Digit-Pair Stimuli as a Measure of Speech Reception Thresholds during Hearing Testing in the Paediatric Population within a Multilingual Context

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Authors contributions

This work was carried out in collaboration between both authors. They co-designed the study, co-wrote the protocol and author TS wrote the first draft of the manuscript. Author TS managed the literature searches, and collected data. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to investigate whether digit-pair stimuli offered a more precise measure for Speech Reception Threshold (SRT) testing in the paediatric population, in comparison to the phonetically balanced kindergarten (PBK) list during hearing testing in multilingual contexts.

Participants: A sample of 30 English first language speaking participants, aged between 5-7 years was included in the study. All participants were required to have normal hearing sensitivity and age-appropriate speech-language development.

Methods: Speech-language development was screened prior to the audiological assessment to ensure normal development. A basic audiological assessment was performed on the participants consisting of otoscopy, tympanometry, pure tone audiometry and SRT testing. Live-voice presentation was used for determination of the SRT scores; and these were than compared to the pure tone average (PTA) scores.

Results: Findings from the study have suggested that speech stimuli do show sensitivity to children’s development, and thus ensure a more reliable method of assessing the SRT-PTA
1. INTRODUCTION

Pure tone audiometry and speech testing are two of the methods used in the formal clinical assessment of auditory thresholds [1]. Speech recognition threshold (SRT) testing provides an index of hearing sensitivity for speech and serves as a baseline measure for determining the presentation levels for suprathreshold word recognition tests. SRT is believed to be related primarily to the pure-tone average (PTA) and the steepness of the hearing loss [2]. The ability of the ear to unravel the complexities of speech depends on many aspects of hearing, including sensitivity as measured by the pure-tone audiogram [3]. The relationship between speech intelligibility and sensitivity has been used as the basis of formulae for predicting speech performance from the pure tone audiogram [4].

In a study conducted by Picard et al. [2], speech audiometry in noise-exposed workers was investigated in order to evaluate the SRT-PTA relationship, and whether it is affected by cognitive-linguistic factors [2]. In their study 807 SRTs and PTAs were collected from French noise exposed workers, and the results indicated that by examining the relationship between SRT and PTA, it was possible to predict SRT from the sensitivity of pure tones [2]. This literature emphasises the importance of the SRT-PTA relationship, and supports the current research study in its rationale to use SRT-PTA relationship in determining hearing sensitivity; especially in the difficult to test populations including paediatics.

Carhart [5] defines speech audiometry as the technique where standardized samples of a language are presented through a calibrated system to measure some aspect of hearing ability. Speech audiometry is also defined as any method for assessing the state or the ability of the auditory system of the individual, using speech sounds as the response evoking stimuli [3]. Speech audiometry has remained a fundamental tool in audiological assessment, and it can be used diagnostically to examine speech processing abilities throughout the auditory system [6]. It can also be used as one method of cross-checking the validity of pure-tone thresholds [7]. The three-frequency average of the pure tone air-conduction thresholds at 500, 1000 and 2000Hz was discovered by both Fletcher [8] and Carhart [9]. It was noted that SRT in patients with a fairly flat hearing loss could be predicted from this three-frequency average, which is also called the PTA [10]. Many audiologists predict SRT from the PTA, and this relationship is used to cross check results. A difference of ±6dB between SRT and PTA is considered good, ± between 7-12dB is considered fair and if scores differ by ±13dB it is considered to be a poor correlation [10]. Thus SRT is a critical reliable measure of pure tone thresholds and many audiologists use this significant relationship to determine reliability and validity of results [10].

Speech audiometry allows for the assessment of speech perception and is a necessary consideration for many audiologic procedures and clinical decisions that affect both children and adults [11]. The perception of speech is a key skill that provides important information regarding overall auditory perception skills and can be of value in outlining the prognosis of speech, language, reading, and cognitive abilities of children [11]. This claim highlights the need for ensuring the choice of appropriate test materials, as well as conducting speech testing in a manner that enhances reliability and validity of speech audiometry [6]. The familiarity of the material is important for both test and interpretation. The more one is acquainted with a stimulus, the more readily one will recognize it. Normally very uncommon words are excluded from the test material, and sometimes the very common words are also omitted [12]. Certain groups of patients (persons with minimum scholastic aptitude, children and persons for whom English is a second language) may not score accurately on speech tests with English unfamiliar material which may have no relation to their auditory capacity, and therefore confounding the diagnostic test [12]. Write [12] believes that this difficulty is largely remediated if lists are composed of fairly common words only.

Keywords: Digit pairs; pure tone average; speech reception threshold; paediatric.
The primary reason that SRT is considered a valuable part of diagnostic audiologic evaluation is that it lends validity to pure tone thresholds [13]. There is strong correlation between the average pure tone thresholds obtained at the frequencies known to be important to speech (i.e., 500, 1000 and 2000Hz) and SRT, and this correspondence between speech and pure tone thresholds occurs for those who present with normal hearing and those with hearing loss [13]. Large discrepancies between SRT and PTA may suggest functional or nonorganic hearing loss. In children a discrepancy of 10dB or greater can be obtained, and this is thought to result from the child responding to the loudness of speech and does not reflect threshold for speech [14].

SRT offers reliability with the difficult to test patient, and the apparent face validity of using speech stimuli to assess sensitivity since communication depends upon listening to speech rather than pure tones [13]. Speech tests serve a multiplicity of purposes. In addition to their function as valuable checks on pure tone audiometry they also contribute in differentiating between sensory and neural dysfunctions and in evaluating patients’ every day hearing difficulties [13]. Another valuable reason for including the SRT in the hearing evaluation is that it provides a basis for selecting the sound level at which a patient’s speech recognition abilities should be tested [13].

In a study conducted in South Africa, research was aimed at evaluating the manner in which SRT is tested in multilingual populations [6]. The purpose of the study was similar to that of the current study, as it investigated whether digit-pair stimuli offered a more accurate measure of testing SRT in the adult population in second language English speakers [6]. The study acknowledged that failure to obtain accurate SRT scores could affect results and lead to misdiagnosis of hearing loss. Therefore this study aimed to avoid this challenge by using alternative stimuli such as digits when testing SRT [6]. This study highlighted the need for using digit-pair stimuli when testing the hearing of a South African citizen, to avoid over diagnosing hearing loss in South Africa, where resources are limited [6]. Forty participants were used in the study (17 males and 23 females). The participants were aged between 18-25 years and were all Tswana first language speakers. This differs from the current study which aimed to also investigate if digit-pair stimuli offer a more accurate measure for SRT; moreover the current study focused on the paediatric population, who speak English as a first language.

The challenge that audiologists face is that speech perception is not directly measurable as it is perceived objectively and is especially difficult to assess in children [11]. Frequently, speech perception skills have to be estimated or inferred from a child’s responses on tests, resulting in an inaccurate estimate of his/her abilities [11]. The main reason for this is that speech perception is an abstract construct rather than a concrete entity, and therefore it is difficult to measure in an absolute sense [15]. Most tests of speech perception were not developed with this abstract construct in mind, and instead have been designed with more concrete constructs which are intended as measures of monosyllabic word recognition, phoneme recognition and sentence recognition [15].

In an article by Mendel [11] literature was reviewed on existing test materials in the assessment of speech perception in the paediatric population and the level of sensitivity and standardization that is used when assessing performance of speech perception in children. The study indicated the relevance of using appropriate stimuli to assess speech perception in children [11]. Mendel’s [11] study supports the need for the current study as it highlights the necessity to develop speech perception materials that are appropriate for different populations such as those who are: difficult to test, have degrees of hearing impairment and auditory processing disorders and those of different ages and developmental abilities [11]. Mendel’s [11] study is similar to the current study as it recognizes that not all methods for assessing speech perception are suitable for children, and those tests with complex stimuli may be too difficult for children to achieve their true accurate and reliable SRT scores [11]. Choosing an appropriate word recognition test for a child is difficult because of the many factors which can affect the child’s performance [11]. Of primary importance are the child’s receptive vocabulary, the response modality and reinforcement techniques [16]. There are some tests available which attempt to reduce the pragmatic and developmental problems inherent in this population [16]. The main concern here is with those speech tests of hearing, specifically designed for English speaking children that evaluate a child’s ability to make correct phonemic classification mainly on the basis of acoustical information [16]. Mendel’s study [11] is
relevant in highlighting that in order for reliable and valid results to be obtained, specific test principles and variables need to be re-evaluated when assessing speech perception in children, as these are factors which can have an influence on scores, results and diagnosis.

Kirk et al. [15] point out that speech perception performance in the paediatric population is different to assess than in adults and this difference can be attributed to several variables. These authors list the child’s vocabulary and language competency, chronological age, and cognitive abilities as having a potential impact on the results. In addition, some test results often show a gap between a child’s actual competence and his/her demonstrated performance [11]. Thus, a child often has better speech perception skills than is demonstrable on objective test measures. Therefore it is important to address test principles and variables when evaluating speech perception performance in children; and the current researcher believes that this is particularly crucial in a multilingual/multicultural context where these factors play a role in test selection and administration.

The most popular test materials used by audiologists to measure SRT are spondaic words [13]. Spondaic words are two syllable words spoken with equal stress on each syllable e.g. ‘cowboy’ [13]. Spondee word lists were developed by Hudgins, Hawkins, Karlin and Stevens [17] for speech threshold determination as the identification functions are steeper than for monosyllabic words due to higher linguistic redundancy or predictability of spondees. Through the years, efforts have been made repeatedly to improve the original spondee test material developed by Hudgins, Hawkins, Karlin and Stevens [17]. Those efforts have included improving familiarity of the list of words as well as improving homogeneity [1]. When reviewing development of speech material in the paediatric population, there is a paucity of published information on the development of new speech materials for paediatrics. Existing test materials are reviewed with an emphasis on the level of sensitivity and standardization that they have for accurate assessment of a child’s speech perception performance [11]. It is crucial that the audiologists know the child’s vocabulary level to select the appropriate test when assessing speech perception. Madell [14] indicates that a child’s vocabulary age must be determined by selecting test materials which contain vocabulary words that are in the child’s lexicon, so that results may be an accurate reflection of speech perception abilities.

The criteria to be considered when selecting stimuli material for SRT testing are: familiarity, phonetic dissimilarity, representative sample of English speech sounds and homogeneity and audibility of the test materials [17]. Ramkisson, Proctor, Lansing and Bilger [18] explored the use of digit pairs as alternative stimuli for SRT testing in adults. Digit pairs have been reported as not only more familiar but also more intelligible in comparison to other speech material as they are non-linguistically loaded, used in daily living and may therefore be more familiar to the paediatric population [18].

Stimuli used in speech testing consist of two categories: open set tests and closed set tests [19]. A closed set test refers to restricted items i.e. numbers [19]. The child being tested understands what all the possible stimuli can only be selected from that limited number of potential items [19]. Open set testing differs as the child is required to repeat what he hears without any clues [19]. Lower scores are often recorded in open set testing as it is more difficult than closed set testing. The selection of appropriate test protocol is essential in obtaining reliable test results. Speech threshold information is very useful in offering basic information about auditory status, confirming pure tone thresholds and determining the level to begin speech perception testing [19]. The current study used digit pairs because of the advantage of numbers being from a closed set, allowing the child to repeat words that may be more familiar than the open set words used in the PBK.

It has been noted that audiological management can be affected by linguistic diversity [20], and in a multilingual country such as South Africa; professionals are faced with a language mismatch between themselves and a majority of their clients. The PBK [21] is an open set test with kindergarten level vocabulary and is based upon what is considered familiar monosyllabic words for children entering their first year of school in the United States of America [10]. Young children have limited vocabularies, and therefore it is important to make sure that tests selected assess auditory perception and not vocabulary knowledge [19]. The PBK is a standardized SRT test, with Western spondaic words which may be difficult even for English first language children to recognize [13] and that it why the current study proposes to use stimuli
that is more familiar and meaningful to children such as numbers [19]. Older children with good language skills will be able to perform well on standard tests that were developed for adults [19]. Young children may not have the vocabulary. The test procedure for SRT requires that the person be familiar with the material being presented, as familiarity makes the testing easier [19].

A study by Robinson and Koenigs [1] using adults as subjects indicated the advantages of digits as speech threshold material as an alternate to spondees since the homogeneity of digits offers the possibility of better results. The study evaluated different materials for SRT using ascending and descending procedures. The study used a sample of 32 normal hearing subjects, and SRT was obtained from all participants using spondee words and digits as test materials [1]. Research findings indicated that a descending procedure yielded better results for both test materials; however findings also revealed that digit material resulted in lower threshold scores than the spondees [1].

Digits provide a closed set response paradigm in that only eight or nine potential responses exist, and are likely to be familiar to almost all age groups, which minimizes the learning effects associated with a word-recognition task [22]. In a study performed by Wilson, Burks and Weakley [22] a comparison of word-recognition abilities was assessed using digit pairs and digit triplets in multitalker babble. The study compared recognition performances using digit pairs and digit triplets in multitalker babble. Participants included 16 young adults between the ages of 20-29 with normal hearing and 32 older listeners between the ages of 46-85 years with a sensorineural hearing loss [22]. The research results showed that using digits as test material is clinically recommended when assessing both normal hearing participants and those who present with a hearing loss [22]. Digits were reported to have a steeper psychometric function than other equivalent numbers of monosyllabic words. Digits 1 through 10 (excluding 7) are a special case of monosyllabic words that have been used in auditory testing [22]. This literature highlights how digits have been used successfully in achieving more reliable results in the adult population, but the study was limited in that it was not performed on children as well.

Audiologists are recognized as the single most important resource for non-medical habilitation or rehabilitation of hearing loss [23]. Challenges unique to South Africa include linguistic diversity, which can affect audiological management [24]. A child’s optimal development and achievement can be affected if hearing loss goes undetected [25]. Therefore early detection of hearing loss in children is crucial in audiology. In 2007 the HPCSA issued a position statement for Early Hearing Detection and Intervention (EHDI) programmes in South Africa. The programme advocates early detection of and intervention for, infants with hearing loss (EHDI programmes) [26]. The consequences of undetected hearing loss are pervasive and far-reaching for children as critical developmental periods for optimal language acquisition are forfeited [27]. Persistent delays in language, speech and cognitive development restrict acquisition of proficient literacy skills which prohibit academic achievement resulting in diminished vocational prospects and poor societal participation and contribution [28]. Evidence demonstrates significant long term societal costs as a result of increased expenses for specialized education and losses in productivity due to unemployment. This is in contrast to the proven long term cost savings associated with early identification of infant hearing loss [28]. Thus EHDI emphasises the need for accurate assessments to be conducted on infants and children so that reliable results can be achieved to arrive at correct diagnoses, hence the current study which seeks to assess the speech reception thresholds in children.

Speech-processing evaluation is included in the routine audiological examination so as to determine the extent to which altered thresholds disrupt perception of complex signals [13]. This speech processing is performed using speech reception threshold (SRT), as SRT provides the audiologist with results that can be compared to the participant’s pure tone average (PTA) indicating reliability of findings and thus allowing for a cross check principle to be applied [7]. The PBK is a standardized SRT test, with Western spondaic words which may be difficult even for English first language children to recognize [13]. Digit pairs have been reported as not only more familiar, but also more intelligible in comparison to other speech material [16].

Part of an audiologist’s role is to meet the needs of clients from different cultural and linguistic backgrounds [29]. In a multilingual country like South Africa, where 11 official languages are spoken, the issue of appropriate audiological
assessment is a current and relevant one [24]. Clients may often perform poorly on English tests due to being less familiar with the language, and audiological test results may not be a true reflection of the client’s abilities [6]. Thus it has been recommended that when administering speech audiometry on non-native English speakers that familiar stimuli, such as digits should rather be used [18]. These findings are on adults, and there is a paucity of documented information with regards to the paediatric population. Therefore this current research is needed in the South African context in order to allow for the appropriate audiological assessment of hearing disorders of children in a multilingual/multicultural society. Factors such as cultural sensitivity and different language use are recognized to have an effect on speech audiometric performance [29]. Thus the use of digits as speech stimuli in a multilingual/multicultural society may help to contribute toward minimising misdiagnosis through using stimuli that is more appropriate and familiar, therefore providing more accurate and reliable testing. Although the current study is confined to participants who speak English as their first language, it is hoped that findings will be of benefit in providing South African evidence that can be referred to when the use of digit-pairs is investigated in second-language English speakers.

2. METHODOLOGY

2.1 Primary Aim

The main aim of the current research was to examine whether digit pairs provided a more accurate measure when testing SRT in the paediatric population.

By assessing children with normal hearing sensitivity and speech-language development, the impact of hearing loss and speech-language delay was excluded, eliminating the possibility of these as confounding variables. Speech production screening was performed by assessing the child’s articulation. Hearing falling within normal limits was determined by performing otoscopic examinations, tympanometry, and pure tone air conduction audiometry on each participant.

2.2 Secondary Aims

The specific objectives of the current research were:

1. To determine the SRT-PTA correlation among children (aged 5-7 years) with normal hearing sensitivity and language development using the PBK word list.
2. To determine the SRT-PTA correlation among children (aged 5-7 years) with normal hearing sensitivity and language development using the digit pairs stimuli.
3. To compare which of the two materials yielded a better SRT-PTA correlation.

The hypotheses for the current study were the following:

H₀: The participants’ SRT-PTA correlation would be the same for the PBK and digits pairs lists used.
H₁: The participants’ SRT-PTA correlation would be different (i.e. participants would present with different SRT-PTA correlations).

2.3 Research Design

The current study was a cross sectional prospective quantitative study, with the utilization of the single group correlation design [30].

2.4 Description of Participants

2.4.1 Sampling strategy

The participants included in the study were English first language speaking children (5-7 years of age) with normal hearing sensitivity and language development. 30 participants were included in the study. Participants were randomly selected from various English speaking nursery and pre-schools in Johannesburg, South Africa. Parents were contacted by e-mail and via the teachers at the schools, inviting them to allow their children to participate in the study.

2.4.2 Selection criteria- participant inclusion criteria

English first language speaking children with normal speech-language development (as determined by articulation screening and case history forms) and normal hearing sensitivity (as determined by the otoscopic results, tympanograms and pure tone air conduction results) were included in the study.

2.4.3 Selection criteria- participant exclusion criteria

Children who presented with the following were excluded from the study:
• Children who presented with speech-language delay.
• Children who presented with abnormal hearing sensitivity.
• Children who did not speak English as their first language.
• Children who did not fall into the specified age group.

2.5 Ethical Considerations

Ethical clearance was sought and obtained from the Medical Ethics Committee at the University, Protocol Number: M110314.

According to Leedy and Ormond [31], when human beings are included in research, ethical issues should be considered, with the responsibility of the researcher ensuring not to expose the research participant(s) to any physical or psychological harm. Prior to data collection, a letter was distributed to all the potential participants' parents describing the purpose and nature of the study. A description of the rationale for the study, as well as the procedures involved was provided.

The ethical considerations that were observed in the current study included:

• Consent and Assent: Only those participant’s parents who were willing to let their children participate in the study were used. Each participant’s parent was presented with an informed consent form. Inclusion and exclusion criteria were additionally stated on the information sheet. Each participant was presented with an assent form on the day of the assessment, and the study was described and demonstrated to the child, and they were only included in the study if they agreed to participate.

• Autonomy: The participants and their parents had freedom of choice in accepting the invitation to participate in the study. They were also informed of their right to withdraw from the study at any time without any negative consequences to them.

• Confidentiality: Participant’s parents were informed about confidentiality. Each participant was allocated a research code number which served as their identity on all their assessment forms, thus their personal identity was only be known to the researcher.

• Withdrawal: The participants were informed that their participation in the research was voluntary and should they feel that they did not want to continue with the study for any reason, withdrawal from the study would be accepted at any time, without any negative consequences to them.

2.6 Data Collection

Data were collected using equipment from the University’s Speech and Hearing Clinic. For the purpose of the study a hearing test was performed on each participant.

2.6.1 Materials

The following equipment was utilized during the study:

• Phonetic Inventory
• Welch-Allen Otoscope
• Interacoustics Impedance Audiometer AT235
• Interacoustics AC40 Audiometer
• PBK wordlist (Appendix A)
• Digit pairs wordlist (Appendix B)

2.6.2 Methods

The assessments took place in sound proof booths at the University’s Speech and Hearing Clinic. Data were gathered by performing speech screening, otoscopic examinations, tympanometry, pure tone air conduction audiometry and SRT testing. Two SRT test measures were performed, using the PBK and the digit pairs lists. SRT-PTA correlation was compared for the two tests. This assessment determined each participant’s hearing sensitivity. The results were recorded and analysed. Equipment used is annually calibrated and it was ensured that all equipment had been biologically calibrated on days of data collection as well.

Articulation screening was performed on each participant assessing various sounds that could be found in the PBK and digit pair wordlists. The aim of the articulation screener is to determine the child’s ability to produce each speech sound correctly within a one word structure. Correct articulation is needed to pronounce each given word correctly [32]. Articulation was screened
with the use of a phonetic inventory. This is an important part of the study as a child’s misarticulation of sounds could influence the findings of the study. Specifically, this measure was to ensure that the child was producing the stimuli in the manner in which they heard and that responses were not confounded by an articulation problem.

Otoscopic examinations were conducted bilaterally in order to inspect the pinna for abnormalities, to check for ear-canal collapse and to examine the integrity of the tympanic membrane. The tympanic membrane is to be intact, pearly-grey in colour, with an evident light reflex, umbo, and long handle of the malleus [23]. If no abnormalities are detected in otoscopy, then outer and middle ear pathologies can be excluded and participants could be included in the study. Otoscopy was conducted through the use of a Welch Allyn otoscope.

Tympanometry was then performed in order to diagnose middle ear pathology [33]. Abnormal middle ear function suggests possible abnormal hearing sensitivity and thus any participants who presented with middle ear pathology were not able to participate in the study.

Type A tympanograms are indicative of normal middle ear functioning and are indicated with the following norms:

- Middle ear pressure: +50 to -150daPa
- Static compliance: 0,28-1,8cm³/ml
- Ear canal volume: 0,3-1,0cm³ [34]

Type A tympanograms were the inclusion criterion for this study, however participants who deviated slightly from the above norms but still presented with normal hearing sensitivity were included in the study. Tympanometry was conducted utilizing an Interacoustics impedance audiometer.

Following tympanometry, pure tone air conduction audiometry through the use of the AC40 audiometer was conducted in order to obtain the hearing thresholds of the participants at frequencies between 250 Hz and 8000 Hz through the descending method. The tone was presented at 40dBHL as normal hearing was suspected and testing began in the right ear. The bracketing method was used to obtain threshold where intensity is lowered in 10dB increments until there is no response, and the level is then raised in 5dB steps until the patient responds. This technique is repeated until the patient’s hearing threshold is reached [35]. Hearing thresholds is defined as the lowest intensity at which the listener can identify the presence of the signal at least 50% of the time. For paediatrics, hearing thresholds between – 10 and 15dB HL are considered to be normal [36]. Pure Tone Average was taken as the average of thresholds at frequencies 500Hz, 1000Hz and 2000Hz [37]. The presence of a hearing loss was determined by the pure tone average. In terms of the current study, it allowed the audiologist to exclude participants who presented with a hearing loss, in order to remove hearing loss as a confounding variable.

Once normal hearing sensitivity had been established, SRT was performed by using two lists as speech stimuli on each participant (Appendix A & B). Speech material provides an estimate of auditory sensitivity as measured by pure tone audiometry, and this is one of the main measures sought in the use of speech audiometry for diagnostic purposes. SRT is the lowest hearing level at which a patient can understand speech. Spondees are used as they consist of two syllables that are pronounced with equal stress [38]. It is important for the patient to be familiar with the words being presented to them and that the vocabulary is familiar and understood. SRT threshold is the level where the patient repeats 50% or more of the words being presented to him correctly [38]. The aim was to compare the SRT results from the PBK and the digit pairs stimuli SRT list with the PTA of the participant, and to determine which SRT yielded a better, more reliable result.

The importance of familiarity with the speech stimulus materials dates back to Hudgins [39] as familiarization can improve threshold and reduce variability. The participants were familiarized with the spondee lists (PBK and digit pairs) at 40dBSL. The level was decreased in 10dB increments each time the participants gave a correct response. When the participants did not respond at a level, a further 3 spondee words were presented at that level. The level was then increased by 5dB increments until the participants gave two out of four correct responses [36].

Presentation of test materials to children is usually performed using monitored live voice as this allows for greater flexibility when needed when working with a child [10]. The audiologist
can reinforce when indicated, use encouragement, change instructions and otherwise do what is necessary to elicit responses [16]. This mode also allows for modifications to suit the participant’s ability and the available test time as it permits either faster or slower presentation, omission of carrier phrase, and/use of selected words [10]. When monitored live voice presentation was used, the audiologist made sure to monitor the use of the presentation level of the volume unit (VU) meter in order to achieve maximum homogeneity of audibility for each speaker [10], and therefore the peak VU-meter was constantly monitored to ensure that the presentation of each syllable peaked at 0. No carrier phrase preceded the word stimulus during testing. The SRT results, established for each list was then correlated to the PTA for each participant. The SRT-PTA correlation for each stimuli list was determined and comparisons made to determine which wordlist yielded the best SRT-PTA correlation.

2.7 Validity and Reliability

Reliability can be defined as the extent to which a test is effectively measuring anything at all, and validity can be described as the extent to which the test is measuring what it is supposed to measure [40]. Validity refers to the tests ability to measure what it claims to measure and how well the test satisfies the intended purpose [40]. A total of 30 participants participated in the current study, and therefore a statistically valid sample was used. Confounding variables weaken the internal validity of a study [41]. Hearing loss and articulation problems were confounding variables in the current study, and therefore were controlled for by excluding participants who presented with these. Validity was also guaranteed by using the cross-check principle [7] as this allowed for the SRT scores to be correlated with the PTA results of the audiogram [6].

Reliability is important to demonstrate a consistent relationship between scores on the test and the attribute being measured [40]. Factors that contribute to consistency are characteristics of the individual being tested and the testing situation [40]. Thus reliability of the current study was assured by the test environment. Threshold measurement may also be affected if ambient noise levels are high at the time of the test [36]. The evaluation should be conducted in a sound treated environment designed specifically for hearing threshold measurement. The test environment in the current study consisted of a sound proof booth which was not affected by background noise and was kept constant for all participants and the length of the test was approximately half an hour for each participant. Reliability was further guaranteed by biologic calibration of equipment on days of data collection. Infection control was aimed at reducing or eliminating the spreading and contracting of disease and infection [42]. In the South African context, across any setting in which a practitioner might work, infection control is of considerable concern to Audiologists [42]. The current study aimed to ensure reliable results by following infection control measures with regard to cleanliness and hygiene. Routine precautions included:

- Hand washing before and after handling of the patient.
- Non-disposable equipment such as earphones, tympanometry probe tips and toys were disinfected and sterilized after each usage.
- Disposable items were directly disposed of in clinical waste bags after use [42].

2.8 Data Analysis

This study made use of descriptive and inferential statistics during the analysis of the SRT-PTA correlation. For inferential statistics, the nonparametric Spearman’s correlation coefficient and linear regression were employed. Descriptive statistics are used to describe the main features of a collection of data in quantitative terms [43]. Descriptive statistics are distinguished from inferential statistics, in that descriptive statistics aim to quantitatively summarize a data set rather than being used to support inferential statements about the population that the data are thought to represent [44]. Inferential statistics comprises of the use of statistics and random sampling to make inferences concerning some unknown aspect of a population [44].

3. RESULTS AND DISCUSSION

The results of the current study are described and discussed in accordance with its aims. The results of each method will be presented and evaluated descriptively, followed by an
inferential statistical analysis of the data, as well as a discussion and elaboration on the findings.

It is important to identify the characteristics of the sample studied. All participants in the sample were English first language speakers and thus were proficient in the English language. All participants attended private nursery or primary schools, where the medium of instruction is English and where they have received a fair-good education in numeracy. This sample is therefore not a fair representation of the general population of 5-7 year old children in South Africa, who have not been given the opportunity to receive a good education with a foundation of numeracy. However the researcher believed this to be the ideal population to assess the accuracy and sensitivity of the digit pairs.

The final sample comprised of 28 children aged between 54 and 84 months (5-7 years). The sample was equally distributed in terms of gender as depicted in Table 1. From the case history forms no parent/guardian reported on language delay or hearing difficulties of their child. No significant medical history factors were noted by any of the parents/guardians. 30 participants took part in the current study, and they were all English first language speaking, and ranged from the ages of 5-7 years (see Table 1). Of the total sample of 30 participants, all presented with normal hearing; however 2 participants were eliminated from the study due to tympanometry results; thus total sample size was 28.

Table 1. Participants' profile (N=28)

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>54-84 Months</td>
<td>Female 14</td>
</tr>
<tr>
<td>Mean</td>
<td>70.7 Months</td>
<td>Male 14</td>
</tr>
</tbody>
</table>

On otoscopic evaluation, all participants presented with normal findings as indicated by ear canals clear of infections and any obstructions, as well as clear tympanic membranes and the presence of the cone of light. 2 participants presented with grommets in their ears (as depicted in Table 2). The ears canals which consisted of grommets did not affect the results of further audiological testing and thus these participants were included in the study. 23 participants presented with type A tympanograms bilaterally. The 5 participants with abnormal tympanometry results presented with type A tympanograms either unilaterally or bilaterally (as depicted in Table 2). The abnormal tympanometric results from these participants did not however have any negative effect on their hearing sensitivity, as determined by pure tone testing. Two participants obtained type C tympanograms, with very negative pressure and these were the two that were excluded from the study. All participants presented with normal hearing sensitivity, bilaterally.

In addressing the specific aim of determining the SRT-PTA correlation among children (aged 5-7 years) with normal hearing sensitivity and language development using the PBK word list; the following results were found:

In the right ear the mean for the SRT-PBK list score was 8.9dBHL, with a standard deviation of 5.8dBHL. The left ear presented with a mean score of 9.3dBHL and a standard deviation of 6.3dBHL for the SRT-PBK list. The average combined SRT-PBK list presented with a mean score of 9.1dBHL and standard deviation of 5.5dBHL. The PTA score in the right ear was 6.25dBHL with a standard deviation of 3.84dBHL and the left ear presented with a mean score of 7.98dBHL and a standard deviation of 5.32dBHL. In both ears the PTA was indicated by a mean score of 7.1dBHL and a standard deviation of 3.9dBHL. The SRT/PTA correlation for the PBK list presented with a mean of 5.4dBHL and standard deviation of 4.4dBHL in the right ear. In the left ear the SRT/PTA correlation displayed a mean score of 4.6dBHL and a standard deviation of 4.6dBHL. The average combined SRT/PTA correlation was shown by a mean score of 5.0dBHL and a standard deviation of 3.2dBHL (see Table 3).

The results from the SRT-PBK list indicated that these findings fall within the normative data for individuals with normal hearing. Normal hearing is classified for children between -10dB to 15dB [36]. The SRT results in both ears fell within this normative data indicating normal speech reception thresholds. Lower thresholds for the SRT-PBK was seen in the right ear, however the SRT/PTA correlation for the left ear yielded a lower threshold. The SRT-PBK list was proved as a good measure for determining the PTA-SRT correlation because a good correlation was obtained for both ears. It appears that the SRT-PBK list is a good diagnostic measure for assessing speech reception threshold; and can be reliably used as a measure of exercising the cross-check principle in this population. This appears to be so even though, Thibodeau [13]
acknowledges that the PBK list may be difficult even for English first language children to recognize. The current findings revealed that the participants, who were all English first language speakers, managed to score reliable speech thresholds as indicated by the good correlation between SRT and PTA. This finding does raise implications that familiar and meaningful stimuli should be used when assessing speech reception in paediatrics [19]. Nonetheless, for the current study; these findings laid solid ground for objective comparison of participant performance when digit-pairs were to be used.

In addressing the specific aim of determining the SRT/PTA correlation among children (aged 5-7 years) with normal hearing sensitivity and language development using the digit-pair stimuli, the following results were found:

The right ear presented with a mean score of 7.9 dBHL and a standard deviation of 6.7 dBHL.

The left ear displayed a mean score of 9.3dBHL and a standard deviation of 6.3dBHL. The average-combined SRT-Digit list presented with a mean score of 8.6 dBHL and a standard deviation of 5.8 dBHL. The PTA in the right ear was 6.25dBHL with a standard deviation of 3.84dBHL and the left ear presented with a mean score 7.98dBHL and a standard deviation of 5.32dBHL. The average combined mean was indicated by a score of 7.1dBHL and a standard deviation of 3.9 dBHL The SRT/PTA correlation was indicated in the right ear by a mean score of 5.7dBHL and a standard deviation of 4.3dBHL. In both ears the mean score was 5.6 dBHL with a standard deviation of 3.6dBHL (see Table 4).

Findings of the results from the SRT-Digit list indicated results falling within the normative data. In both ears the SRT was under 15dBHL indicating normal speech reception [36]. Thresholds obtained in the right ear were lower than thresholds obtained in the left ear. Accuracy of SRT can be determined by comparing it to the PTA. SRT and PTA are generally required to be within 5-10dBHL of one another in order to be considered accurate and reliable [13]. The SRT/PTA relationship was considered to be reliable and good for the SRT-Digit list as the correlation results fell within the normative data for both ears. This supports findings of Madell and Flexer [19] who found that digit-pairs offer a good diagnostic measure of speech reception as they have the advantage of being from a closed set, and thus are considered to yield lower thresholds scores than in open set testing which is regarded to be more difficult.

<table>
<thead>
<tr>
<th>R-Otoscopy</th>
<th>L-Otoscopy</th>
<th>R-Tympanometry</th>
<th>L-Tympanometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAD</td>
<td>26</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>Grommet</td>
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<td>As</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>28</td>
<td>Total</td>
</tr>
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</table>

Table 2. Otoscopy and tympanometry results (N= 56 ears)

<table>
<thead>
<tr>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>PTA</td>
<td>7.98</td>
</tr>
<tr>
<td>SRT-PBK</td>
<td>9.3</td>
</tr>
<tr>
<td>SRT(PBK)/PTA correlation</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Table 3. Mean and standard deviation of pure tone and SRT-PBK thresholds (N=56 ears)
A statistical comparison of the results obtained from both wordlist yielded findings that were not statistically significant (p = 0.1). This means there was not a statistically significant difference in the SRT-PTA correlations obtained using the two different wordlists. Thus the null hypothesis which stated that the participants SRT-PTA correlation would be the same for the two lists utilised is accepted.

While closely comparing which of the two materials yielded a better SRT-PTA correlation, the following differences in the results were noted between the two SRT lists:

In the right ear the mean score for the SRT-PBK list was 8.9 dBHL, with a standard deviation of 5.8 dBHL while the mean score for the SRT-Digit list was 7.9 dBHL with a standard deviation of 6.7 dBHL. The left ear presented with a mean score of 9.3 dBHL and a standard deviation of 6.3 dBHL for both the SRT-PBK list and SRT-Digit (see Table 5). The average combined SRT-PBK list presented with a mean score of 9.1 dBHL and standard deviation of 5.5 dBHL and with a mean score of 8.6 dBHL and a standard deviation of 5.8 dBHL for the SRT-Digit list. The SRT (PBK)/PTA correlation was indicated by a mean score of 5.4 dBHL and a standard deviation of 4.4 dBHL in the right ear, and in the left ear by a mean score of 4.6 dBHL and a standard deviation of 4.6 dBHL. The average combined SRT (PBK)/PTA correlation was displayed by a mean score of 5.0 dBHL and 3.2 dBHL. The SRT (Digit)/PTA correlation presented with a mean score of 5.7 dBHL and standard deviation of 4.0 dBHL in the right ear, and with a mean score of 5.5 dBHL and standard deviation of 4.3 dBHL in the left ear. The average combined mean score was 5.6 dBHL and the standard deviation was 3.6 dBHL.

Findings of the current study on digit-pair stimuli as a measure of SRT reveal that no statistically significant differences exist; however closer scrutiny of the scores as indicated in Table 5 reveals some slight differences. This could be seen in the results of the thresholds for the two SRT lists. In the right ear, the mean that indicated a lower threshold for speech reception was with the digit-pair wordlist, this list also showed a higher standard deviation indicating a wider variation of results. The left ear displayed the same results for both lists and thus no significant difference was found between the two lists. In both ears the SRT-Digit list yielded lower threshold scores. The results indicating the correlation for the SRT/PTA relationship was different for the two ears. The SRT/PTA relationship is characterized by looking at the correlation between PTA and SRT [10]. When comparing the results for the SRT/PTA correlation using the two different wordlists the SRT-PBK wordlist yielded lower thresholds for the right ear and left ear, as well as both ears in comparison to the SRT-Digit list. The reason that the SRT-PBK list may have yielded lower thresholds for the SRT/PTA correlation is that in pure tone evaluation of paediatrics false positive responses are viewed as part of the normal threshold procedure, especially when stimuli are presented at or near threshold [46]. Pure tone testing is subjective, and the difficulty with paediatrics is that they show false positives, as they incorrectly perceive the presence or absence of stimuli near threshold and as a result tend to then present with false positives [46]. Thus this can then have an effect on the thresholds obtained at all frequencies, and will affect the PTA, which may then not be a true representative of the participant’s thresholds. This was seen in the current findings of the results of the SRT/PTA correlation as lower thresholds were obtained on the SRT-Digit list in comparison to the SRT-PBK list, therefore as the higher thresholds were obtained on the SRT-PBK list these results correlated better with the PTA that was obtained, as higher thresholds may have been obtained due to the false-positives.

Although the differences between the lists were not statistically significant, the highest correlation for both ears was however with the SRT-Digit list, as indicated by the Spearman’s correlation coefficient in Table 6. The Spearman’s correlation coefficient displayed that the SRT-Digit wordlist showed the higher correlation (r = 0.43) followed closely by the SRT-PBK list (r = 0.39).

<table>
<thead>
<tr>
<th>Table 4. Mean and standard deviation of pure tone and SRT-digit pairs thresholds (N=56 ears)</th>
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<tbody>
<tr>
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<tr>
<td></td>
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<tr>
<td>SRT-PBK</td>
</tr>
<tr>
<td>SRT (PBK)/PTA correlation</td>
</tr>
<tr>
<td>SRT (Digit)/PTA correlation</td>
</tr>
</tbody>
</table>

Khoza-Shangase and Singer; AIR, 17(1): 1-18, 2018; Article no.AIR.12130
These results indicated that the highest correlation for both ears was the SRT-Digit list; however the Spearman’s correlation coefficient revealed that the SRT-Digit list displayed a higher correlation for the right ear with ($r = 0.30$) and ($r = 0.24$) for the SRT-PBK list. The opposite of these results occurred in the left ear with the left ear presenting with a higher correlation for the SRT-PBK list ($r = 0.42$) and with ($r = 0.32$) for the SRT-Digit list. However the results indicated that there generally seemed to be a fairly good correlation among both wordlists when compared to PTA.

It must also be noted that during speech reception testing, there was a noticeable difference in the participants’ responses to the two different lists. The selection of speech materials for children should be within the children’s speech and language competence, and digits are noted as being more familiar in children’s vocabulary [22]. This was evident during testing as when the participants were presented the spondee words with the SRT-PBK stimuli, as the stimuli decreased in intensity and the participants were not able to detect a word they remained silent, and only responded with a spondee word when the level was increased in intensity. With the SRT-Digit pairs list at the lower levels many of the participants were able to detect the first half of the pair, but incorrectly said the second half e.g. when presented with the spondee “Two-six” the participant would reply “Two-four”. This occurred with many of the spondee words on the digit-pairs list with 95% of the participants indicating that even at low intensity levels they could detect the numbers as opposed to words, but were not able to respond with the full spondee words as the SRT-Digit list was not predictable and they were not able to use auditory closure to respond correctly with the full spondee word. On the contrary many of the participants displayed the use of auditory closure when responding to spondees on the PBK wordlist, and they were able to use this auditory processing technique to help them respond accurately.

Speech perception is an abstract construct, and in order to provide a comprehensive assessment of a child’s capabilities, appropriate test protocol needs to be selected to ensure reliable test results [11]. In the current researcher’s opinion

<table>
<thead>
<tr>
<th>Stimulus list</th>
<th>Correlation value</th>
<th>Mean</th>
<th>Standard deviation</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<td>Right</td>
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<tr>
<td>SRT-PBK</td>
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<td>0.41</td>
</tr>
<tr>
<td>SRT-Digit</td>
<td>0.32</td>
<td>0.30</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Khoza-Shangase and Singer; AIR, 17(1): 1-18, 2018; Article no.AIR.12130

Table 5. Mean and standard deviation of pure tone and speech reception thresholds (N=56 ears)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation</th>
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<tbody>
<tr>
<td></td>
<td>Left</td>
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<td>PTA</td>
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<td>SRT-PBK</td>
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<td>7.9</td>
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<td>SRT(PBK)/PTA correlation</td>
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<tr>
<td>SRT(Digit)/PTA correlation</td>
<td>5.5</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table 6. Pearson’s correlation coefficients (N=56 ears)

Ramkissoon et al. [18] compared the SRT of native English speakers and non-native English speakers using digit-pairs vs. standardized bisyllabic spondees as stimuli. This assessed the accuracy of the 2 stimuli by comparing the SRT obtained to the PTA. The present study confirmed Ramkissoon et al. [18] findings that using digit-pairs as stimuli resulted in SRT measures that more closely approximated PTA and facilitated more accurate SRT. Higher correlation was indicated in the left ear using the SRT-PBK list; however for the right ear and both ears the SRT-Digit list yielded higher correlation results. These findings reveal that Digit Pairs more accurately measured hearing threshold for speech than the PBK, and better hearing sensitivity was shown.

Current findings have significant implications for the SRT testing of children in multilingual populations such as South Africa since they validate the value and accuracy of using digit-pairs. Investigating the use of digit-pairs in children who do not speak English as a first language would need to be done, but it is this researcher’s view that since numbers are often the first to be learned in this age group (and so are not heavily dependent on English language); that findings would not vary significantly from the current study.
digit-pairs are an excellent measure of assessing speech perception skills, as they allow for both reliable and valid results to be obtained, as was seen in the findings of the current study. Digit-pairs accurately measured the SRT in paediatrics as indicated by the good correlation between SRT and PTA. The choice of SRT material has an impact on audiological decision making because test validity is evaluated by SRT-PTA correlation [18]. Audiologists face the challenge that speech perception is not directly measurable, especially in children, and therefore it can be difficult to assess and a child often has better speech perception skills than is demonstrable on objective test measures [11]. Digit-pairs more accurately assessed the speech reception of paediatrics. It can be argued that by using digit-pairs auditory perception is more accurately measured as compared to using the PBK list as many children (especially in South Africa), may not be familiar with the western spondaic words [19]. Digit Pairs offer an advantage of being from a closed set, and thus allow for the child to repeat words that may be more familiar than the open set words used in the PBK [19]. The digit-pairs in this study effectively measured SRT of all the participants, and thus the use of digit-pairs may be more applicable for second language English speakers. Word lists that are developed in other languages are only appropriate to the speakers of that language whereas commonly familiar English digits may be used for a diverse group of new English learners [47]. According to Ramkissoon [47] digits have a cross-linguistic appeal that is not apparent in other SRT measures that are currently being used and therefore in the current researcher’s opinion, if digit-pairs are able to more accurately assess the SRT in children who do not possess a wide range of vocabulary, it may extend its viability to other populations such as second language English speakers. In a country such as South Africa, where eleven official languages are recognized and English is only the fifth most commonly spoken language [24], audiologist’s face challenges in delivering services that are linguistic and culturally appropriate to the vast majority of the diverse population in South Africa [24]. Thus in the researcher’s opinion, digit-pairs have been proved to be reliable and valid in the current study, and they function as an efficient method in measuring hearing sensitivity and should therefore be considered as a valuable method of auditory perception testing not just in paediatrics but in other populations as well.

4. CONCLUSION AND RECOMMENDATION

The aim of the current study was to evaluate the effectiveness of digit-pair stimuli as an alternative measure of SRT in the paediatric population and to determine if digit-pairs could yield better more, reliable results when compared to words from the PBK list. Results from the current study have shown that there is efficacy in using digit-pairs as a measure of SRT as they did reveal that digit-pairs did result in lower threshold scores for speech reception and, a stronger correlation to the pure tone average.

The current study aimed to determine the appropriateness of using speech perception test materials that could yield more accurate results in the paediatric population. Findings from the study have suggested that speech stimuli do show sensitivity to children’s development, and thus ensure a more reliable method of assessing the SRT-PTA relationship. Using digit-pairs to assess speech in hearing thus helps to develop and implement more appropriate test materials when evaluating SRT in the paediatric population. As a result of this study South African audiologists have more evidence indicating digit-pair stimuli as a reliable test to use on the South African population when assessing speech perception. This study also provides audiologists with important information of using more appropriate assessment materials when working with children who come from diverse language background and may require more familiar stimuli such as digit-pairs.

This study has important clinical implications as findings have highlighted the need for ensuring that appropriate test materials are used when working with paediatrics to ensure the most valid and reliable measures are being used to produce results that will reflect accurately on the child’s hearing status, allowing the audiologist to correctly diagnose and manage hearing loss. Findings have also suggested the possibility of reliably utilising digit-pairs within a multilingual context, although this would still need to be confirmed in future studies.

4.1 Implications of the Study

Findings from the current study have indicated the need for further development of more sensitive assessment procedures that should take into consideration that the cognitive, motoric and attentional demands of the test should be
age-appropriate and that performance should be independent of vocabulary knowledge. This research indicates the need for making sure that test material is appropriate in assessing the SRT of children in order that they are not misdiagnosed with a hearing impairment, and it may as well provide measures that objectively and accurately assess specific aspects of children’s speech perception abilities. Findings from the study further implicate the need for the development of appropriate SRT test materials in a multicultural country such as South Africa, as diagnosis and management plans for patients can be influenced by test materials that are not culturally appropriate. Digit-pair stimuli have the possibility of contributing toward reliability and validity of audiological testing.

4.2 Limitations of the Study

Significant findings were identified in the current study; however these results must be interpreted with caution due to the following factors:

- This study may have been limited by the fact that the sample size was small with only 28 participants.
- The 28 participants used were all English first language speakers all from the same culture and from upper class suburban areas in Johannesburg. They all attend private school and thus have a vast exposure to vocabulary from both their homes and schools. Thus these participants are not considered a fair representative sample of English first language children of the same age found in South Africa; and are not representative of the general South African population in this age group.
- The study may also have been limited by error of measurement as a 5dB increment was used to obtain SRT. A response criterion of two out of four correct responses determined the SRT score using 5dB increments, however SRT thresholds may have been lower or higher if a 2dB increment was used, thus giving more specific scores and lending greater validity and reliability to the PTA.
- Live voice presentation, even when monitored with a sound level meter, gives rise to unacceptable variability of intensity both within and between lists and to variations of pronunciation between different presentations of the same list.

4.3 Recommendations for Future Research

- A larger sample could provide more information in a replication of the study.
- This study has implications for second language English speakers, as it may prove to be a useful diagnostic measure when testing speech reception in second language English speakers who may not have the proficiency of the English language and may perform better on the SRT-Digit list as the numbers may prove to be more familiar, thus yielding a more reliable and accurate SRT score.
- It is recommended that the study be replicated on participants with suspected hearing loss, in order to determine the use of the SRT-Digit list in the presence of hearing loss as a confounding variable.
- It is recommended to replicate the study with a recorded voice instead of live voice presentation to establish if the manner of presentation of speech stimuli has an effect on the results in paediatrics.

ETHICAL APPROVAL

All authors hereby declare that the study was examined and approved by the appropriate ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 2012-2013 World Medical Association’s Declaration of Helsinki.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

APPENDIX A

PBK Wordlist

Children spondee list

- Ice-cream
- Sailboat
- Aeroplane
- Football
- Paintbrush
- Snowman
- Cowboy
- Cupcake
- Toothbrush
- Bathroom
- Shoelace
- Tennis ball
- Torch light
- Toothpaste

APPENDIX B

Digit Stimuli Wordlist

Digit pairs list

- One-two
- Three-four
- One-five
- Four-eight
- Two-six
- Nine-three
- Five-two
- Nine-four
- Three-ten
- Four-three
- Ten-nine
- Eight-six
- Five-one
- Two-three
- One-eight

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