 2015). Data must not be altered to support a specific outcome (Leedy & Ormrod, 2015). The results of each test were calculated automatically on both the hearScreen™ application and the DIN test. The ECLiPS and CHAPPS have a predetermined scoring method that determines each participants score based on responses to various questions. Each question was weighted to contribute to the total score. All of these results were placed in an excel spreadsheet displaying all the data collected for each participant. This spreadsheet was then put into the Statistical Package for the Social Sciences (SPSS, v22. Chicago, Illinois) program and the program determined if any correlations were present. Data could not be altered as it was not known what the results should be to allow for correlations to exist.

### 2.4. Reliability, Validity and Trustworthiness

The hearScreen™ application validity has been determined. A study conducted by Mahomed-Asmail, Swanepoel, Eikelboom, Myburgh, & James Hall, (2016) compared the hearScreen™ application with pure tone audiometers used for conventional screening. The study found no significant specificity or sensitivity differences, with 75% sensitivity and 98.5% specificity (Mahomed-Asmail et al., 2016). This study also found that this method of hearing screening is slightly more accurate in identifying children who present with normal hearing as the hearScreen™ application has a 1.5% lower false-positive rate (Mahomed-Asmail et al., 2016).

The HearZA DIN test was developed for South Africa and has been validated (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2015). Differences between smartphones with five different headphones were not significant (Potgieter et al., 2015). The study conducted by (Potgieter et al., 2015) found that this test can be conducted with standard earphones or headphones.

Evaluation of Children's Listening and Processing Skills (ECLiPS) scales' reliability has been determined through test-retest reliability as well as inter-rater reliability. It has been determined that the ECLiPS has a high test-retest reliability (Barry & Moore, 2015). Parent-parent inter-rater reliability and parent-teacher inter-rater reliability were determined. Parent-parent inter-rater comparison yielded generally high correlations while parent-teacher inter-rater comparison yielded slightly lower correlations (Barry & Moore, 2015). This may be due to parents being more aware of difficulties in their child as they spend every day with their child (Barry & Moore, 2015). The ECLiPS has been designed to assess listening difficulties, and it has been validated (Barry & Moore, 2015).

Research shows that the CHAPPS has been reliable in identifying listening difficulties, specifically processing in noise, in children (Smoski, Brunt & Tannahill, 1992). However, as the CHAPPS is a questionnaire, it should only be used as a screener as is not a reliable diagnostic tool for APD or LiD (Drake et al., 2006). The CHAPPS has been determined as a reliable informational tool based on parent or teacher observation of children's listening difficulties (Drake et al., 2006).

## 2.5. Participants

Purposive stratified non-random sampling was used in this study (Leedy & Ormrod, 2015). Participants were obtained from four private primary schools in the City of Tshwane, Gauteng Province, South Africa. Participants included 446 children, their parents/guardians and teachers. The children from the private mainstream English primary schools were ages 6 to 13 years and thus were separated by grade. All children were either English first or second language speakers. All children were proficient in English as this was the medium used in the schools. All children from grade one to grade seven were screened. Children who passed a pure-tone hearing screening (bilateral PTA < 25 dB HL) using the hearScreen™ application and presented with normal middle ear functioning as determined through tympanometry were included as participants. To ensure that the ECLiPS questionnaire was accurately completed, only the relevant teachers responsible for the respective age groups completed the questionnaire. Parents/guardians required were the parents/guardians the participants live with.

## 2.6. Equipment

*Participant selection*

The following apparatus was utilized in this study. A Welch Allyn Pocketscope™ with reusable specula. This otoscope was used to determine the integrity of the tympanic membrane and external ear canal visually. An ERO SCAN™ Pro was used to perform diagnostic tympanometry to indicate middle ear functioning.
Hearing screening was conducted with a calibrated screening audiometer run on a smartphone (Samsung SM-J200H) with circumaural headphones (Sennheiser HD

280 Pro) using the hearScreen™ application (hearScreen, hearX group, South Africa) to determine if normal hearing thresholds were present. The frequencies of 1, 2 and 4 kHz were tested at an intensity of 20 dB to determine if normal hearing was present (Swanepoel, Myburgh, Howe, Mahomed, & Eikelboom, 2014). Calibration was performed according to prescribed standards (ISO 389-1 1998; ANSI/ASA S3.6-2010). To ensure an optimal testing environment, the software monitored the environmental noise, using Maximum Permissible Ambient Noise Levels (MPANL) during testing.

*Research data collection*

The Samsung SM-J200H smartphone with Sennheiser HD 280 Pro circumaural headphones were used to determine the Speech Reception Threshold (SRT) through presenting the South African English DIN test in diotic and antiphasic conditions. The SA English DIN test presented 23 digit triplets with the digits ranging from 0-9 (Potgieter et al., 2016). The digits were presented by a female speaker who is a native South African English speaker (Potgieter et al., 2016). Initial presentation level was 0 dB SNR. If any of the first three digits were incorrectly reported, the next three digits were presented at 4-dB higher SNR. Thereafter, when all three digits were correctly heard, repeated and entered onto the application, the next three digits were presented at a 2-dB lower SNR (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016). An incorrect response prompted the next three digits to be presented at a 2-dB higher SNR (Potgieter et al., 2016; Potgieter et al., 2017). The final result was calculated by averaging the SNR of the last 19 presented digit triplets (Potgieter et al., 2016; Potgieter et al., 2017). Masking the digits was done through matching white noise to the average speech spectrum of the chosen digits (Potgieter et al., 2016). The masking noise level that was presented is equal to the average level of the digits when they are said without silences (Smits et al., 2013). The dB SNR was the level at which the listener was able to correctly recognize 50% of the digit triplets (Potgieter et al., 2016). By using the DIN, the BILD was determined through subtracting the antiphasic SNR from the diotic SNR.

The ECLiPS questionnaire was completed by the parents/guardians and used as a screening tool for listening deficits. The ECLiPS consists of 38 questions which form a profile of listening and communication abilities (Barry & Moore, 2015) (Barry, Tomlin, Moore, & Dillon, 2015). The tool is made up of five subscales, namely Speech & Auditory Processing (SAP); Memory & Attention (M&A); Pragmatic & Social Skills (PSS); Environmental & Auditory Sensitivity (EAS); and Language/Literacy/Laterality (LLL). Responses to each question consist of five points on a Likert scale, which expresses the extent to which the parent agrees or disagrees with the question. The possible answers include (Strongly Agree), A (Agree), NAD (Neither Agree nor Disagree), D (Disagree), SD (Strongly Disagree). The ECLiPS has been normalized and standardized with a scoring method based on a mean of 10 (SD 3.0) in a UK population (Barry & Moore, 2015). The answer of each question has a specific score namely SA= 2, A =1, NAD = 0, D = -1, SD= -2 for questions 9, 21, 25. SA= -2, A= -1, NAD = 0, D = 1, SD = 2 for the remaining questions (Barry & Moore, 2015). The score obtained for each question is then added to determine the total score as well as subscales scores. Each subscale is made up of responses from only a predetermined subset namely: Speech & Auditory Processing (SAP) is calculated from the responses to questions 1, 5, 11, 16, 19, 24, 31, 33, 38. Environmental & Auditory Sensitivity (EAS): Questions 3, 6, 10, 15, 18,22,29,35. Language/Literacy/Laterality (L/L/L): Questions: 2, 12, 20, 27, 30, and 37. Memory& Attention (M&A): Questions: 4, 8, 13, 17, 21, 25, 28, 32 and Pragmatic & Social Skills (SS): Questions: 7, 14, 23,26,34,36 (Barry & Moore, 2015). Each score is divided by the number of questions that contributed to the score to determine a raw score. Raw scores are converted to scale scores according to age and gender. Scaled scores are then converted to percentiles. Scores range from 0 to 100. Scores below the 10$^{th}$ percentile are seen as clinically significant, and this is equivalent to a score of 6. Thus, a score of below 6 indicates a listening difficulty (Barry & Moore, 2015). Through completion of the ECLiPS, information regarding concerns for listening and learning as well as information about everyday listening abilities were gathered (Barry & Moore, 2015). The ECLiPS was primarily designed to support the mapping out of the broader cognitive profile of a child referred because of listening difficulties (Barry & Moore, 2015). Therefore, not all items in the questionnaire are based purely on speech in noise understanding. The questionnaire is developed with the premise that the non-speech in noise items are behaviours or characteristics associated with a LiD, thus allowing for a holistic overview of each child. Therefore, all questionnaire items need to be considered when analysing the questionnaires (Barry & Moore, 2015). The CHAPPS questionnaire was completed by the teachers and additionally used as a screening tool for listening deficits (Appendix I). The CHAPPS consists of 36 questions that were answered by comparing the participants listening ability to the listening abilities of the other learners in the class (Based on a US population) (Smoski, Brunt, & Tannahill, 1998). The CHAPPS questions form part of 6 subscales which assessed listening in noise, in quiet, in ideal conditions, against multiple inputs, the participant's auditory memory/sequencing and, finally, their auditory attention span (Smoski, Brunt, & Tannahill, 1998). Responses to each question consist of a seven-point scale ranging from +1 to -5 to indicating the child's level of difficulty with the statement made in the question. The answers include: less difficulty, the same amount of difficulty, slightly more difficulty, more difficulty, considerably more difficulty, significantly more difficulty and cannot function at all. The CHAPPS has a predetermined scoring method that determines each participants score based on responses to the questions. Each question is weighted to contribute to the total score. The answer of each question has a specific score namely less difficulty (+1), same amount of difficulty (0), slightly more difficulty (-1), more difficulty (-2), considerably more difficulty (-3), significantly more difficulty (-4) and cannot function at all (-5) (Smoski, Brunt, & Tannahill, 1998). This score was then compared to a normative range. Scores range from +36.0 to -180.0. A score below -11.0 is indicative of difficulty (Smoski, Brunt, & Tannahill, 1998). All of the CHAPPS questions contribute to form a profile of listening behaviours, and the non-speech perceptions questions are based on the premise that these are behaviours associated with children who have difficulty with listening. Thus, all questions need to be considered as the total score of the CHAPPS is the determiner of any LiD (Smoski, Brunt, & Tannahill, 1998).

**2.7. Procedures**

Once ethical clearance was granted by the Research Ethics committee of Department of Speech-Language Pathology and Audiology and Research Ethics Community, Faculty of Humanities at the University of Pretoria and the relevant consent was obtained, data collection commenced at two private primary schools in the City of Tshwane, Gauteng province in South Africa.

*Participant selection*

The otoscope was used to determine the integrity of the tympanic membrane and external ear canal visually. While the ERO SCAN™ Pro was used to perform diagnostic tympanometry. This indicated middle ear functioning and ruled out any possible middle ear pathologies. The hearScreen™ application was used to screen the participants hearing. This screening was necessary to confirm that the participants presented with normal hearing (1, 2 and 4 kHz < 20dB HL) before further testing could take place. Grade one to grade seven learners of each school were screened in a standard (quiet) room. Participants who did not pass the pure tone hearing screening were retested and if they did not pass the pure tone hearing screening a second time they were excluded and referred for further intervention (Appendix H), as possible LiD could be as a result of a hearing loss. Participants who passed the hearing screening received letters stating that normal hearing thresholds were obtained (Appendix G).

*Research data collection*

The participants who passed the screening were then used for data collection. Data collection consisted of the DIN test counterbalanced in the standard binaural diotic and antiphasic conditions. Standard binaural diotic conditions are when the test stimuli are presented binaurally and identically to each ear (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). Antiphasic conditions make use of test stimuli that are phase inverted between the ears (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). Antiphasic conditions have been found to improve the sensitivity of the DIN to unilateral, asymmetrical and conductive hearing loss (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). Participants were instructed that they would hear three digits, and once they had heard all three digits, they needed to repeat them out loud to the tester who recorded their response on the smartphone. For both conditions, the digit triplets were masked by diotic steady-state noise that matched the long term average speech spectrum of the digits (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016). Each participant performed one diotic version and one antiphasic version. A counterbalanced procedure was followed. The BILD was then calculated by subtracting the diotic from the antiphasic condition.

The ECLiPS was completed by the parents/guardians of the participants who passed the hearing screening. The parents/guardians were required to complete the 38-question scale that determined a profile of listening and communication problems that were present for a child (Barry & Moore, 2015). This information was then used to compare to the results of the DIN test and correlated with the results of the BILD.

Additionally, the CHAPPS was completed by the teachers of the participants who passed the hearing screening. The teachers were required to complete the 36 question scale to rate listening ability in various environments (Smoski, Brunt, & Tannahill, 1998). This information was then used to compare to the results of the DIN test and correlated results with the BILD.

The BILD, the total ECLiPS score and total CHAPPS score of each participant were then compared to identify any potential correlations.

**2.8. Data analysis**

The Statistical Package for the Social Sciences (SPSS, v25. Chicago, Illinois) was used to conduct the analysis. Descriptive statistics were calculated for the results obtained. Univariate associations between outcome measures and age were tested using Pearson and Spearman’s correlations (Laerd Statistics, 2018). Pearson’s correlation was used to evaluate the linear relationship between SRTs, BILD, and ECLiPS. Spearman’s correlation is a non-parametric test and was therefore used to evaluate the linear relationship between SRTs, BILD, and the CHAPPS as the CHAPPS is a non-parametric questionnaire (Laerd Statistics, 2018). Pearson's rank correlation coefficient was used to determine if statistically significant correlations were evident between variables (ECLiPS scores, CHAPPS scores, BILD score, diotic and antiphasic SRTs). Linear regression models were run to understand the effect of the ECLiPS and CHAPPS subgroup scores on diotic, antiphasic SRTs, and BILD. Homoscedasticity and normality of the residuals were determined (Laerd Statistics, 2018). Separate models were run for the ECLiPS and CHAPPS subgroups since a small sample included children with both ECLIPS and CHAPPS results. By running these subgroups separately, a larger, more accurate sample size can be used.

## 3. ARE LISTENING DIFFICULTIES IN NORMAL-HEARING CHILDREN RELATED TO BINAURAL INTELLIGIBILITY LEVEL DIFFERENCE?

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### 3.1. Abstract

**Purpose:** In both clinical practice and the literature, parent reports and poor speech recognition in noise performance are commonly associated with listening difficulty (LiD). However, the relationship between these reports and skills is unclear. This study investigated the relationship between questionnaire measures of LiD and psychoacoustic measures of speech recognition in noise.

**Method:** 446 typically developing, normal-hearing (pure-tone thresholds ≤ 20 dB HL) school children (73.8% male), 6-13 years old, were recruited. Diotic and antiphasic speech reception thresholds (SRTs), and the difference between them, the binaural intelligibility level difference (DIN-BILD), were determined using the South African English DIN. Parents completed the ECLiPS (246/446) and teachers the CHAPPS (429/446) questionnaires to identify children with possible LiD.

**Results:** The ECLiPS classified 36/246 (14.6%), and the CHAPPS 103/429 (23.1%) children with LiD by questionnaire published criteria. Both questionnaires were obtained for 229 participants, of which 3.1% (7/229) were classified with LiD based on both CHAPPS and ECLiPS scores. There was no significant relationship between the DIN-BILD or speech recognition in noise (antiphasic and diotic conditions) and ECLiPS or CHAPPS total scores across the 246 ECLiPS and 429 CHAPPS participants. Age had a significant effect on BILD, SRTs and CHAPPS total score.

**Conclusions**: LID, determined by total scores on parent and teacher questionnaires, was not predictive of BILD or poor speech recognition in noise. LiD is a clinical entity for which a DIN test could inform abilities but not identify the condition.

**Keywords:** digits-in-noise; BILD; LiD; children; ECLiPS; CHAPPS; smartphone hearing screening.

### 3.2. Introduction

Listening difficulty (LiD) is most often associated with difficulty understanding speech in noise, for example, in reverberant or other challenging listening environments (Pienkowski, 2017; Moore, 2012). LiD due to hearing loss is common and uncontroversial, but LiD, as presented in this paper, may also occur without peripheral hearing loss determined through conventional pure tone audiometry (Pienkowski, 2017; Moore, 2012; Rudner & Lunner, 2014). For example, approximately 5% of 2,924 children attending one large pediatric audiology service (in Nottingham, UK) had normal audiograms but reported LiD (Hind et al., 2011).

Some children with LiD may receive additional testing for auditory processing disorder (APD), although very few appear to receive a diagnosis of APD (Moore et al., 2018). Ferguson and colleagues (2011) found that caregiver-reported difficulty with everyday speech understanding in noise was the most common complaint of a small group of children diagnosed with APD (13/19 = 68%). A history of early otitis media has been shown to cause persistent listening deficits once hearing returned to normal (PTA < 25 dB HL; Graydon et al., 2017), although a sub-clinical hearing loss, for example, extended high-frequency hearing loss (Hunter et al., 1996), may contribute to such observations. Another form of sub-clinical hearing loss is cochlear synaptopathy, a loss of inner hair cell ribbon synapses and their post-synaptic afferent nerve fibres (Pienkowski, 2017), that may be due to excessive noise exposure (Liberman, 2015). Impaired cognition (e.g., language, memory, attention), leading to reduced academic and auditory test performance, is now an accepted, major contributor to LiD (Moore et al., 2010). Academic achievement in children with LiD may also suffer owing to the acoustically challenging nature of typical school environments (Dockrell & Shield, 2012). Poor school performance was the main reason for a referral for central auditory processing evaluation through a large audiology service at Cincinnati Children's Hospital (Moore et al., 2018).

Unfortunately, there is no single hearing test that currently serves as a gold standard to detect LiD ( British Society of Audiology, 2017). There are, however, several teachers and caregiver questionnaires, such as the Children's Auditory Processing Performance Scale (CHAPPS), which compares the child's listening ability with that of age-related peers (Smoski, Brunt, & Tannahill, 1998). Another tool that has become available more recently is the Evaluation of Children's Listening and Processing Skills (ECLiPS). This test allows for a comprehensive profile of listening, communication, cognitive and language difficulties to be determined while gathering information about everyday listening abilities of the child (Barry & Moore, 2015). Completed by parents, statements in the ECLiPS are based on commonly observed behaviours (Barry, Tomlin, Moore, & Dillon, 2015). So it is essential that both this tool and the CHAPPS, are completed by individuals who have a good knowledge of the child. However, as these tools are completed only through observations, they should be interpreted with caution (Barry & Moore, 2015). Information obtained could, for example, be used to supplement other, more objective results of speech recognition in noise abilities (Barry & Moore, 2015).

Simple speech-in-noise assessments, for example, the digits-in-noise test (DIN), can be used to detect LiD in children (Denys et al., 2018; Koopmans, Goverts, & Smits, 2018; Moore et al., 2019). The DIN measures speech perception in noise and involves linguistic and cognitive as well as auditory abilities (Moore et al., 2014). The DIN measures the signal-to-noise ratio (SNR), where the listener can correctly recognize 50% of three successive digits presented in background noise. The DIN test makes use of simple, naturally spoken digits from 0 to 9, requiring minimal language proficiency (Kaandorp et al., 2016) and thereby enabling children from as young as four years to be able to take the test (Koopmans et al., 2018; Moore et al., 2019; Smits, Goverts, & Festen, 2013).

Recently, the use of binaural phase inverted (antiphasic) digits was introduced as a method of increasing sensitivity of the DIN test to various types of hearing loss (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019; Swanepoel, De Sousa, Smits, & Moore, 2019; Smits, Watson, Kidd, Moore, & Goverts, 2016). It has been found that the antiphasic condition advantage in DIN decreases as the severity of the hearing loss increases due to timing cue deterioration (Wilson et al. 1994). This is due to asynchronous neural firing at higher auditory centres (Jerger et al. 1984; Welsh et al. 2004; Vannson et al. 2017). Thus, it can be proposed that DIN tests may be more sensitive to pathology beyond the peripheral hearing system (Denys et al., 2018). It has been highlighted that there may be value, including DIN testing, in a protocol to identify children with LiD (DeBonis, 2015). By completing both a standard diotic and antiphasic DIN test, the binaural intelligibility level difference (BILD) can also be determined. BILD is a psychoacoustic effect based on the classic binaural masking level difference (BMLD) (Hirsh, 1948; Licklider, 1948). BMLD is the difference in threshold for detection of a low-frequency tone presented simultaneously with a masking noise in each ear, between the stimuli being identical in the two ears ($N_0S_0$), and a 180-degree phase difference between the ears of either the masker ($N_\pi S_0$) or the tone ($N_0S_\pi$). BILD is a speech version of BMLD where, typically, a word is substituted for the tone. Both speech intelligibility and speech detection thresholds improve when the word is shifted from interaural in-phase ($N_0S_0$) to 180 degrees out-of-phase ($N_0S_\pi$), relative to a masking noise that remains identical in the two ears (Johansson & Arlinger, 2002). BILD is thus an indirect measure of the ability to understand speech-in-noise, relying on both accurate coding of interaural phase in the auditory brainstem (Palmer, Jiang, & McAlpine, 2000; Gilbert, Shackleton, Krumbholz, & Palmer, 2015), and decoding and identification of speech in the auditory cortex. Because it is a "derived" (Moore and Ferguson, 2014) or "subtraction" (Dillon et al., 2014) measure of auditory perception, BILD may also be less reliant on the cognitive aspects of a task than the contributing, individual speech-in-noise measures.

The hypothesis that BILD may be an indicator of an impaired auditory system underlying LiD is based on two premises. First, that the measure reflects binaural temporal integration in the brainstem, at microsecond resolution (Joris et al., 1998) and, second, that cognitive cancellation, as outlined above, eliminates the possibility of top-down cortical influences, including attention, linguistic and efferent effects, on the observed performance of the children.

This study hypothesized that there is a relationship between DIN BILD and SRTs with LiD, as identified by questionnaires completed by parents and teachers.

### 3.3. Method

Approval to conduct this study was granted by the Research Ethics Committee, Faculty of Humanities, University of Pretoria, before data collection commenced.

*Participants*

Four hundred and forty-six typically developing children between the ages of 6 to 13 years (mean 10.0 years, SD=2.2) were recruited from four private mainstream English primary schools in Pretoria, South Africa. Participants were majority male (73.8%; *n*=329). Only children presenting with normal bilateral hearing sensitivity (≤ 20 dB HL at octave frequencies, 1, 2, and 4 kHz) and normal tympanometry were included for analyses.

*Material and Apparatus*

Otoscopy using Welch Allyn Pocketscope™ with reusable specula was used to determine the integrity of the tympanic membrane and external ear canal. An ERO SCAN™ Pro was used to perform diagnostic tympanometry to indicate middle ear functioning. Hearing screening was conducted with a calibrated screening audiometer run on a smartphone (Samsung SM-J200H) with circumaural headphones (Sennheiser HD 280 Pro) using the hearScreen™ application (hearScreen, hearX group, South Africa) to determine if normal hearing thresholds were present. The frequencies of 1, 2, and 4 kHz were tested at 20 dB HL to determine if normal hearing was present. Calibration was performed according to prescribed standards (ISO 389-1 1998; ANSI/ASA S3.6-2010). The DIN tests were conducted using a research smartphone application (Samsung SM-J200H) and circumaural headphones (Sennheiser HD 280 Pro).

The ECLiPS questionnaire was completed by the parents/guardians and used as a screening tool for listening deficits. The ECLiPS consists of 38 questions on listening and communication abilities (Barry & Moore, 2015) (Barry, Tomlin, Moore, & Dillon, 2015). The tool is made up of five subscales, namely Speech & Auditory Processing (SAP), Memory & Attention (M&A), Pragmatic & Social Skills (PSS), Environmental & Auditory Sensitivity (EAS), and Language/Literacy/Laterality (LLL). Responses to each question consist of five points on a Likert scale, expressing the extent to which the parent agrees or disagrees with the question. The possible answers include SA (Strongly Agree), A (Agree), NAD (Neither Agree nor Disagree), D (Disagree), SD (Strongly Disagree). The ECLiPS has been normalized and standardized with a scoring method based on a mean of 10 (SD 3.0) in a UK population (Barry & Moore, 2015). The answer of each question has a specific score namely SA= 2, A =1, NAD = 0, D = -1, SD= -2 for questions 9, 21, 25. SA= -2, A= -1, NAD = 0, D = 1, SD = 2 for the remaining questions (Barry & Moore, 2015). The score obtained for each question is then added to determine the total score as well as subscales scores. Each subscale is made up of responses from only a predetermined subset, namely: Speech & Auditory Processing (SAP) is calculated from the responses to questions 1, 5, 11, 16, 19, 24, 31, 33, 38. Environmental & Auditory Sensitivity (EAS): Questions 3, 6, 10, 15, 18,22,29,35. Language/Literacy/Laterality (L/L/L): Questions: 2, 12, 20, 27, 30, and 37. Memory& Attention (M&A): Questions: 4, 8, 13, 17, 21, 25, 28, 32 and Pragmatic & Social Skills (SS): Questions: 7, 14, 23, 26, 34, 36 (Barry & Moore, 2015). Each sub-scale score is divided by the number of questions to determine a raw score. Raw scores are converted to scale scores using standardized scales for age and gender, based on a south-eastern UK sample. Scaled scores are then converted to percentiles. A score of below 6 (10%) is categorized as a “listening difficulty” (Barry & Moore, 2015).

The CHAPPS questionnaire was completed by the teachers and additionally used as a screening tool for listening deficits. The CHAPPS consists of 36 questions that were answered by comparing the participants listening ability to the listening abilities of the other learners in the class (Based on a US population) (Smoski, Brunt, & Tannahill, 1998). The CHAPPS questions form part of 6 subscales, which assessed listening in noise, in quiet, in ideal conditions, against multiple inputs, the participant’s auditory memory/sequencing, and, finally, their auditory attention span (Smoski, Brunt, & Tannahill, 1998). Responses to each question consist of a seven-point scale ranging indicating the child’s level of difficulty with the statement made in the question relative to that of their peers. The answers include: less difficulty (+1), the same amount of difficulty (0), slightly more difficulty (-1), more difficulty (-2), considerably more difficulty (-3), significantly more difficulty (-4) and cannot function at all (-5). (Smoski, Brunt, & Tannahill, 1998). Each sub-scales scores are added to make up the total score. Total scores range from +36.0 to -180.0. A score below -11.0 is considered indicative of difficulty (Smoski, Brunt, & Tannahill, 1998).

*Procedures*

Children were first screened in a standard (quiet) room to determine if they met the criteria for this study. The screening consisted of an otoscopic examination, tympanometry, and pure tone audiometry. The children who had a type A tympanogram and passed the pure tone hearing screen were selected as participants for further testing. If any abnormalities were detected during otoscopy or tympanometry, children were referred for a medical examination. If the children failed pure-tone hearing screening, they were referred to an audiologist for full audiometric testing. Only the children who passed the screening were included in this study.

Data collection using DIN consisted of standard binaural diotic and antiphasic conditions that were counterbalanced. Standard binaural, diotic DIN uses test stimuli presented binaurally and identically to each ear (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). In the diotic condition, the better ear is usually assumed to be the determiner of performance (Potgieter, Swanepoel, Myburgh, & Smits, 2018). However, binaural summation will also influence diotic SRT (Vannson et al. 2017). Antiphasic DIN uses digits that are phase inverted between the ears (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). Masking noise remains binaurally in phase. Antiphasic DIN improves sensitivity to unilateral, asymmetric, and conductive hearing loss (De Sousa, Swanepoel, Moore, Myburgh, & Smits, 2019). Children were instructed that they would hear three digits and, once they had heard all three digits, they needed to repeat them out loud to the tester who recorded their response on the smartphone. Digit triplets were masked by diotic steady-state noise that matched the long term average speech spectrum of the digits (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016).

Initial presentation level was 0 dB SNR. If any of the first three digits were incorrectly reported, the next three digits were presented at 4-dB higher SNR. On any trial, when all three digits were correctly heard and repeated, the next three digits were presented at a 2-dB lower SNR (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016). An incorrect response after the first trial prompted the next three digits to be presented at a 2-dB higher SNR (Potgieter et al., 2016; Potgieter et al., 2017). A total of 23 digit triplets were used in each DIN test. The final result was calculated by averaging the SNR of the last 19 presented digit triplets (Potgieter et al., 2016; Potgieter et al., 2017).

*Analysis*

The Statistical Package for the Social Sciences (SPSS, v25. Chicago, Illinois) was used to conduct the analysis. Descriptive statistics were calculated for the results obtained. Univariate associations between outcome measures and age were tested using Pearson and Spearman's correlations. Pearson's correlation was used to evaluate the linear relationship between SRTs, BILD, and ECLiPS. Spearman's correlation is a non-parametric test and was therefore used to evaluate the linear relationship between SRTs, BILD, and the CHAPPS as the CHAPPS is a non-parametric questionnaire. Pearson's rank correlation coefficient was used to determine if statistically significant correlations were evident between variables (ECLiPS scores, CHAPPS scores, BILD score, diotic and antiphasic SRTs). Linear regression models were run to understand the effect of the ECLiPS and CHAPPS subgroup scores on diotic, antiphasic SRTs, and BILD. Homoscedasticity and normality of the residuals were determined. Separate models were run for the ECLiPS and CHAPPS subgroups since a small sample included children with both ECLIPS and CHAPPS results. By running these subgroups separately, a larger, more accurate sample size can be used.

## 3.4. Results

**Table 1. Description of participants with completed ECLiPS and CHAPPS questionnaires.**

| | ECLiPS group | CHAPPS group |
|---|---|---|
| *N* | 246 | 429 |
| Mean age (SD) | 10.3 (2.1) years | 9.9 (2.2) years |
| Age range | 6 to 13 | 6 to 13 |
| Mean BILD (SD) | 7.4 (1.9) dB SNR | 7.4 (1.8) dB SNR |
| Mean Diotic SRT (SD) | -9.2 (1.1) dB SNR | -9.2 (1.1) dB SNR |
| Mean Antiphasic SRT (SD) | -16.6 (1.9) dB SNR | -16.5 (1.8) dB SNR |
| Participants at-risk of LiD (n) | 14.6% (36) | 23.1% (103) |
| Mean total score (SD) | 53.2 (33.8) | 6.3 (27.0) |

BILD and SRT scores (diotic and antiphasic) were determined for 429 and 246 participants with completed ECLiPS and CHAPPS questionnaires, respectively. The majority of participants (73.8%; 329/446) were male and were first language English speakers (88.1%; 393/446). The remaining participants were English second language speakers with English being the medium taught at school. ECLiPS and CHAPPS questionnaires were both available in 229 participants with no significant correlation between scores (p=.695; r = 0.026).

### BILD and SRT performance

Linear regression to determine whether age predicted BILD, diotic, and antiphasic SRT (Table 1) were run separately due to collinearity (Table 2). Age was significantly related to BILD ($p$=0.02) and SRTs ($p$=0.00) (diotic and antiphasic). Figure 1 and Figure 2 are scatterplots showing SRTs, BILD, CHAPPS and ECLiPS, and CHAPPS against age for the participants with ECLiPS scores (Fig. 1) and participants with CHAPPS scores (Fig. 2)

**Table 2. Linear regression models to determine whether age predicted BILD, diotic and antiphasic SRT (all participants, n=446)**

| | BILD | Diotic SRT | Antiphasic SRT |
|---|---|---|---|
| *p* | 0.02 | 0.00 | 0.00 |
| *F* | 1,444 | 1,444 | 1,444 |
| Df | 9.709 | 52.706 | 57.709 |
| Adjusted $R^2$ | 0.019 | 0.104 | 0.113 |
| Unstandardized Coefficients B | 0.118 | -0.166 | -0.284 |
| 95% CI | 0.044 to 0.193 | 0.211 to -0.121 | -0.357 to -0.211 |

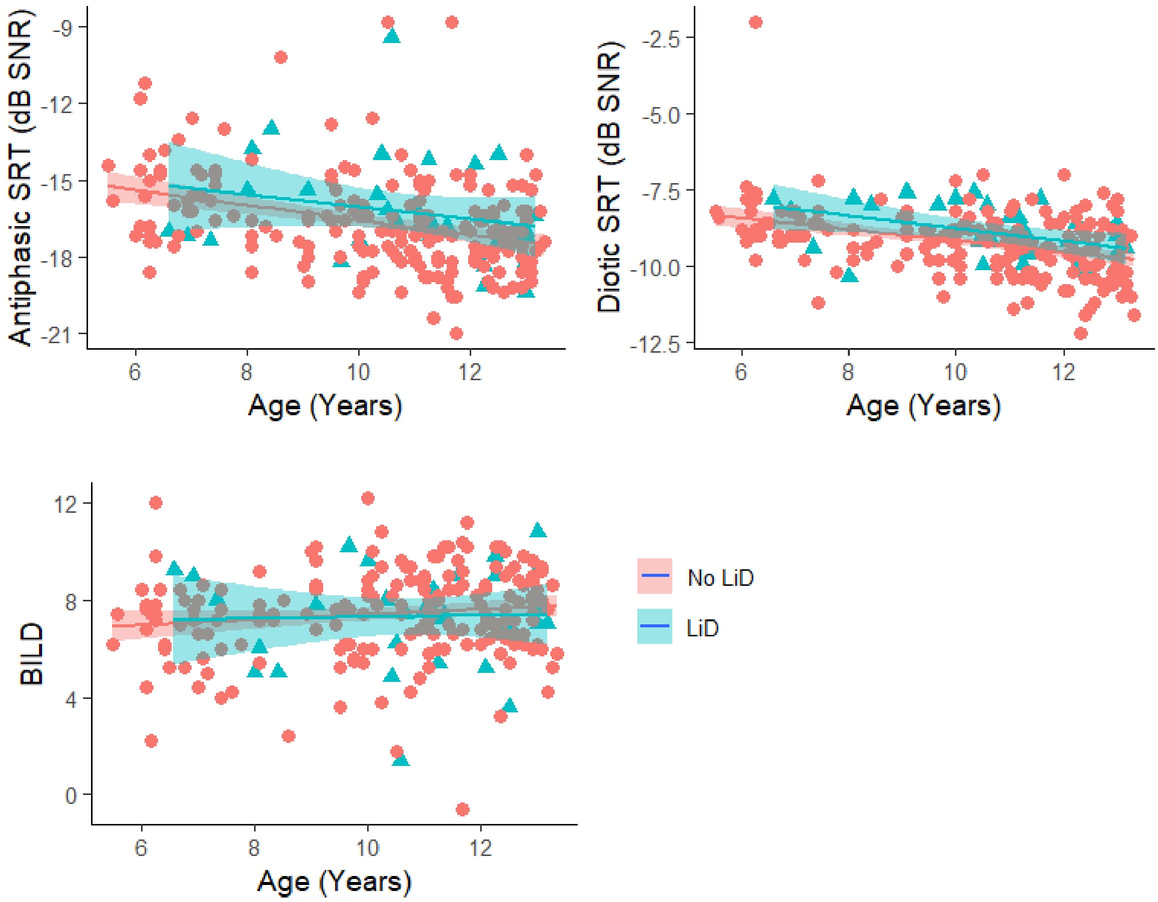


**Figure 1. Scatterplot showing the effects of age on antiphasic SRT, diotic SRT, and BILD (dB). Low, total ratings of listening ability are highlighted in blue for the ECLiPS as per published criteria.**

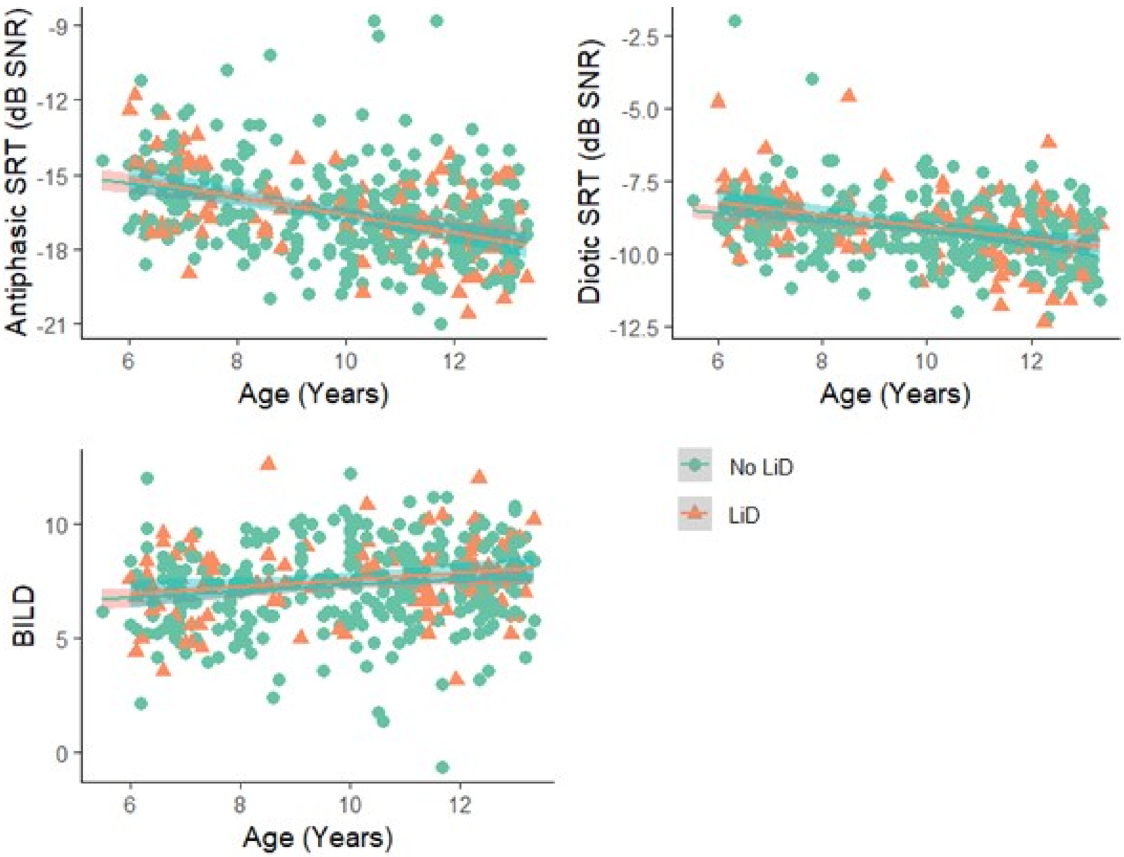


**Figure 2. Scatterplot showing the effects of age on antiphasic SRT, diotic SRT, and BILD (dB), Low, total ratings of listening ability are highlighted in orange for the CHAPPS as per published criteria.**

## Questionnaire results for LiD

There were no significant correlations between BILD and ECLiPS scores (p>0.01). Binomial logistic regression evaluated the effect of BILD, SRTs (diotic and antiphasic) on the likelihood that participants were classified at-risk of LiD on the ECLiPS (<5$^{th}$ %ile) separately due to collinearity. No significant ($p$ > 0.01) effects were found. (Fig.3).

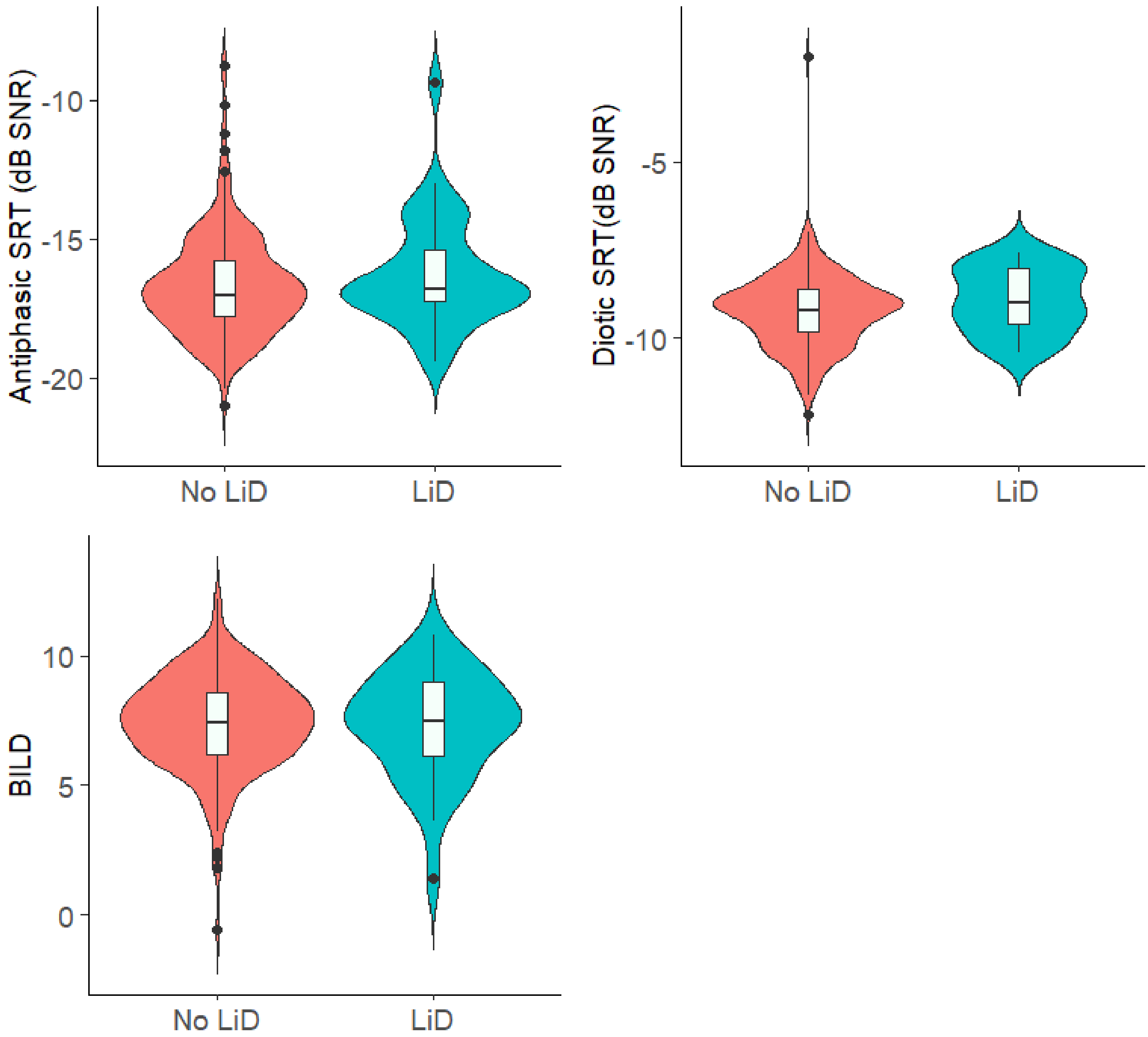


**Figure 3. Distribution and density of Antiphasic SRT, Diotic SRT, and BILD according to ECLiPS total percentile scores as per published criteria.**

There were no significant correlations between BILD and the CHAPPS scores (p>0.01) Binomial logistic regression evaluating the effects of age, BILD, SRTs (diotic and antiphasic) on the likelihood that participants were classified at-risk of LiD on the CHAPPS (>-11 score) separately due to collinearity. No significant ($p$ > 0.01) effects were found (Fig. 4).

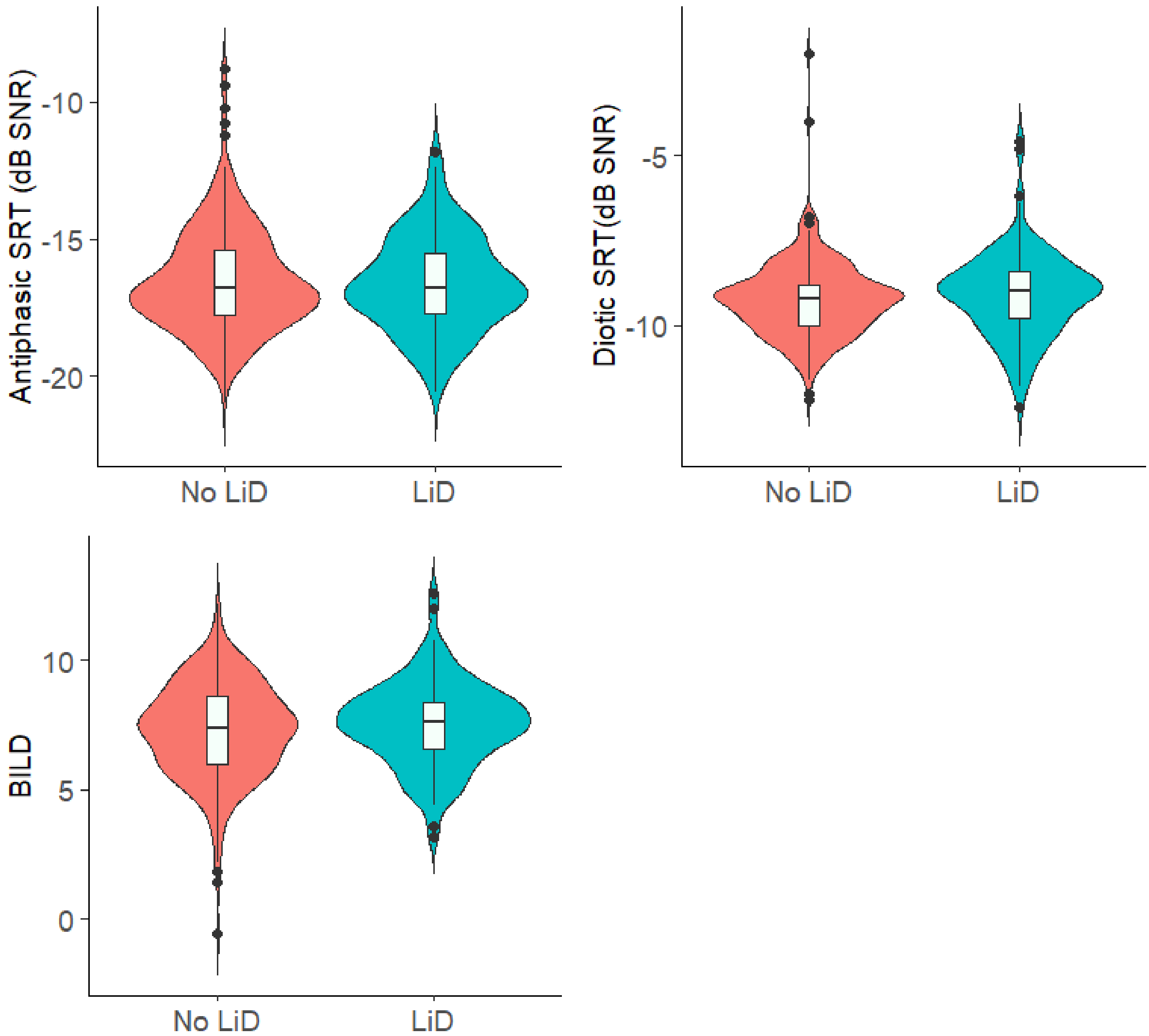


**Figure 4. Distribution and density of antiphasic SRT, diotic SRT, and BILD according to CHAPPS total scores as per published criteria.**

### 3.5. Discussion

A sub-group of children with normal peripheral hearing are reported to struggle to understand speech in the presence of background noise. Numerous contributing reasons for LiD have been proposed, one of the most common being auditory processing disorders (Moore, 2007). In this study, BILD and DIN SRTs were compared to the ECLiPS and CHAPPS questionnaires.

This study's regressions showed no significant predictive value of the ECLiPS or CHAPPS questionnaire to determine DIN BILD or DIN SRT (diotic and antiphasic). Iliadou and Bamiou (2012) also reported no correlation between BMLD and the commonly used CHAPPS questionnaire. As mentioned previously, BMLD is a psychoacoustic effect that BILD is based on (Hirsh, 1948; Licklider, 1948). BILD is a speech version of BMLD where, typically, a word is substituted for the tone. In their study, clinically referred children were grouped as either fitting a diagnosis of auditory processing disorder or non-auditory processing disorder. Children were placed in the APD group when they presented with abnormal results in at least one ear or if they performed poorly on at least two tests with at least one of the tests being non-speech (Iliadou & Bamiou, 2012). These requirements have been proposed by the American Speech-Language-Hearing Association (ASHA; 2005), American Academy of Audiology (2010), and the British Society of Audiology (2011) as the requirements for a positive diagnosis of APD. When compared to normal controls, the CHAPPS score for both auditory processing and non-auditory processing groups was significantly worse on the performance in noise subscale, as rated by parents (Iliadou & Bamiou, 2012). Interestingly, the auditory processing and non-auditory processing groups had no significant difference in the performance in noise subscale of the CHAPPS (Iliadou & Bamiou, 2012). This study similarly found that when objectively determining SIN abilities, there is no relationship with either the CHAPPS total score or sub-scale scores. Only the Speech in Babble test (monaural) had modest correlations with the CHAPPS sub-scales. Thus, the CHAPPS was not able to identify participants with poor speech-in-noise performance.

The ECLiPS and CHAPPS identified a total of 14.6% (36/246) and 23.1% (103/429) children with potential LiD, respectively, based on their published normative cut-offs.

However, binomial logistic regressions evaluating the effect of BILD, SRTs (diotic and antiphasic) on the likelihood that participants were classified as at-risk of LiD on the ECLiPS and CHAPPS found no significant relationships. Therefore, participants who presented with both normal ECLIPS and/or CHAPPS scores and poor SRTs still have a deficit hearing speech-in-noise. This is especially concerning as the noise levels present in a classroom are directly related to academic achievement (Shield & Dockrell, 2003 & 2008). Possible reasons for very poor SRTs other than a potential LiD could be, due to a lack of stimulation to auditory pathways possibly due to otitis media (Graydon, Rance, Dowell, & Van Dun, 2017), testing at different times of the day and auditory fatigue from a full day of school. Using the DIN to identify children who may not fit the criteria for LiD according to questionnaires, but who do have real problems with speech in noise may aid in identifying children at risk of poor performance in noisy classroom settings. The ability to recognize speech in noise is highly dependent on a child’s ability to separate speech from background noise, to receive benefit from fluctuations in the noise and to receive benefit from binaural cues (Koopmans, Goverts, & Smits, 2018). Thus, DIN may be measuring these aspects in particular and not those that contributing to LiD as assessed by questionnaires.

A study conducted on children who presented with normal hearing but experienced listening difficulties in noise as measured by self-, teacher, and parental reports found that these children presented with a significantly poorer BMLD score (Mridula, Dhamani, Leung, & Carlile, 2014). This suggests that the BMLD can aid in identifying listening difficulties in noise experienced by children. However, the BILD scores in our study did not correlate with the ECLiPS or CHAPPS scores. LiD is a broad term that consists of a range of processing and listening problems (Moore et al., 2019). The BMLD and the DIN test, are therefore most likely measuring a particular aspect of listening, namely identifying target signals in the presence of noise. A study using the ECLiPS indicated that it was sensitive to cognitive difficulties, which may be contributing to the LiD rather than screening for LiD as a whole (Barry, Tomlin, Moore, & Dillon, 2015). It is, therefore, possible that the DIN test may be more sensitive to listening difficulties experienced specifically in noise. However, is it important to note that the DIN is only a simple speech-in-noise test as it makes use of simple, naturally spoken digits from 0 to 9, requiring minimal language proficiency (Kaandorp et al., 2016).

It has been found that performance on speech recognition in noise can be influenced by a child's vocabulary, cognitive abilities as well as their language competency (Mendel 2008). These are referred to as top-down processes that develop through childhood. Poor performance on auditory tasks may be due to these top-down factors (Moore et al. 2011). However, the DIN was designed to measure the auditory, bottom-up, speech recognition abilities in noise (Smits, Theo Goverts, & Festen, 2013). Therefore, LiD may be influenced primarily by top-down processes, and so DIN may be insensitive to the breadth of factors that contribute to LiD.
This study found that BILD and SRTs improve with age, as reported previously for Dutch children (Koopmans, Goverts, & Smits, 2018). It has been hypothesized that auditory factors and non-auditory factors both contribute to this ageing effect (Koopmans, Goverts, & Smits, 2018). A study conducted by Moore et al. (2011), however, did not find a significant age effect on BMLD, the psychoacoustic effect on which BILD is based. This, however, could be due to small sample size (Moore et al. 2011).

Limitations of the current study include a possible response bias from parents completing the questionnaires who may have been concerned to disclose difficulties their child experiences within the school setting. Furthermore, the CHAPPS questionnaire was completed by teachers as opposed to parents. The teachers had only known the participants for five to six months at the time when the CHAPPS was completed, and thus, they may not have had an accurate perception of potential LiD. Teachers completed the CHAPPS questionnaire based on their perception of the learners' performance in the classroom. Additionally, a study found that when comparing CHAPPS results to other tests of auditory processing, no consistent associations are found, suggesting the CHAPPS may not be an appropriate tool for LiD (Moore, Edmondson-Jones, Ferguson, & Gran, 2010). Other studies have found that the CHAPPS is subjective, and the reliability varies according to rater experience and understanding (Lam & Sanchez, 2007). Furthermore, the CHAPPS subscales and average total lack of predictive value (Lam & Sanchez, 2007). Drake et al. (2006) found no relationship between the CHAPPS total and the diagnosis of APD. Similarly, the CHAPPS has previously demonstrated a poor ability to predict risk for APD (Wilson et al., 2011). The CHAPPS has, therefore, been recommended only be used as a means to bring attention to concerns about a child to identify possible difficulties (Wilson et al., 2011).

## CONCLUSION

LID, determined by validated questionnaires, was not predictive of BILD or poor speech recognition in noise. DIN SRT (diotic and antiphasic) and DIN BILD along with the ECLiPS and CHAPPS questionnaires may, therefore, be measuring different aspects of performance related to listening, such as temporal or spectral resolution or the ability to identifying target signals rather than LiD as a whole. LiD is a clinical entity in which measures of speech recognition in noise, using a simple measure like the DIN test, could support and confirm the risk.

### Declaration of Conflicts of Interest

The 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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# 4. DISCUSSION AND CONCLUSION

## 4.1. Summary of Results

A sub-group of children with normal peripheral hearing are reported to struggle to understand speech in the presence of background noise. Numerous contributing reasons for LiD have been proposed, one of the most common being auditory processing disorders (Moore, 2007). In this study, BILD and DIN SRTs were compared to the ECLiPS and CHAPPS questionnaires.

This study showed no significant predictive value of the ECLiPS or CHAPPS questionnaire to determine DIN BILD or DIN SRT (diotic and antiphasic). Iliadou and Bamiou (2012) also reported no correlation between BMLD and the commonly used CHAPPS questionnaire. As mentioned previously, BMLD is a psychoacoustic effect that BILD is based on (Hirsh, 1948; Licklider, 1948). In their study, clinically referred children were grouped as either fitting a diagnosis of auditory processing disorder or non-auditory processing disorder. Children were placed in the APD group when they presented with abnormal results in at least one ear or if they performed poorly on at least two tests with at least one of the tests being non-speech (Iladiou & Bamiou, 2012). These requirements have been proposed by the American Speech-Language-Hearing Association (ASHA; 2005), American Academy of Audiology (2010) and the British Society of Audiology's (2011) as the definition for APD. When compared to normal controls, the CHAPPS score for both auditory processing and non-auditory processing groups was significantly worse on the performance in noise subscale, as rated by parents (Iladiou & Bamiou, 2012). Interestingly, the auditory processing and non-auditory processing groups had no significant difference in the performance in noise subscale of the CHAPPS (Iladiou & Bamiou, 2012). This study similarly found that when objectively determining SIN abilities, there is no relationship with either the CHAPPS total score or sub-scale scores. Thus, the CHAPPS was not able to identify participants with poor speech-in-noise performance. Only the Speech in Babble test (monaural) had modest correlations with the CHAPPS sub-scales. Thus, the CHAPPS was not able to identify participants with poor speech-in-noise performance.

The ECLiPS and CHAPPS identified a total of 14.6% (36/246) and 23.1% (103/429) children with potential LiD, respectively, based on their published normative cut-offs. However, binomial logistic regressions evaluating the effect of BILD, SRTs (diotic and antiphasic) on the likelihood that participants were classified as at-risk of LiD on the ECLiPS and CHAPPS found no significant relationships. Therefore, participants who presented with both normal ECLIPS and/or CHAPPS scores and poor SRTs still have a deficit hearing speech-in-noise. However, the questionnaires did not indicate any potential LiD. This is especially concerning as the noise levels present in a classroom are directly related to academic achievement (Shield & Dockrell, 2003 & 2008). Possible reasons for poor SRTs other than a potential LiD could be, due to a lack of stimulation to auditory pathways possibly due to otitis media (Graydon, Rance, Dowell, & Van Dun, 2017), testing at different times of the day and auditory fatigue from a full day of school. Using the DIN to identify children who may not fit the criteria for LiD according to questionnaires, but who do have real problems with speech in noise may aid in identifying children at risk of poor performance in noisy classroom settings. The ability to recognise speech in noise is highly dependent on a child's ability to separate speech from background noise, to receive benefit from fluctuations in the noise masking speech and to receive benefit from binaural cues (Koopmans, Goverts, & Smits, 2018). Thus, DIN may be measuring these aspects in particular and not those that contributing to LiD.

A study conducted on children who presented with normal hearing but experienced listening difficulties in noise as measured by self-, teacher, and parental reports found that these children presented with a significantly poorer BMLD score (Mridula, Dhamani, Leung, & Carlile, 2014). This suggests that the BMLD can aid in identifying listening difficulties in noise experienced by children. However, the BILD scores in this study did not correlate with the ECLiPS or CHAPPS scores. LiD is a broad term that consists of a range of processing and listening problems (Moore et al., 2019). The BMLD and the DIN test, are therefore most likely measuring a particular aspect of listening, namely identifying target signals in the presence of noise using binaural unmasking. A study using the ECLiPS indicate that it was sensitive to cognitive difficulties, which may be contributing to the LiD rather than screening for LiD as a whole (Barry, Tomlin, Moore, & Dillon, 2015). It is, therefore, possible that the DIN test may be more sensitive to listening difficulties experienced specifically in noise.

However, is it important to note that the DIN is only a simple speech-in-noise test as it makes use of simple, naturally spoken digits from 0 to 9, requiring minimal language proficiency (Kaandorp et al., 2016).

It has been found that performance on speech recognition in noise can be influenced by a child's vocabulary, cognitive abilities as well as their language competency (Mendel 2008). These are referred to as top-down processes that develop through childhood. Poor performance on auditory tasks may be due to these top-down factors (Moore et al. 2011). However, the DIN was designed to measure the auditory, bottom-up, speech recognition abilities in noise (Smits, Theo Goverts, & Festen, 2013). Therefore, LiD may be influenced primarily by top-down processes, and so DIN may be insensitive to the breadth of factors that contribute to LiD.

This study found that BILD and SRT improve with age. Similarly, a recent study found significant improvements in SRTs as age increased with an adult-like performance from the ages of 10 to 12 years (Koopmans, Goverts, & Smits, 2018). Studies have also found that children achieve adult-like performance by the age of ten and upwards when using stationary speech-shaped noise (Corbin et al. 2016; Elliott 1979; Hall et al. 2002; Holder et al. 2016; Neuman et al. 2010; Nishi et al. 2010; Wilson et al. 2010). It has been hypothesized that auditory factors and non-auditory factors both contribute to this ageing effect (Koopmans, Goverts, & Smits, 2018). A study conducted by Moore et al. (2011), however, did not find a significant age effect on BMLD, the psychoacoustic effect on which BILD is based. This, however, could be due to small sample size (Moore et al. 2011).

Limitations of the current study include a possible response bias from parents completing the questionnaires who may have been concerned to disclose difficulties their child experiences within the school setting. Furthermore, the CHAPPS questionnaire was completed by teachers as opposed to parents. The teachers also had only known the participants for five to six months at the time when the CHAPPS was completed, and thus, they may not have had an accurate perception of potential LiD. Teachers completed the CHAPPS questionnaire based on their perception of the learners' performance in the classroom. Additionally, a study found that when comparing CHAPPS results to other tests of auditory processing no consistent associations are found, suggesting the CHAPPS may not be an appropriate tool for LiD (Moore, Edmondson-Jones, Ferguson, & Gran, 2010). Other studies have found that the CHAPPS is subjective, and the reliability varies according to rater experience and understanding (Lam & Sanchez, 2007). Furthermore, the CHAPPS subscales and average total lack of predictive value (Lam & Sanchez, 2007). Drake et al. (2006) found no relationship between the CHAPPS total and the diagnosis of APD. Similarly, the CHAPPS has previously demonstrated a poor ability to predict risk for APD (Wilson et al., 2011). The CHAPPS has, therefore, been recommended only be used as a means to bring attention to concerns about a child to identify possible difficulties (Wilson et al., 2011).

### 4.2. Clinical Implications

This was the first study comparing DIN BILD and DIN SRTS to LiD as determined through parent/teacher questionnaires. The DIN measures speech perception in noise and involves linguistic and cognitive demand (Moore et al., 2014). This study found no relationship between BILD/DIN SRTs with LiD and thus demonstrates that LiD may be a more complex disorder than purely a speech perception in noise deficit. The finding of a mechanistic basis for LiD in children could allow for treatment (Schilder et al., 2019) or other timely management to minimize the possible consequences, such as speech and language delays, reading problems and academic underachievement, associated with LiD (Bantwal & Hall, 2011). A measure sensitive to LiD or a sub-set of LiD could be valuable in assessing aural rehabilitation of children with communication disorders (Hsu, 2017). This study found that BILD and DIN SRT may not be a good measure of identifying LiD as captured by CHAPPS and ECLIPS. This means that DIN SRTs could identify specific difficulties in SIN ability but not necessarily LiD, which includes a host of other influences also – e.g. attention. LiD may be more affected by top-down processes while DIN SRTs are a measure of bottom-up processes that are purely auditory  (Smits, Theo Goverts, & Festen, 2013).

### 4.3. Critical Evaluation

A critical evaluation is necessary to evaluate the study regarding its strengths and limitations.

*Strengths of the study*

This study had a large total study sample (*n*=446), allowing for exploration of the relationship between ECLiPS scores (*n*= 246), CHAPPS scores (*n*=429), diotic, antiphasic and BILD SRT results. This study was the first to explore a relationship between LiD in children and BILD as determined through diotic and antiphasic DIN test paradigm. The spread of results was stratified across age which allowed any age effects of the DIN to be determined. This study made use of two different questionnaires that determine potential LiD to allow for a definite conclusion about the relationship between BILD and DIN SRTs and LiD in children.

*Limitations of the study*

A possible response bias from parents completing the questionnaires who may have been concerned to disclose difficulties their child experiences within the school setting. Only 246 participants returned the ECLiPS, and 429 returned the CHAPPS. This difference in response rates meant that combined analysis in a large group could not be conducted. Furthermore, the CHAPPS questionnaire was completed by the teachers as opposed to parents. The teachers also had only known the participants for five to six months at the time when the CHAPPS was completed, and thus, they may not have had an accurate perception of potential LiD. Teachers completed the CHAPPS questionnaire based on their perception of the learners' LiD in the classroom. Additionally, a study found that when comparing CHAPPS results to other tests of auditory processing no consistent associations are found, suggesting the CHAPPS may not consistently identify a LiD (Moore, Edmondson-Jones, Ferguson, & Gran, 2010). Other studies have found that the CHAPPS is subjective, and the reliability varies according to rater's experiences and understanding (Lam & Sanchez, 2007). Furthermore, the CHAPPS subscales and average total lack of predictive value (Lam & Sanchez, 2007). Drake et al. (2006) found no relationship between the CHAPPS total and the diagnosis of APD. Similarly, the CHAPPS showed a poor ability to predict participant risk for APD (Wilson et al., 2011). The CHAPPS should only be used as a means to bring attention to concerns about a child but to identify possible difficulties (Wilson et al., 2011). A further limitation was that only participants SRTs were determined and not pure tone thresholds. Thus, this study was not able to correlate DIN SRTs and BILD to pure tone averages.

## 4.4. Future Research

Additional research is required to determine a means of identifying LiD in children.

- More complex and demanding tests of speech reception in noise such as sentences in noise should be compared to questionnaires measuring LiD to determine if a correlation exists.
- Normative data relevant to a South African population should be determined for the ECLiPS questionnaire, to allow for more accurate interpretation of ECLiPS results when used on a South African child.
- More comprehensive testing should be done using DIN SRTs. Children's pure tone thresholds should be determined and correlated to SRTs.
- DIN SRTs should be compared to language performance to determine if the DIN can be used as a means to diagnose children with language difficulties.

## 4.5. Conclusion

LID, determined by validated questionnaires, was not predictive of BILD or poor speech recognition in noise. DIN SRT (diotic and antiphasic) and DIN BILD along with the ECLiPS and CHAPPS questionnaires may, therefore, be measuring different aspects of performance related to listening, such as temporal or spectral resolution or the ability to identifying target signals rather than LiD as a whole. LiD is a clinical entity in which measures of speech recognition in noise, using a simple measure like the DIN test, could support and confirm the risk.

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# 6. APPENDICES

## Appendix A: Faculty of Humanities Ethical Approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

30 November 2018

Dear Ms Frisby

| | |
|---|---|
| **Project:** | **Listening difficulties in children and its relationship to Binaural Masking Level Differences** |
| **Researcher:** | **C Frisby** |
| **Supervisors:** | **Prof DCD Swanepoel, Dr F Mahomed Asmail and Ms KC Swanepoel** |
| **Department:** | **Speech-Language Pathology and Audiology** |
| **Reference number:** | **15011985 (GW2018112HS)** |

Thank you for the **well written** 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 a meeting held on 29 November 2018. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should 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

pp

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

cc: Prof DCD Swanepoel (Supervisor), Dr F Mahomed Asmail (Co-supervisor) and Ms KC Swanepoel (Co-supervisor)
Dr J van der Linde (HoD)

**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 school

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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

Dear Principal,

I am currently 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. Therefore, I would like to offer this hearing screening service free of charge to learners at your school. The service will be provided to Grade 1 to Grade 7 learners between the ages of 6 to 12 years old at your school. I will be conducting the screening myself. The tests take approximately 10 to 15 minutes per learner to conduct. Children who do not pass the hearing screening will receive a referral letter that their parents can use as a source of referral for possible further testing at their own discretion.

Informed consent must be provided by parents in order to conduct the screening (consent form *attached*). Informed assent will also be obtained from participants before any tests are performed (assent form *attached*). Each learner who passes the screening will also be tested using the Digits-In-Noise test, which will give an indication of how well they perceive speech in the presence of noise. The parents/guardians of the children who pass the hearing screening will be requested to complete a brief questionnaire (Evaluation of Children's Listening and Processing Skills) for each learner. The teachers of the children who pass the hearing screening will also be requested to complete a brief questionnaire (the Children's Auditory Processing Performance Scale). Both of these questionnaires aim to identify children with potential listening difficulties.

The information that will be obtained from the hearing screening will be used for research purposes only. All of the participants' information will be kept strictly confidential. Please note that should a teacher, parent/guardian or learner wish to



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

withdraw from the research project at any time, they may do so without any consequences.

The results and information obtained from the hearing screening 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.

I trust that you 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 complete the consent form provided below.

I look forward to receiving your response regarding the provision of hearing screening services to learners at your primary school.

Yours sincerely,

Caitlin Frisby

**Researchers**

Prof D W Swanepoel, Dr F Mahomed-Asmail, Mrs K De Sousa

**Research Supervisors**



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**Consent form:**

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

**Signature** ________________________________________

**Date:** ________________________________________

**School one:**

**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** [signature]

**Date:** 3/5/2019

ANCHOR CHRISTIAN ACADEMY
PO BOX 32063
TOTIUSDAL
0134
082 392 2154



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**School two:**

Consent form:

I, Madeleen Gorst - Allman (Name) the principal of St Paulus Pre - and Primary (School) hereby gives permission for the above-mentioned hearing screening to take place at my primary school.

Signature M Gorst - Allman

Date: 2018 - 11 - 12

**School three:**

Consent form:

I, MARK GEORGE WHITELAW (Name) the principal of Waterkloof House Prep School (School) hereby give permission for the above-mentioned hearing screening to take place at my primary school.

Signature

Date: 13 November 2018

**School four:**

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



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Appendix C: Letter to the teacher

UNIVERSITEIT VAN PRETORIA
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**Faculty of Humanities**
Department of Speech-Language Pathology and Audiology

Dear Teacher,

I am currently 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. Therefore, I would like to offer this hearing screening service free of charge to learners at your school. The service will be provided to Grade 1 to Grade 7 learners between the ages of 6 to 12 years old at your school. I will be conducting the screening myself. The tests take approximately 10 to 15 minutes per learner to conduct. Children who do not pass the hearing screening will receive a referral letter that their parents can use as a source of referral for possible further testing at their own discretion. Each learner who passes the screening will also be tested using the Digits-In-Noise test, which will give an indication of how well they perceive speech in the presence of noise. As the teacher of the learners who pass the hearing screening, you will be requested to complete a brief questionnaire (Children's Auditory Processing Performance Scale) for each learner. You will also be required to send a questionnaire to the parents/guardians of the learner (Evaluation of Children's Listening and Processing Skills).

The information that will be obtained from the hearing screening will be used for research purposes only. All of the participants' information will be kept strictly confidential. Please note that should a parent, child or teacher wish to withdraw from the research project at any time, they may do so without any consequences.

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



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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 in the completion of the questionnaire for each of your learners who have been identified as having normal hearing through their participation in the hearing screening, please fill in the consent form below.

Yours sincerely,

______________________________

Caitlin Frisby
**Researcher**

__________________________________________________________

Prof D W Swanepoel, Dr F Mahomed-Asmail, Mrs K De Sousa
**Research Supervisors**



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**Consent form:**

I, ………………………………………………………………….. (Name) a teacher at ………………………………………………………………… (School) hereby agree to complete the provided questionnaire related to each learner who has passed the hearing screening provided at my primary school.

**Signature** ________________________________________

**Date:** ________________________________________



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Appendix D: Letter to Parent/Guardian

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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

Dear Parent/Guardian,

The University of Pretoria's Department of Speech-Language Pathology and Audiology provides a hearing screening service free of charge. This service is being provided at your child's primary school.

A master's student from the Department of Speech-Language Pathology and Audiology at the University of Pretoria will be providing these services. The screening will take approximately 10 to 15 minutes to conduct. If your child does not pass the hearing screening test, 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, which will give an indication of how well they perceive speech in the presence of noise. The teacher of the learners who pass the hearing screening will be requested to complete a brief questionnaire (Children's Auditory Processing Performance Scale) for each learner. We request that parent/guardian of each child who passes the hearing screening also complete a brief questionnaire (Evaluation of Children's Listening and Processing Skills) as well as a short questionnaire on the learners' case history included below.

The information that will be obtained from the hearing screening will be used for research purposes only. All personal information obtained will be kept strictly confidential. Each learner will receive a unique arbitrary coded number that will replace their name in all documents to ensure confidentiality. There will be no consequences should your child wish to withdraw from the research project at any time.
The data obtained will be stored at the Department of Speech-Language Pathology and Audiology of the University of Pretoria for 15 years for further research and archiving purposes.



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Should you wish for your child to receive the hearing screening service, please complete the form below.

Kind regards

________________________________

Caitlin Frisby

**Researcher**

__________________________________________

Prof D W Swanepoel, Dr F Mahomed-Asmail, Mrs K De Sousa

**Research Supervisors**



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**Consent form:**

I, ……………………………….……………………….. (name), hereby grant permission that hearing screening may be conducted on my child, …………………..…………………………………(name) in grade________, and I acknowledge that the information will be used for research purposes as specified above.

**Case History Questionnaire:**

| | |
|---|---|
| Has your child ever been exposed to loud noise? | |
| Does your child have a history of middle ear infections? Were these treated with antibiotics or grommets? | |
| Does your child have any known auditory processing difficulties? Such as reading difficulties, difficulty with particular subjects, poor auditory attention? | |
| Has your child had any previous hearing test? If so, results? | |
| Any history of hearing loss in the family? Please specify. | |
| Has your child ever had any surgery on his/her ears? Please specify. | |

Signature of Parent/Guardian: ______________________________

Date: ________________________



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Appendix E: Assent form

UNIVERSITEIT VAN PRETORIA
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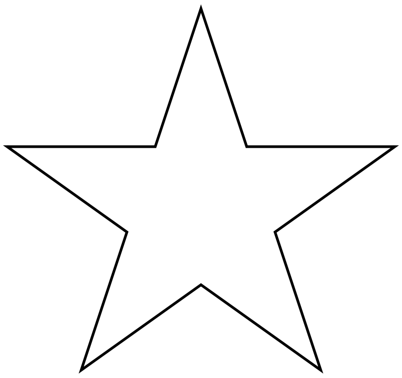
**Faculty of Humanities**
Department of Speech-Language Pathology and Audiology

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

1) Today I am going to test how well your ears can hear
2) We will be doing four tests
3) In the first test, I am going to look into your ear with a light. You must just sit still for this.
4) In the second test, I am going to put a little probe into your ear, and you just need to sit still.
5) In the third test, you must raise your hand whenever you hear a “beep-beep” sound.
6) In the fourth test, you will hear numbers that you must say out loud to me.
7) The test will not hurt you
8) Tell me if you want me to stop the test at any time
9) If you want me to test your ears, please colour in the star or write your name at the bottom



Name: ……………………………………………………………………..



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Appendix F: Data collection form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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

| | |
|---|---|
| **Name** | |
| **Unique coded number** | |
| **Date of Birth** | |
| **Grade** | |
| **First Language** | |
| **Second Language** | |
| **School** | |
| **Date of testing** | |
| **Tester** | |

**Otoscopy:**

| Right Ear | Left Ear |
|---|---|
| | |

**Tympanometry:**

| Ear | Right | Left |
|---|---|---|
| **Pressure** | | |
| **Volume** | | |
| **Compliance** | | |
| **Type** | | |



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

***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 <u>Pass</u> on *hearScreen*:**

**Digit-In-Noise Test:**

| | |
|---|---|
| Signal-to-noise Ratio for diotic digits | |
| Signal-to-noise Ratio for antiphasic digits | |

| | |
|---|---|
| Binaural Intelligibility Level Difference | |

**Overall results:**

| | |
|---|---|
| Pass | Refer |



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Appendix G: Pass Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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

Date: …………………………………..

Dear Parent/Guardian,

The University of Pretoria's Department of Speech-Language Pathology and Audiology provides a hearing screening service free of charge. Based on your consent, this service was provided to your child.

The results from this hearing screening service indicate that your child has passed the hearing screening, and there are currently no concerns with regards to his/her hearing. It is recommended that your child undergoes an annual hearing test to ensure that early intervention can take place should a hearing problem arise.

Kind regards

Caitlin Frisby
**Researcher**

Prof D W Swanepoel, Dr F Mahomed-Asmail, Mrs K De Sousa
**Research Supervisors**

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# Appendix H: Referral Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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

Date: _______________

Dear ____________________________

A hearing screening test was conducted on your child ________________________________ (name) on _______________20__.

During this evaluation, it was determined that your child should be referred for further audiological intervention. Therefore, we would like to refer you to:

| **Specialist** | | **Reason** | |
|---|---|---|---|
| | Audiologist | | Full audiometric test battery |
| | Ear Nose and Throat Specialist | | Possible middle ear infection |

We urge you to attend to this matter as soon as possible.

Kind regards

________________

Ms Caitlin Frisby

**Researcher**

________________________________________

Prof D W Swanepoel, Dr Mahomed-Asmail, Mrs K De Sousa

**Research Supervisors**



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# Appendix I: Example of the ECLiPS

Evaluation of Children's Listening & Processing Skills

ECLiPS

**▼ ADULT**

Forename | Surname | Relationship to child (please tick): ☐ PARENT ☐ GUARDIAN ☐ TEACHER ☐ OTHER

For how long have you known the child? Years / Months

Today's date: Day / Month / Year

**▼ CHILD**

Forename | Surname | Gender (please tick): ☐ MALE ☐ FEMALE

Main language spoken at home | Date of birth: Day / Month / Year | Age of child: Years / Months

Please tick the relevant response to each item:

| | | | | | |
|---|---|---|---|---|---|
| **Left or Right Handed?** | ☐ Left | ☐ Right | ☐ Uses both | | |
| **Hearing difficulties?** | ☐ Yes | ☐ Sometimes | ☐ No | | *Diagnosed?* ☐ Yes ☐ No |
| **Ear infections?** | ☐ Often | ☐ Sometimes | ☐ Rarely | ☐ Never | *Diagnosed?* ☐ Yes ☐ No |
| **Vision problems?** | ☐ Yes | ☐ Sometimes | ☐ No | | *Diagnosed?* ☐ Yes ☐ No |
| **Language problems?** | ☐ Yes | ☐ Maybe | ☐ No | | *Diagnosed?* ☐ Yes ☐ No |
| **Literacy problems?** | ☐ Yes | ☐ Maybe | ☐ No | | *Diagnosed?* ☐ Yes ☐ No |
| **Social development problems?** | ☐ Yes | ☐ Maybe | ☐ No | | *Diagnosed?* ☐ Yes ☐ No |

**Additional comments:**

J.G. Barry & D.R. Moore

Sept 2014 Version **UK-1**

THE CHECKLIST EXPLAINED

*You will read a number of statements about your child. You must decide based on what you know, how much you agree with each statement. There are no right or wrong answers. Every child has different strengths and weaknesses.*

*When you have made a decision, just tick the box that most represents how much you agree with the statement.*

*If you really do not know what to answer, put an 'X' by the item and add a comment if you wish.*

***To help, the tick boxes are colour-coded like a thermometer.***
***[illegible] means you feel [illegible] ([illegible]) with a statement.***
***[illegible] means you feel [illegible] (do not agree).***
***The stronger the colour, the more strongly you agree or not.***

Strongly Agree | Agree | Neither Agree nor Disagree | Disagree | Strongly Disagree

## ▼ CHECKLIST

Please indicate how much you agree with *ALL* of the statements

Takes time to realise that someone has said something to him/her 01

Writes numbers down wrong 02
*For example - writes '9' as '6', or '3, 5, 7' as '3, 7, 5'*

Finds it tiring being in groups of people 03

Needs strategies for remembering 04

When there is a sudden noise, is confused about where to look 05
*For example - looks in wrong direction or looks confused*

Complains about loud sounds 06
*For example - ambulance siren*

Has obsessive interests 0

Finds it difficult to do more than one thing at a time 0

Follows conversations with ease d

Complains about sounds being unpleasant 1

Seems to struggle to hear at times 11

Mishears words 12
*For example - shoulder/solder, hand/ham*

Zones out 13
*Mind seems to be elsewhere, seems not to be there*

Gets frustrated because others misunderstand what he/she means to say 14
*For example - might say 'but that's not what I said'*

Becomes upset if daily routine is changed 15

Seems deaf when lots of people are talking 16

Forgets what was doing, after a distraction 17

Becomes upset when too much is happening at once 18

Becomes confused when in groups of people 19

Needs help from others when writing homework down 20

Can repeat back a series of instructions 21
*'What did I ask you to do?...go upstairs, get a book and turn the light off on the way down'*

Finds places with lots of echoes distressing 22

Says some sentences, or words over and over 23

When it is noisy, becomes confused 24
*Looks slightly lost /confused /unsure in noisy places like restaurants, canteens, playgrounds*

Remembers series of instructions 25
*For example - 'buy me two lemons and an orange from the shop'*

ECLiPS

| Item | Strongly Agree | Agree | Neither Agree nor Disagree | Disagree | Strongly Disagree | No. |
|---|---|---|---|---|---|---|
| Says things that are off-topic | | | | | | 26 |
| Confuses left and right | | | | | | 27 |
| Needs things repeated to understand | | | | | | 28 |
| Becomes upset in crowded spaces | | | | | | 29 |
| Says some words wrong<br>*For example - shoulder/soldier* | | | | | | 30 |
| Mishears what you say directly to him/her | | | | | | 31 |
| Forgets about things that happen on a schedule<br>*For example - going swimming on a Tuesday; going to ballet on Wednesday* | | | | | | 32 |
| Gives late responses to things people have said | | | | | | 33 |
| If interrupted when doing something, has to start over again from the beginning | | | | | | 34 |
| Needs to get away because things become too much<br>*For example - a lot of noise, a lot of things happening around him/her* | | | | | | 35 |
| Obsesses<br>*For example - will go on and on about something* | | | | | | 36 |
| Writes letters the wrong way<br>*For example - 'b' for 'd'* | | | | | | 37 |
| Has problems understanding what people say<br>*For example - may look blank, may say huh?, may give off-topic answers or no response* | | | | | | 38 |

# Appendix J: Example of the CHAPPS



## Appendix 5–B

## CHILDREN'S AUDITORY PROCESSING PERFORMANCE SCALE (CHAPPS)

### CHILDREN'S AUDITORY PROCESSING PERFORMANCE SCALE

Child's Name ______________________ Age (Years ______ Months ______ ) Date ____________

Name of person completing questionnaire ________________________________________

Relationship: Parent ______ Teacher ______ Other________________________________

**PLEASE READ INSTRUCTIONS CAREFULLY**

Answer all questions by comparing this child to other children of similar age and background. Do not answer the questions based only on the difficulty of the listening condition. For example, all 8-year-old children, to a certain extent, may not hear and understand when listening in a noisy room. That is, this would be a difficult listening condition for all children. However, some children may have more difficulty in this listening condition than others. You must judge whether or not this child has MORE difficulty than other children in each listening condition cited. Please make your judgment using the following response choices: (CIRCLE a number for each item.)

RESPONSE CHOICES:

LESS DIFFICULTY........................+1
SAME AMOUNT OF DIFFICULTY..............0
SLIGHTLY MORE DIFFICULTY...............–1
MORE DIFFICULTY........................–2
CONSIDERABLY MORE DIFFICULTY...........–3
SIGNIFICANTLY MORE DIFFICULTY..........–4
CANNOT FUNCTION AT ALL.................–5

Listening Condition—*NOISE:*

If listening in a room where there is background noise such as a TV set, music, others talking, children playing, etc., this child has difficulty hearing and understanding (compared with other children of similar age and background).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. When paying attention ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 2. When being asked a question ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 3. When being given simple instructions ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 4. When being given complicated, multiple, instructions ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 5. When not paying attention ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 6. When involved with other activities, i.e., coloring, reading, etc........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 7. When listening with a group of children ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

Listening Condition—*QUIET:*

If listening in a quiet room (others may be present, but are being quiet), this child has difficulty hearing and understanding (compared with other children).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8. When paying attention ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 9. When being asked a question ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 10. When being given simple instructions ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 11. When being given complicated, multiple, instructions ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 12. When not paying attention ........ | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13. When involved with other activities, i.e., coloring, reading, etc. | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 14. When listening with a group of children | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

Listening Condition—*IDEAL:*

When listening in a quiet room, no distractions, face-to-face, and with good eye contact, this child has difficulty hearing and understanding (compared with other children).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 15. When being asked a question | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 16. When being given simple instructions | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 17. When being given complicated, multiple, instructions | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

Listening Condition—*MULTIPLE INPUTS:*

When, in addition to listening, there is also some other form of input (i.e., visual, tactile, etc.), this child has difficulty hearing and understanding (compared with other children).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 18. When listening and watching the speaker's face | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 19. When listening and reading material that is also being read out loud by another | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 20. When listening and watching someone provide an illustration such as a model, drawing, information on the chalkboard, etc. | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

Listening condition—*AUDITORY MEMORY/SEQUENCING:*

If required to recall spoken information, this child has difficulty (compared with other children).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 21. Immediately recalling information such as a word, word spelling, numbers, etc. | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 22. Immediately recalling simple instructions | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 23. Immediately recalling multiple instructions | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 24. Not only recalling information, but also the *order* or *sequence* of the information | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 25. When delayed recollection (1 hour or more) of words, word spelling, numbers, etc. is required | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 26. When delayed recollection (1 hour or more) of simple instructions is required | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 27. When delayed recollection (1 hour or more) of multiple instructions is required | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 28. When delayed recollection (24 hours or more) is required | +1 | 0 | –1 | –2 | –3 | –4 | –5 |

Listening Condition - *AUDITORY ATTENTION SPAN:*

If extended periods of listening are required, this child has difficulty paying attention, that is being attentive to what is being said (compared with other children).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 29. When the listening time is less than 5 minutes | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 30. When the listening time is 5 to 10 minutes | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 31. When the listening time is over 10 minutes | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 32. When listening in a quiet room | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 33. When listening in a noisy room | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 34. When listening first thing in the morning | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 35. When listening near the end of the day, before supper time | +1 | 0 | –1 | –2 | –3 | –4 | –5 |
| 36. When listening in a room where there are also visual distractions | +1 | 0 | –1 | –2 | –3 | –4 | –5 |